traverses laterally over a third occlusal point adjacent to the second occlusal point and a third buccal point adjacent to the second buccal point.

220. The method of claim 218, wherein the first lingual point and the second lingual point are spaced apart such that a field of view of the scanning device includes at least one overlapping portion of the plurality of teeth when the scanning device is positioned to image the first and second lingual points respectively.

221. The method of claim 218, wherein the scan path begins at a third buccal point.

222. The method of claim 218, wherein the scan path begins at a third palatal point.

223. The method of claim 218, wherein the scan path begins at a third labial point.

224. A method comprising, within a single dental visit, the steps of:

acquiring a three-dimensional representation of one or more intraoral structures including at least one tooth prepared for a dental restoration; and

processing the three-dimensional representation to provide feedback to a dentist concerning the at least one tooth.

225. The method of claim 224, wherein the feedback includes a physical dimension.

226. The method of claim 224, wherein the feedback includes a dimension of the at least one tooth prior to preparation for the dental restoration.

227. The method of claim 224, wherein the feedback includes a contour of the at least one tooth.

228. The method of claim 224, wherein the feedback includes a clearance relative to one or more adjacent teeth for a dental restoration associated with the at least one tooth.

229. The method of claim 224, wherein the feedback includes a clearance relative to one or more teeth in an opposing occluded arch.

230. The method of claim 224, wherein the feedback includes a position of the at least one tooth.

231. A computer program product comprising computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of:

acquiring a three-dimensional representation of one or more intraoral structures including at least one tooth prepared for a dental restoration;

analyzing the three-dimensional representation;

generating a feedback signal, the feedback signal representing the analysis of the three-dimensional representation; and

outputting the feedback signal to a dentist.

232. The computer program product of claim 231, wherein the feedback signal includes a physical dimension.

233. The computer program product of claim 231, wherein the feedback signal includes a dimension of the at least one tooth prior to preparation for the dental restoration.

234. The computer program product of claim 231, wherein the feedback signal includes a contour of the at least one tooth.

235. The computer program product of claim 231, wherein the feedback signal includes a clearance relative to one or more adjacent teeth for a dental restoration associated with the at least one tooth.

236. The computer program product of claim 231, wherein the feedback signal includes a clearance relative to one or more teeth of an opposing occluded arch.

237. The computer program product of claim 231, wherein the feedback signal includes a position of the at least one tooth.

238. A system comprising:

an acquisition means for acquiring a three-dimensional representation of one or more intraoral structures including at least one tooth prepared for a dental restoration;

an analysis means for analyzing the three-dimensional representation;

a means for generating a feedback signal, the feedback signal representing the analysis of the three-dimensional representation; and

a signal means for providing the feedback signal to a dentist.

239. The system of claim 238, wherein the feedback signal includes a physical dimension.

240. The system of claim 238, wherein the feedback signal includes a dimension of the at least one tooth prior to preparation for the dental restoration.

241. The system of claim 238, wherein the feedback signal includes a contour of the at least one tooth.

242. The system of claim 238, wherein the feedback signal includes a clearance relative to one or more adjacent teeth for a dental restoration associated with the at least one tooth.

243. The system of claim 238, wherein the feedback signal includes a clearance relative to one or more teeth in an opposing occluded arch.

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244. The system of claim 238, wherein the feedback signal includes a position of the at least one tooth.

245. A method comprising:

acquiring a three-dimensional representation from a dental patient including a digital surface representation of one or more intraoral structures; and

providing a visual display of the three-dimensional representation in real time.

246. The method of claim 245, wherein the visual display of the three-dimensional representation is superimposed on a real time two-dimensional video image of the one or more intraoral structures.

247. The method of claim 245, wherein the one or more intraoral structures include at least one tooth.

248. The method of claim 245, wherein the one or more intraoral structures include at least one tooth surface prepared for a dental restoration.

249. The method of claim 245, wherein the one or more intraoral structures include at least one restored tooth.

250. The method of claim 245, wherein the one or more intraoral structures include at least one implant.

251. The method of claim 245, wherein one or more intraoral structures include at least one area of soft tissue.

252. The method of claim 245, further comprising processing the three-dimensional representation to generate user feedback concerning the one or more intraoral structures, and providing a visual display of the user feedback.

253. The method of claim 252 wherein the feedback includes highlighting areas in the three-dimensional representation requiring additional attention.

254. A computer program product comprising computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of:

acquiring one or more images of one or more intraoral structures;

processing the one or more images into a three-dimensional representation including a digital surface representation of the one or more intraoral structures; and

generating a first visual display signal of the three-dimensional representation in real time.

255. The computer program product of claim 254, further comprising computer code that performs the step of generating a second visual display signal wherein the three-dimensional representation is superimposed on a real time two-dimensional video image of the one or more intraoral structures.

256. The computer program product of claim 254, wherein the one or more intraoral structures include at least one tooth.

257. The computer program product of claim 254, wherein the one or more intraoral structures include at least one tooth surface prepared for a dental restoration.

258. The computer program product of claim 254, wherein the one or more intraoral structures include at least one area of soft tissue.

259. The computer program product of claim 254, wherein the one or more intraoral structures include at least one implant.

260. The computer program product of claim 254, wherein the one or more intraoral structures include at least one restored tooth.

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261. The computer program product of claim 254, further comprising computer code that performs the steps of:

analyzing the three-dimensional representation;

generating a feedback signal representative of the analysis of the three-dimensional representation; and

generating a third visual display signal including the feedback signal.

262. The computer program product of claim 261, wherein the third visual display signal includes highlighted areas of the three-dimensional representation requiring additional attention.

263. A system comprising:

an acquisition means for acquiring a three-dimensional representation from a dental patient, the three-dimensional representation including a digital surface representation of one or more intraoral structures; and

a display means for visually displaying the three-dimensional representation in real time.

264. The system of claim 263, wherein the display means includes a means for superimposing the three-dimensional representation on a real time two-dimensional video image of the one or more intraoral structures.

265. The system of claim 263, wherein the one or more intraoral structures include at least one tooth.

266. The system of claim 263, wherein the one or more intraoral structures include at least one tooth surface prepared for a dental restoration.

267. The system of claim 263, wherein the one or more intraoral structures include at least one area of soft tissue.

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268. The system of claim 263, wherein the one or more intraoral structures include at least one implant.

269. The system of claim 263, wherein the one or more intraoral structures include at least one restored tooth.

270. The system of claim 263, further comprising:

an analysis means for analyzing the three-dimensional representation;

a feedback means for generating a feedback signal representative of the analysis of the three-dimensional representation, wherein the display means includes a means for visually displaying the feedback signal.

271. The system of claim 270, wherein the feedback means includes a means for highlighting areas in the three-dimensional representation requiring additional attention.

272. A handheld imaging device for a three-dimensional imaging system comprising:

an elongated body including a first end, a second end, and a central axis;

a video rate three-dimensional scanning device within the elongated body, the video rate three-dimensional scanning device having an optical axis for receiving images, the optical axis substantially perpendicular to the central axis at a position near the first end of the elongated body; and

the second end adapted for gripping by a human hand, and the second end including a user input responsive to user manipulation to generate control signals for transmission to a processor associated with the imaging system.

273. The device of claim 272, wherein the user input includes a mouse, track ball, button, switch, mini joystick, touchpad, keypad, or thumb wheel.

274. The device of claim 272, wherein the control signals are transmitted to the processor through a wireless communication medium.

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275. The device of claim 272, wherein the user input controls a user interface associated with the imaging system.

276. A handheld imaging device for a three-dimensional imaging system comprising:

an elongated body including a central axis, a first end, and a second end, the second end adapted for gripping by a human hand and a central axis;

a video rate three-dimensional scanning device within the elongated body, the video rate three-dimensional scanning device having an optical axis for receiving images, the optical axis substantially perpendicular to the central axis at a position near the first end of the elongated body; and

a physical offset shaped and sized to maintain a desired distance of the first end from an imaging subject along the optical axis.

277. The device of claim 276, wherein the physical offset includes one or more wheels for slidably engaging a surface of the imaging subject.

278. A method comprising:

acquiring a three-dimensional representation from a dental patient including a digital surface representation of one or more intraoral structures, the intraoral structures including a dental arch;

processing the three-dimensional representation to provide a digital dental model including one or more alignment guides to aid in positioning an orthodontic fixture; and

fabricating a physical model from the digital dental model.

279. The method of claim 278, further comprising constructing the orthodontic fixture on the physical model using the alignment guides.

280. The method of claim 278, further comprising constructing a support for the orthodontic fixture on the digital dental model.

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281. The method of claim 278, wherein the alignment guides include visual markings.

282. The method of claim 278, wherein the alignment guides include at least one substantially horizontal shelf for the orthodontic fixture.

283. The method of claim 278, wherein processing includes virtually placing a plurality of orthodontic brackets onto the three-dimensional representation, and adding a plurality of bracket supports to the digital dental model to support a physical realization of the plurality of orthodontic brackets on the physical model.

284. The method of claim 283, further comprising fabricating the physical realization of the plurality of orthodontic brackets, positioning each one of the plurality of orthodontic brackets onto the physical model, and vacuum forming an appliance over the plurality of orthodontic brackets, the appliance maintaining the plurality of orthodontic brackets in fixed relation to one another.

285. The method of claim 284, further comprising applying the appliance with the plurality of orthodontic brackets to the dental arch.

286. The method of claim 284, wherein the appliance is formed of a soft, clear material.

287. The method of claim 278, further comprising transmitting the digital dental model to a remote dental laboratory.

288. The method of claim 278, wherein processing includes virtually placing a plurality of orthodontic brackets onto the three-dimensional representation in a bracket arrangement, and generating a digital model of a bracket guide adapted to position a physical realization of the plurality of orthodontic brackets in the bracket arrangement on the dental arch.

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289. The method of claim 288, further comprising three-dimensionally printing the bracket guide.

290. The method of claim 278, wherein fabricating the physical model includes fabricating the physical model in an in-house dental laboratory in a dentist's office.

291. A method comprising:

acquiring a three-dimensional representation from a dental patient including a digital surface representation of one or more intraoral structures, the intraoral structures including a dental arch;

adding a plurality of virtual brackets to the three-dimensional representation to provide a bracket model;

processing the bracket model to generate a bracket guide model, the bracket guide model adapted to maintain a physical realization of the plurality of virtual brackets in a fixed orientation with respect to one another, the fixed orientation corresponding to a desired orientation of the physical realization on the dental arch;

fabricating a bracket guide from the bracket guide model; and

attaching the physical realization of the plurality of virtual brackets to the bracket guide model.

292. A computer program product comprising computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of:

acquiring one or more images of one or more intraoral structures, the intraoral structures including a dental arch;

processing the one or more images into a three-dimensional representation of the one or more intraoral structures;

transforming the three-dimensional representation into a digital dental model, the digital dental model including one or more orthodontic fixture alignment guides; and

generating a virtual orthodontic fixture using the alignment guides.

293. The computer program product of claim 292, further comprising computer code that performs the step of constructing a support for the virtual orthodontic fixture on the digital dental model.

294. The computer program product of claim 292, wherein the alignment guides include visual markings.

295. The computer program product of claim 292, wherein the alignment guides include at least one substantially horizontal shelf for the virtual orthodontic fixture.

296. The computer program product of claim 292, wherein transforming includes virtually placing a plurality of orthodontic brackets onto the dental arch of the three-dimensional representation, and adding a plurality of bracket supports to the digital dental model.

297. The computer program product of claim 292, further comprising computer code that performs the step of transmitting the digital dental model to a remote dental laboratory.

298. A system comprising:

an acquisition means for acquiring a three-dimensional representation from a dental patient including a digital surface representation of one or more intraoral structures, the intraoral structures including a dental arch;

a processing means for processing the three-dimensional representation to provide a digital dental model including one or more alignment guides to aid in positioning an orthodontic fixture; and

a first fabrication means for fabricating a physical model from the digital dental model.

299. The system of claim 298, further comprising a means for constructing the orthodontic fixture on the physical model using the alignment guides.

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300. The system of claim 298, wherein the processing means includes a means for constructing a support for the orthodontic fixture on the digital dental model.

301. The system of claim 298, wherein the alignment guides include visual markings.

302. The system of claim 298, wherein the alignment guides include at least one substantially horizontal shelf for the orthodontic fixture.

303. The system of claim 298, wherein the processing means includes a means for virtually placing a plurality of orthodontic brackets onto the three-dimensional representation, and adding a plurality of bracket supports to the digital dental model to support a physical realization of the plurality of orthodontic brackets on the physical model.

304. The system of claim 303, further comprising a second fabrication means for fabricating the physical realization of the plurality of orthodontic brackets, a positioning means for positioning each one of the plurality of orthodontic brackets onto the physical model, and a forming means for vacuum forming an appliance over the plurality of orthodontic brackets, the appliance maintaining the plurality of orthodontic brackets in fixed relation to one another.

305. The system of claim 304, further comprising a means for applying the appliance with the plurality of orthodontic brackets to the dental arch.

306. The system of claim 304, wherein the appliance is formed of a soft, clear material.

307. The system of claim 298, further comprising a communication means for transmitting the digital dental model to a remote dental laboratory.

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308. The system of claim 298, wherein the processing means includes a means for virtually placing a plurality of orthodontic brackets onto the three-dimensional representation in a bracket arrangement, and a model means for generating a digital model of a bracket guide adapted to position a physical realization of the plurality of orthodontic brackets in the bracket arrangement on the dental arch.

309. The system of claim 308, further comprising a printing means for three-dimensionally printing the bracket guide.

310. The system of claim 298, wherein the fabrication means includes a means for fabricating the physical model in an in-house dental laboratory in a dentist's office.

311. A three-dimensional data acquisition system adapted for intraoral acquisition of dental data from one or more intraoral structures, the system including a first operating mode for capturing scan data and rendering a low-quality three-dimensional image from the scan data in real time, and a second operating mode for generating a high-quality three dimensional image from the scan data after exiting the first operating mode, the high-quality three-dimensional image having greater spatial resolution than the low-quality three-dimensional image.

312. The system of claim 311, further including a display that renders the low-quality three-dimensional image superimposed on a video image of the one or more intraoral structures.

313. The system of claim 312, wherein rendering a low-quality three-dimensional image includes rendering the low-quality three-dimensional image at a frame rate of the video image.

314. The system of claim 311, further including a communications interface for transmitting the high-quality three-dimensional image to a dental laboratory.

315. A system comprising:

a scanning device configured to intraorally capture surface image data from a surface within a mouth of a dental patient;

a computer coupled to the scanning device and receiving the surface image data therefrom, the computer configured to resolve the surface image data into a three-dimensional representation, the computer further configured to generate a visualization of the three-dimensional representation and to provide the visualization as a display signal; and

a display coupled to the computer and receiving the display signal therefrom, the display converting the display signal into a viewable image, the display being a touch-screen display adapted to receive a user input through direct contact with a surface of the display, wherein the user input is interpreted by the computer to affect manipulation of the three-dimensional representation.

316. The system of claim 315, wherein the user input affects rotational orientation of the visualization on the display.

317. The system of claim 315, wherein the display includes areas for one or more user controls accessible through the touch-screen display.

318. The system of claim 317, wherein the user controls include a zoom control.

319. The system of claim 317, wherein the user controls include a pan control.

320. The system of claim 317, wherein the user controls include case management controls.

321. The system of claim 320, wherein the case management controls include a control to transmit the three-dimensional representation to a dental lab.

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322. The system of claim 320, wherein the case management controls include a control to evaluate quality of the three-dimensional representation.

323. The system of claim 320, wherein the case management controls include a tool to edit the three-dimensional representation.

324. The system of claim 320, wherein the case management controls include a control to create a dental prescription.

325. The system of claim 317, wherein the user controls include a control to define a cementation void.

326. The system of claim 317, wherein the user controls include a control to define a margin line.

327. The system of claim 317, wherein the user controls include a control to infer a margin line from the three-dimensional representation.

328. The system of claim 317, wherein the user controls include a control to recess a region of the three-dimensional representation below a margin line

329. The system of claim 317, wherein the user controls include a control to virtually fit a dental restoration to a prepared tooth surface.

330. The system of claim 317, wherein the user controls include a virtual dental articulator.

331. The system of claim 317, wherein the user controls include a tool to design a dental restoration fitted to the surface within the mouth of the dental patient.

332. The system of claim 315, wherein the three-dimensional model includes two arches; the display including an area for one or more user controls accessible through the touch-screen display to permit positioning the two arches within a virtual articulator.

333. The system of claim 315, further comprising a user interface displayed on the display and controlled by the computer.

334. The system of claim 333, wherein the user interface is accessible through the touch-screen.

335. A system comprising:

a digital dental impression including three-dimensional digital surface data for one or more intraoral structures, the digital dental impression captured using a three-dimensional intraoral scanning device and stored in a computer readable medium;

a first computer configured to render the digital dental impression from a point of view; and

a second computer at a remote location configured to simultaneously render the digital dental impression from the point of view.

336. The system of claim 335, further including a control for passing control of the point of view between the first computer and the second computer.

337. The system of claim 335, further including the first computer and the second computer including a collaborative tool for manipulating the model.

338. The system of claim 335, further including the first computer and the second computer including a collaborative tool for sectioning the model.

339. The system of claim 335, further including the first computer and the second computer including a collaborative tool for rearranging one or more sections of the model.

340. The system of claim 335, further including the first computer and the second computer including a collaborative cursor control tool.

341. The system of claim 335, further including the first computer and the second computer connected by a communication channel.

342. The system of claim 341, wherein the communication channel includes one or more of VoIP, IRC, video conferencing, or instant messaging.

343. The system of claim 335, wherein the second computer is operated by a consulting dentist.

344. The system of claim 335, wherein the second computer is operated by a dental technician.

345. The system of claim 335, wherein the second computer is operated in a dental laboratory.

346. The system of claim 335, wherein the second computer is operated by an oral surgeon.

347. The system of claim 335, wherein the second computer is operated by a dental specialist including one or more of a periodontist, a prosthodontist, a pedodontist, an orthodontic specialist, an oral and maxillofacial surgery specialist, an oral and maxillofacial radiology specialist, an endodontist, and an oral and maxillofacial pathologist.

348. A method comprising:

seating a dental patient in a clinical office;

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acquiring a digital dental impression including three-dimensional digital surface data for one or more intraoral structures from an intraoral scan of the dental patient;

transmitting the digital dental impression to a dental laboratory before the patient leaves the office;

receiving an evaluation of the digital dental impression from the dental laboratory before the patient leaves the office; and

if the evaluation is unfavorable, repeating the step of acquiring the digital dental impression.

349. The method of claim 348, wherein the evaluation includes an identification of at least one region of the one or more intraoral structures requiring additional preparation, the method including preparing the one or more intraoral structures according to the evaluation.

350. The method of claim 348, wherein the evaluation includes an evaluation of surface continuity.

351. The method of claim 348, wherein the evaluation includes an evaluation of data density.

352. The method of claim 348, wherein the evaluation includes an evaluation of feature detail.

353. The method of claim 348, wherein one or more intraoral structures includes a tooth surface prepared for a dental restoration.

354. The method of claim 353, wherein the digital dental impression includes a case plan for the restoration.

355. The method of claim 354, wherein the case plan includes a type of restoration.

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356. The method of claim 354, wherein the case plan includes a design of restoration.

357. The method of claim 354, wherein the case plan includes a list of restoration components.

358. The method of claim 357, wherein the list of restoration components includes a full ceramic component.

359. The method of claim 357, wherein the list of restoration components includes a PFM component.

360. The method of claim 354, wherein the case plan includes a specification of one or more restoration materials.

361. The method of claim 348 wherein the evaluation includes an evaluation of a margin around a tooth prepared for a restoration.

362. A system comprising:

a means for acquiring a digital dental impression, the digital dental impression including three-dimensional digital surface data for one or more intraoral structures from an intraoral scan of a dental patient seated in a clinical office;

a request means for transmitting the digital dental impression to a dental laboratory before the patient leaves the office;

an evaluation means for determining if the digital dental impression must be reacquired before the patient leaves the office; and

a response means for transmitting the determination to the clinical office.

363. The system of claim 362, wherein the evaluation means includes a means for evaluating surface continuity.

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364. The system of claim 362, wherein the evaluation means includes a means for evaluating data density.

365. The system of claim 362, wherein the evaluation means includes a means for evaluating feature detail.

366. The system of claim 362, wherein one or more intraoral structures includes a tooth surface prepared for a dental restoration.

367. The system of claim 366, wherein the digital dental impression includes a case plan for the restoration.

368. The system of claim 367, wherein the case plan includes a type of restoration.

369. The system of claim 367, wherein the case plan includes a design of restoration.

370. The system of claim 367, wherein the case plan includes a list of restoration components.

371. The system of claim 370, wherein the list of restoration components includes a full ceramic component.

372. The system of claim 370, wherein the list of restoration components includes a PFM component.

373. The system of claim 367, wherein the case plan includes a specification of one or more restoration materials.

374. A system comprising:

a scanning device for real time capture of three-dimensional surface data;

a monitor that renders the three-dimensional surface data in real time;

a processor configured to evaluate quality of the three-dimensional surface data, and to generate a signal representative of a data quality during a scan; and

a feedback device responsive to the signal to produce a user alert concerning the data quality when the data quality degrades below a predetermined threshold.

375. The system of claim 374, wherein the scanning device resolves the three-dimensional surface data from a plurality of two-dimensional image sets, and wherein the evaluation of quality includes evaluation of ability to determine spatial relationships from the plurality of two-dimensional image sets.

376. The system of claim 374, wherein the evaluation of quality includes evaluation of point cloud density.

377. The system of claim 374, wherein the evaluation of quality includes evaluation of scanning device motion.

378. The system of claim 374, wherein the feedback device includes an LED.

379. The system of claim 374, wherein the feedback device includes a speaker.

380. The system of claim 374, wherein the feedback device includes a buzzer.

381. The system of claim 374, wherein the feedback device includes a vibrator.

382. The system of claim 374, wherein the scanning device includes a wand, the feedback device positioned on the wand.

383. The system of claim 374, wherein the feedback device is further responsive to the signal to produce a second user alert when the data quality is within an acceptable range.

384. A method comprising:

scheduling a preparation visit for a dental restoration for a patient;

obtaining a digital surface representation of one or more intraoral structures of the patient, including at least one tooth associated with the dental restoration; and

fabricating a temporary restoration based upon the digital surface representation.

385. The method of claim 384, wherein fabricating a temporary restoration includes transmitting the digital surface representation to a dental laboratory.

386. The method of claim 384, wherein fabricating a temporary restoration includes applying the digital surface representation to prepare a design for the temporary restoration and transmitting the design to a dental laboratory.

387. The method of claim 384, further including three-dimensionally printing the temporary restoration.

388. The method of claim 384, further including three-dimensionally printing the temporary restoration at a dentist's office where the preparation visit is scheduled.

389. The method of claim 384, further including milling the temporary restoration.

390. The method of claim 384, further including milling the temporary restoration at a dental office where the preparation visit is scheduled.

391. The method of claim 384, wherein obtaining a digital surface representation includes three-dimensionally scanning the one or more intraoral structures on a day of the preparation visit.

392. The method of claim 384, wherein obtaining a digital surface representation includes retrieving the digital surface representation from prior dental data for the patient.

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393. The method of claim 384, wherein fabricating the temporary restoration includes fabricating the temporary restoration prior to the preparation visit, the temporary restoration including one or more characteristics of the at least one tooth.

394. The method of claim 393, further comprising, on the day of the preparation visit adapting a surface of the at least one tooth to receive the temporary restoration.

395. The method of claim 393, further comprising, on the day of the preparation visit, adapting the temporary restoration to fit a prepared surface of the at least one tooth.

396. The method of claim 384, wherein the step of fabricating is performed at an in-house dental laboratory at a dentist's office.

397. A method comprising:

acquiring a digital dental impression including three-dimensional digital surface data for one or more intraoral structures, the intraoral structures including at least one tooth surface prepared for an artificial dental object; and

acquiring additional three-dimensional data with greater spatial resolution around the at least one tooth surface prepared for the artificial dental object.

398. The method of claim 397, wherein acquiring additional three-dimensional data includes acquiring additional data from the at least one tooth surface.

399. The method of claim 397, wherein acquiring additional three-dimensional data includes post-processing source data for the digital dental impression.

400. The method of claim 397, wherein acquiring additional three-dimensional data includes post-processing the three-dimensional digital surface data.

401. A computer program product comprising computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of:

acquiring one or more images of one or more intraoral structures, the intraoral structures including at least one tooth surface prepared for an artificial dental object; and

generating a digital dental impression including three-dimensional digital surface data from the one or more images.

402. The computer program product of claim 401, further comprising computer code that performs the step of post-processing source data for the digital dental impression to generate additional three-dimensional data with greater spatial resolution.

403. The computer program product of claim 401, further comprising computer code that performs the step of post-processing the three-dimensional digital surface data to generate additional three-dimensional data with greater spatial resolution.

404. A system comprising:

a first means for acquiring a digital dental impression including three-dimensional digital surface data for one or more intraoral structures, the intraoral structures including at least one tooth surface prepared for an artificial dental object; and

a second means for acquiring additional three-dimensional data with greater spatial resolution around the at least one tooth surface prepared for the artificial dental object.

405. The system of claim 404, wherein the second means includes a means for acquiring additional data from the at least one tooth surface.

406. The system of claim 404, wherein the second means includes a means for post-processing source data for the digital dental impression.

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407. The method of claim 404, wherein the second means includes a means for post-processing the three-dimensional digital surface data.

408. A method comprising:

acquiring a digital surface representation for one or more intraoral structures, the intraoral structures including at least one tooth surface prepared for a dental prosthesis;

fabricating a kit from the digital surface representation, the kit including two or more components suitable for use in fabrication of the dental prosthesis; and

sending the kit to a dental laboratory for fabrication of the dental prosthesis.

409. The method of claim 408, wherein the kit includes one or more of a die, a quad model, an opposing quad model, an opposing model, a base, a pre-articulated base, and a waxup.

410. The method of claim 408, further comprising transmitting the digital surface representation to a production facility, the step of fabricating being performed at the production facility.

411. The method of claim 408, wherein the kit includes one or more components selected from the group of pre-cut components, pre-indexed components, and pre-articulated components.

412. The method of claim 408, where in the step of fabricating is performed at a dentist's office.

413. An artificial dental object including an exposed surface, the exposed surface having a texture integrated therein adapted to enhance acquisition of three dimensional image data from the exposed surface with a multi-aperture three-dimensional scanning device.

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414. The artificial dental object of claim 413 wherein the texture includes pseudo-random three-dimensional noise.

415. The artificial dental object of claim 413 wherein the artificial dental object includes an impression coping.

416. The artificial dental object of claim 413 wherein the artificial dental object includes a fixture.

417. The artificial dental object of claim 413 wherein the artificial dental object includes a healing abutment.

418. The artificial dental object of claim 413 wherein the artificial dental object includes a temporary impression coping.

419. The artificial dental object of claim 413 wherein the artificial dental object includes a dental prosthesis.

420. The artificial dental object of claim 413 wherein the artificial dental object includes a dental appliance.

421. The artificial dental object of claim 413 wherein the artificial dental object includes an item of dental hardware.

422. The artificial dental object of claim 413 wherein the artificial dental object includes a dental restoration.

423. A method comprising:

acquiring a three-dimensional representation of one or more intraoral structures, the intraoral structures including at least one intraoral surface suitable for an artificial dental object;

transmitting the three-dimensional representation to a dental insurer; and

receiving authorization from the dental insurer to perform a dental procedure including the artificial dental object.

424. The method of claim 423, wherein the artificial dental object includes one or more of an implant, a crown, an impression coping, a bridge, a fixture, and an abutment.

425. The method of claim 423, wherein the intraoral surface includes at least one edentulous space.

426. The method of claim 423, wherein the intraoral surface includes at least one tooth surface.

427. A computer program product comprising computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of:

acquiring a three-dimensional representation of one or more intraoral structures, the intraoral structures including at least one intraoral surface suitable for an artificial dental object;

transmitting the three-dimensional representation to a dental insurer; and

receiving authorization from the dental insurer to perform a dental procedure including the artificial dental object.

428. The method of claim 427, wherein the artificial dental object includes one or more of an implant, a crown, an impression coping, a fixture, a bridge, and an abutment.

429. The method of claim 427, wherein the intraoral surface includes at least one edentulous space.

430. The method of claim 427, wherein the intraoral surface includes at least one tooth surface.

Exhibit 1004 page 527 of 1621
DENTAL IMAGING

431. A system comprising:

a means for acquiring a three-dimensional representation of one or more intraoral structures, the intraoral structures including at least one intraoral surface suitable for an artificial dental object;

a first communication means for transmitting the three-dimensional representation to a dental insurer; and

a second communication means for receiving authorization from the dental insurer to perform a dental procedure including the artificial dental object.

432. The system of claim 431, wherein the artificial dental object includes one or more of an implant, a crown, an impression coping, a fixture, a bridge and an abutment.

433. The system of claim 431, wherein the at least one intraoral surface includes an edentulous space.

434. The system of claim 431, wherein the at least one intraoral surface includes a tooth surface.

435. A method comprising:

acquiring a three-dimensional representation of one or more intraoral structures, the intraoral structures including at least one intraoral surface related to a dental procedure; and

transmitting the three-dimensional representation to a dental insurer as a record of the dental procedure.

436. The method of claim 435, wherein the dental procedure relates to one or more of an implant, a crown, an impression coping, a fixture, a bridge, and an abutment.

437. The method of claim 435, further comprising receiving a payment from the insurer for a procedure involving the artificial dental object.

438. The method of claim 435 wherein the intraoral surface includes an edentulous space.

439. The method of claim 435 wherein the intraoral surface includes a tooth surface prepared for an artificial dental object.

440. The method of claim 437 wherein the intraoral surface includes a restored tooth.

441. A computer program product comprising computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of:

acquiring a three-dimensional representation of one or more intraoral structures, the intraoral structures including at one intraoral surface related to a dental procedure; and

transmitting the three-dimensional representation to a dental insurer as a record of the dental procedure.

442. The computer program product of claim 441, wherein the dental procedure relates to one or more of an implant, a crown, an impression coping, a bridge, and an abutment.

443. The computer program product of claim 441, further comprising computer code that performs the step of receiving a record of payment from the insurer for the dental procedure.

444. The computer program product of claim 441, wherein the intraoral surface includes an edentulous space.

445. The computer program product of claim 441, wherein the intraoral surface includes a tooth surface prepared for an artificial dental object.

446. The computer program product of claim 441, wherein the intraoral surface includes a restored tooth.

447. A system comprising:

a means for acquiring a three-dimensional representation of one or more intraoral structures, the intraoral structures including at least one intraoral surface related to a dental procedure; and

a communication means for transmitting the three-dimensional representation to a dental insurer as a record of the dental procedure.

448. The system of claim 447, wherein the dental procedure relates to one or more of an implant, a crown, an impression coping, a bridge, and an abutment.

449. The system of claim 447, wherein the communication means includes a means for receiving a payment from the insurer for the dental procedure.

450. A method comprising:

receiving a three-dimensional representation of one or more intraoral structures from a dentist;

receiving a proposed dental procedure from the dentist;

determining whether the proposed dental procedure is appropriate for the one or more intraoral structures; and

transmitting a reply to the dentist.

451. The method of claim 450, wherein the reply includes an approval to perform the dental procedure.

452. The method of claim 450, wherein the reply includes a denial to perform the dental procedure.

453. The method of claim 450, further comprising authorizing payment for the dental procedure.

454. A computer program product comprising computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of:

receiving a three-dimensional representation of one or more intraoral structures from a dentist;

receiving a proposed dental procedure from the dentist;

comparing the proposed dental procedure to a predetermined list of appropriate procedures for the one or more intraoral structures; and

transmitting a reply to the dentist.

455. The computer program product of claim 454, wherein the reply includes an approval to perform the dental procedure.

456. The computer program product of claim 454, wherein the reply includes a denial to perform the dental procedure.

457. The computer program product of claim 454, further comprising computer code that performs the step of authorizing payment for the dental procedure.

458. A system comprising:

a first means for receiving a three-dimensional representation of one or more intraoral structures from a dentist;

a second means for receiving a proposed dental procedure from the dentist;

an evaluation means for determining whether the proposed dental procedure is appropriate for the one or more intraoral structures; and

a reply means for transmitting a reply to the dentist.

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DENTAL IMAGING

459. The system of claim 458, wherein the reply includes an approval to perform the dental procedure.

460. The system of claim 458, wherein the reply includes a denial to perform the dental procedure.

461. The system of claim 458, further comprising a means for authorizing payment for the dental procedure.

462. A system comprising:

a dental data repository coupled to a communications network, the dental data repository adapted to receive dental data including three-dimensional representations of intraoral structures and prescriptions for dental procedures from a plurality of dentists.

463. The system of claim 462, wherein the dental data repository is adapted to transmit prescriptions and three-dimensional representations to a plurality of dental laboratories.

464. The system of claim 463, wherein at least one of the prescriptions identifies a specific one of the plurality of dental laboratories.

465. The system of claim 462, wherein the dental data repository is further adapted to communicate with one or more dental insurers for authorization of dental procedures.

466. The system of claim 462, wherein the dental data repository is further adapted to communicate with one or more dental insurers to coordinate payment for dental procedures.

467. The system of claim 462, further comprising a dental laboratory interface for the plurality of dental laboratories to provide status on work in progress.

468. The system of claim 462, further comprising a dental laboratory interface for the plurality of dental laboratories to receive work assignments.

469. The system of claim 462, further comprising a dentist interface for the plurality of dentists to monitor work in progress.

470. The system of claim 462, further comprising a dentist interface for the plurality of dentists to submit prescriptions and three-dimensional representations.

471. The system of claim 462, further comprising a transaction engine for transmitting payments among two or more of one of the plurality of dentists, one of the plurality of dental laboratories, and one of the one or more dental insurers.

472. The system of claim 462, further comprising a collaboration interface for two or more of the plurality of dentists to collaborate on a dental matter.

Exhibit 1004 page 533 of 1621
DENTAL IMAGING

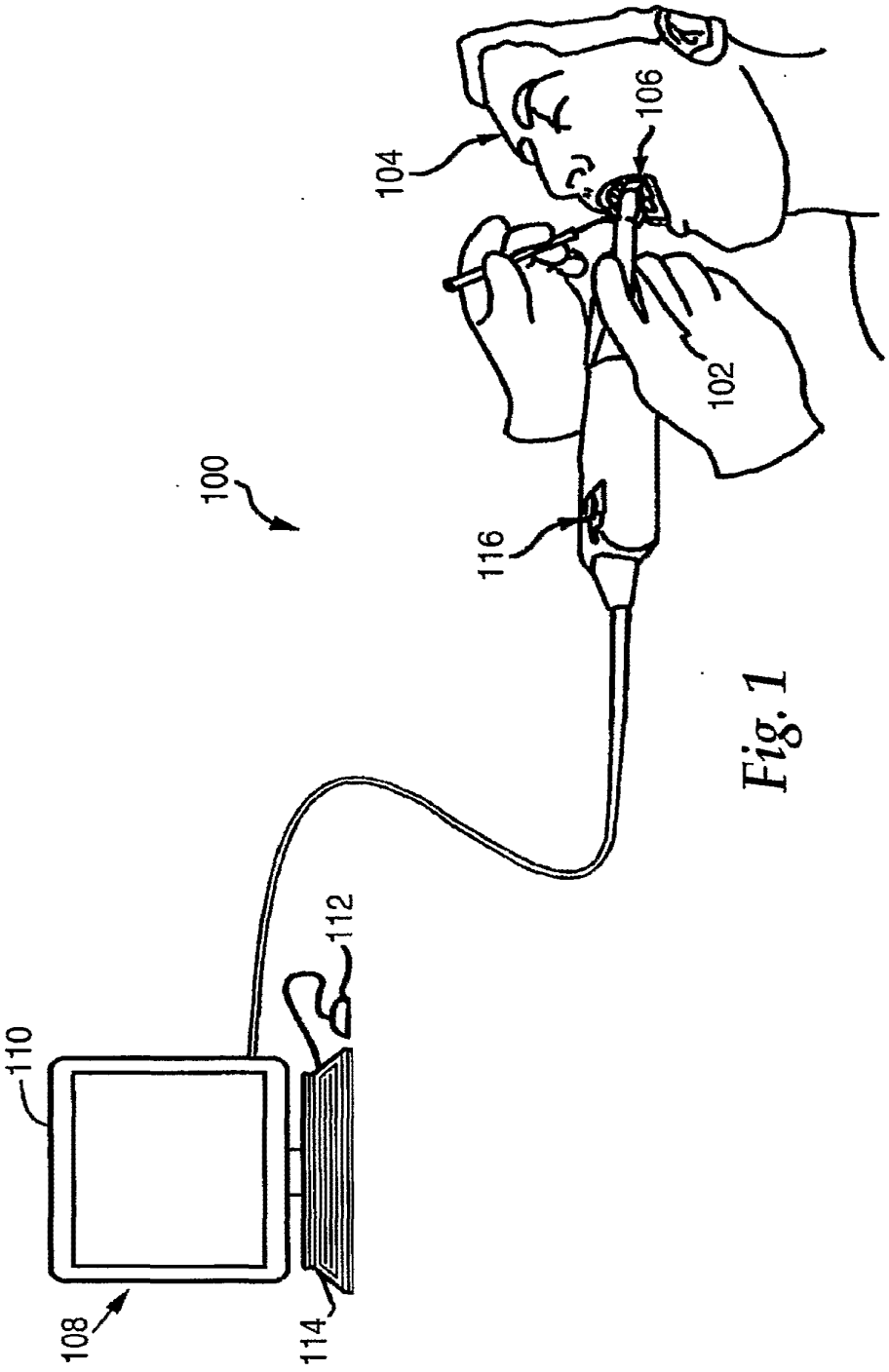


Fig. 1

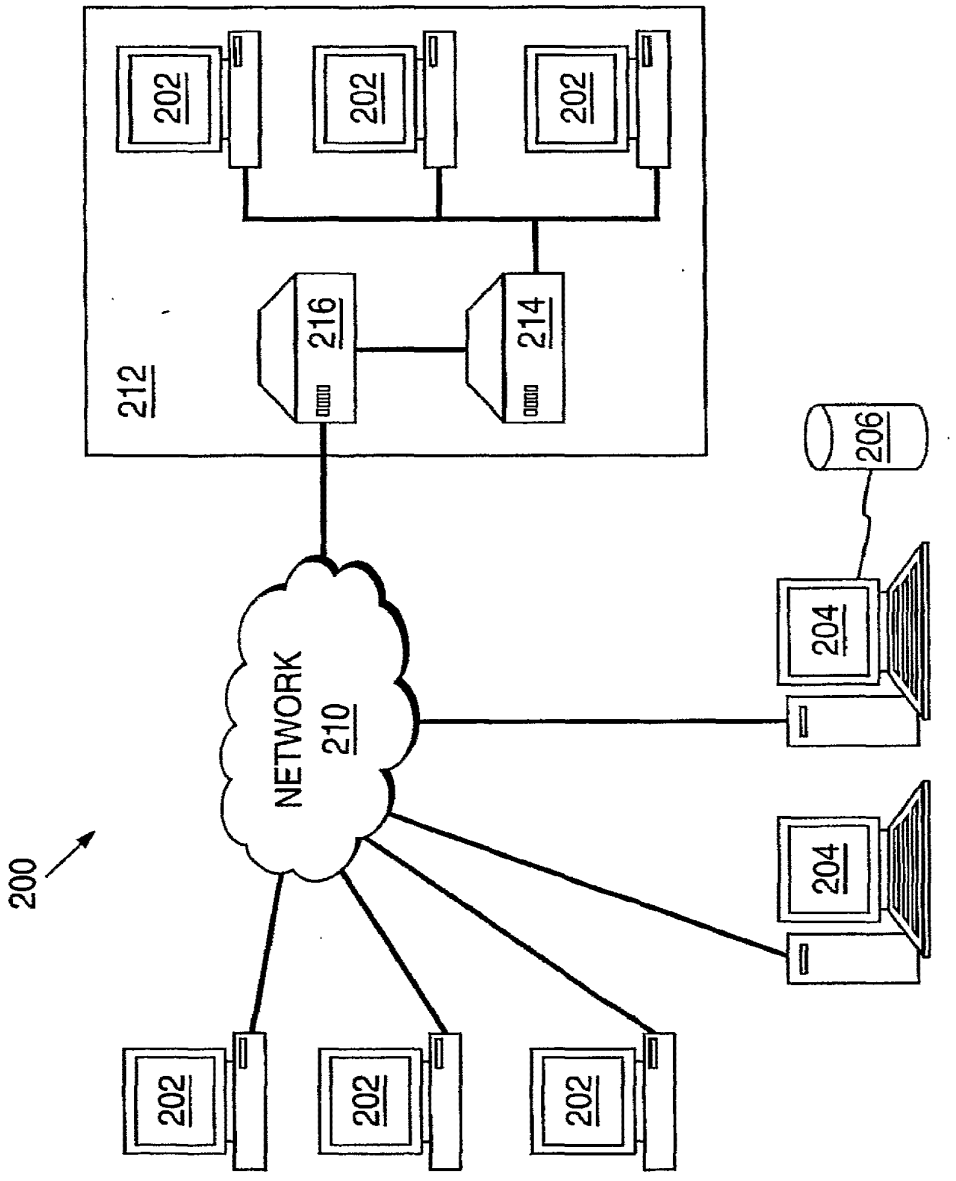


Fig. 2

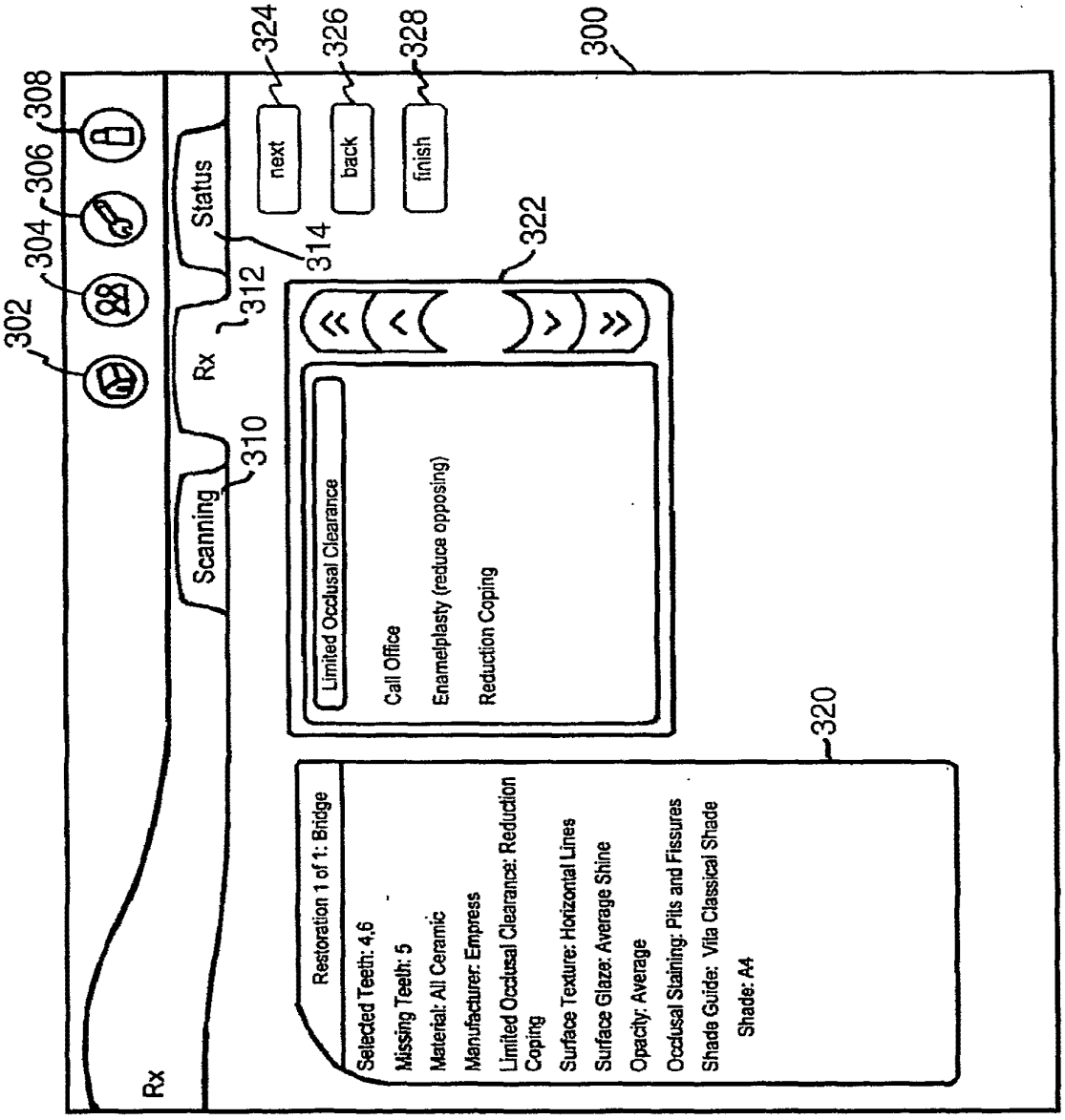

302
304
306
308
Rx
Scanning
Rx
Status
310
312
314
324
326
328
300
next
back
finish
322
Limited Occlusal Clearance
Call Office
Enamelplasty (reduce opposing)
Reduction Coping
320
Restoration 1 of 1: Bridge
Selected Teeth: 4,6
Missing Teeth: 5
Material: All Ceramic
Manufacturer: Empress
Limited Occlusal Clearance: Reduction
Coping
Surface Texture: Horizontal Lines
Surface Glaze: Average Shine
Opacity: Average
Occlusal Staining: Pits and Fissures
Shade Guide: Vita Classical Shade
Shade: A4

Fig. 3

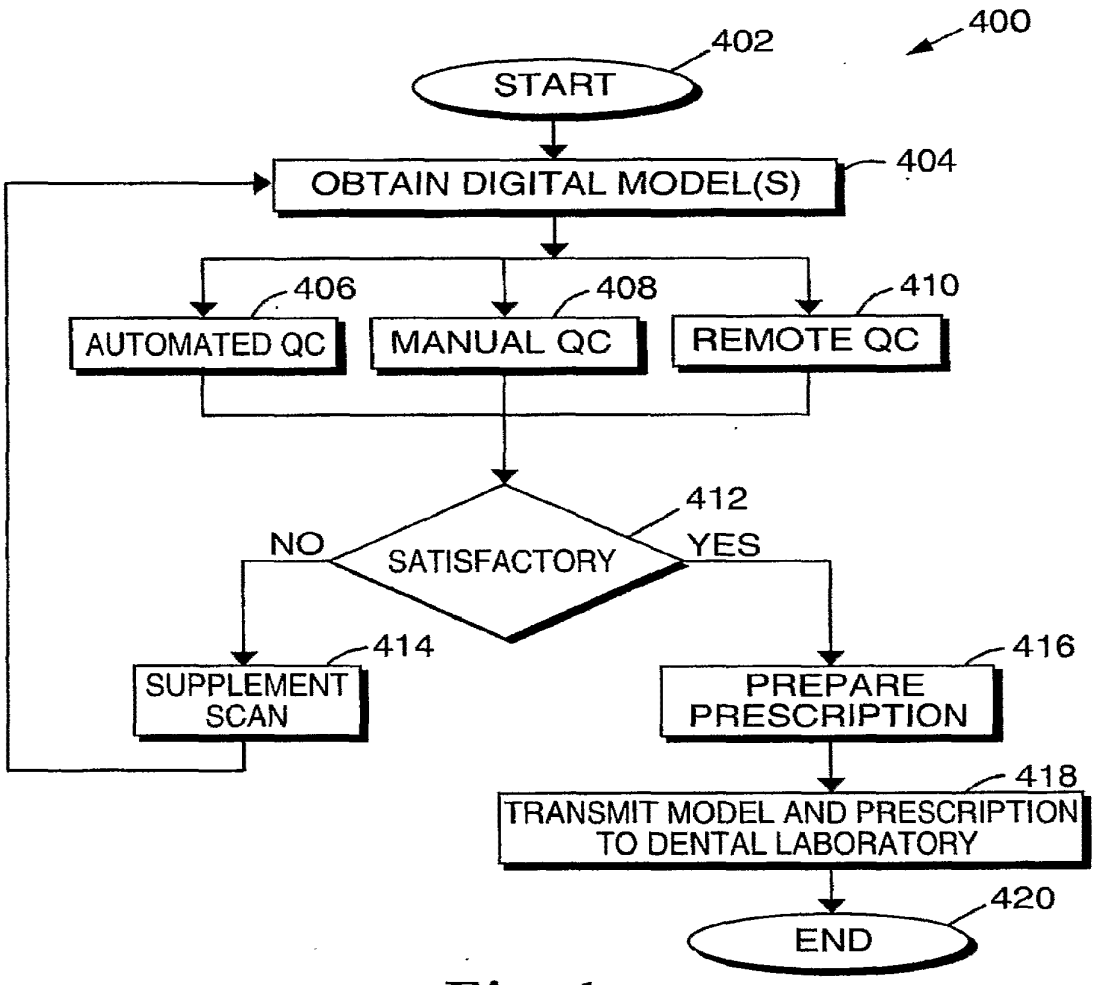

400
402
START
OBTAIN DIGITAL MODEL(S)
404
406
AUTOMATED QC
408
MANUAL QC
410
REMOTE QC
412
NO
SATISFACTORY
YES
414
SUPPLEMENT SCAN
416
PREPARE PRESCRIPTION
418
TRANSMIT MODEL AND PRESCRIPTION TO DENTAL LABORATORY
420
END

Fig. 4

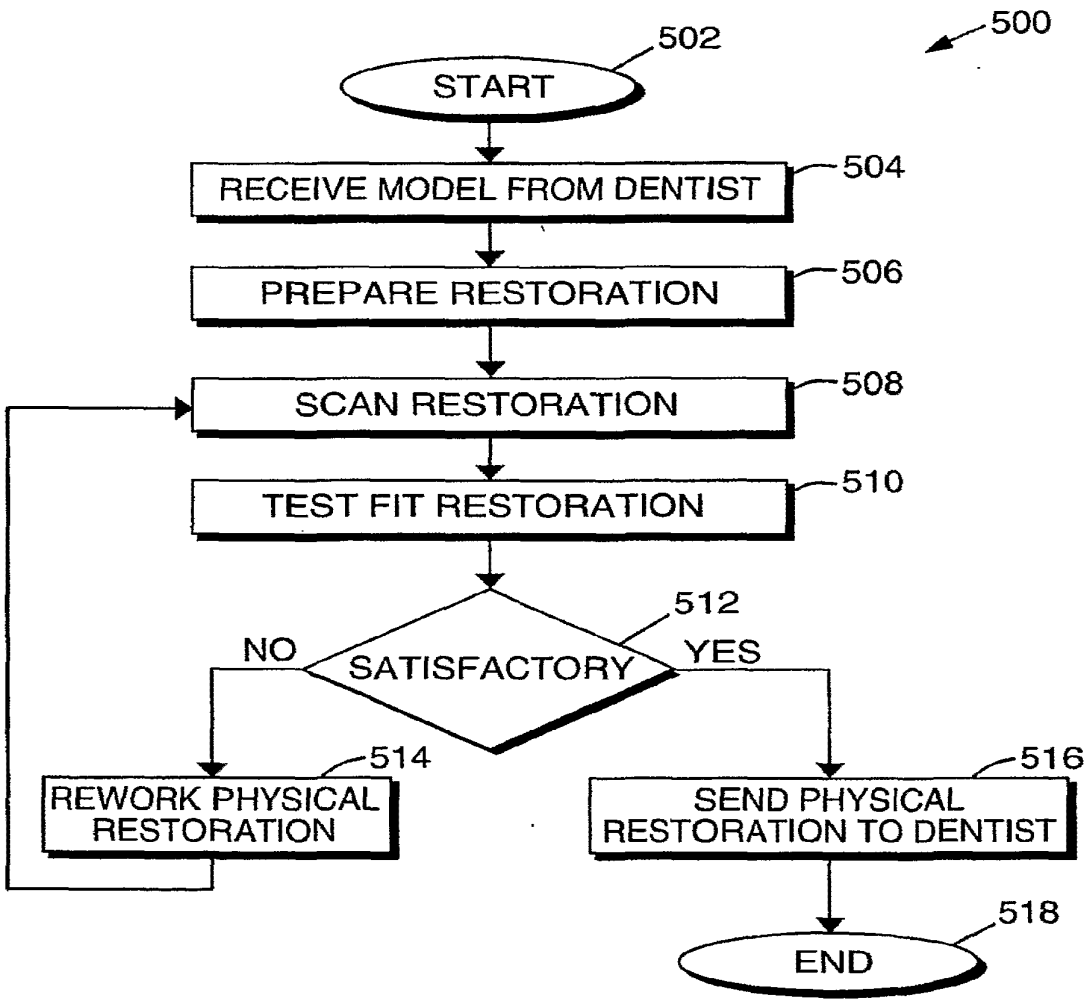

500
502
START
RECEIVE MODEL FROM DENTIST
504
PREPARE RESTORATION
506
SCAN RESTORATION
508
TEST FIT RESTORATION
510
512
NO
SATISFACTORY
YES
REWORK PHYSICAL RESTORATION
514
SEND PHYSICAL RESTORATION TO DENTIST
516
518
END

Fig. 5

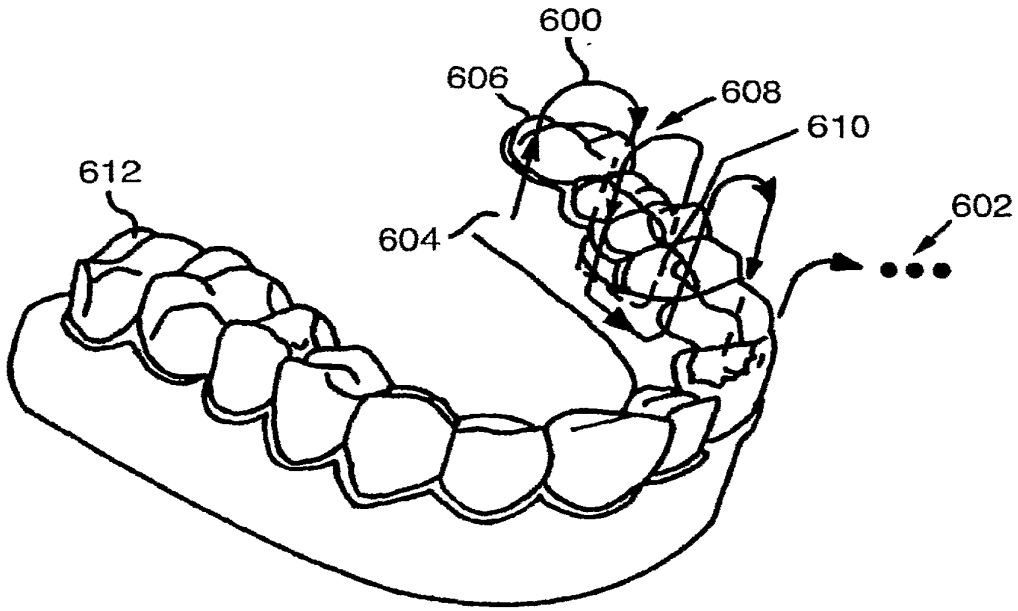


Fig. 6

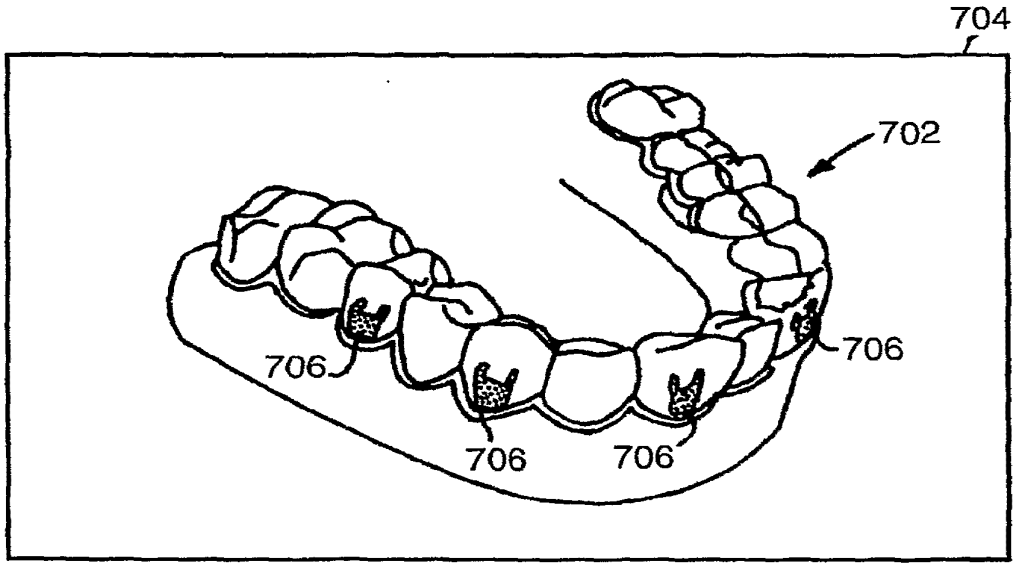


Fig. 7A

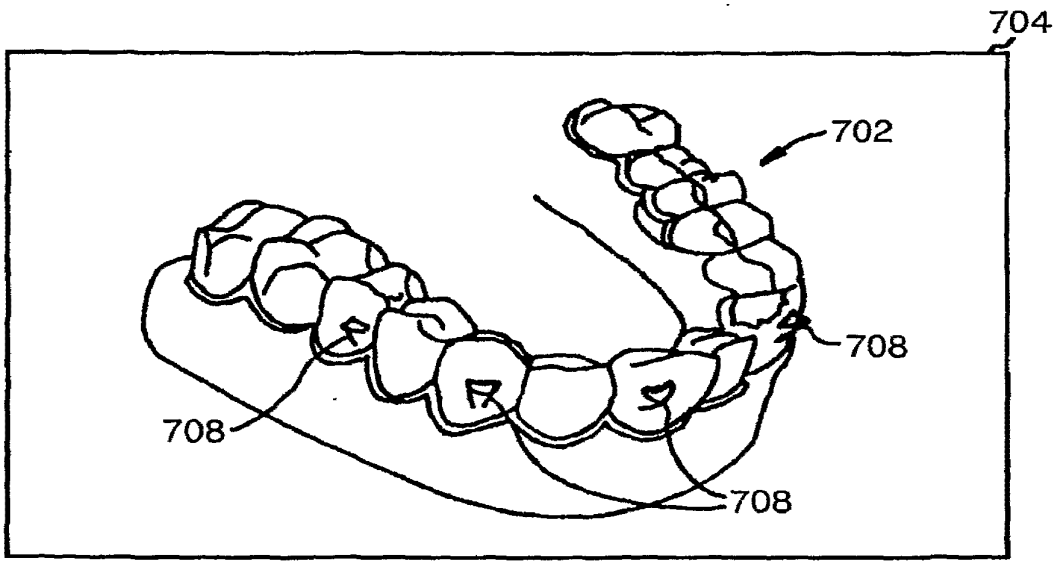


Fig. 7B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2007/001547

A. CLASSIFICATION OF SUBJECT MATTER

G06Q 10/00(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC G06Q 10/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean Utility models and applications for Utility models since 1975
Japanese Utility models and applications for Utility models since 1975

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

PAJ, FPD, USPAT, eKIPASS "Keyword: dental, intraoral, inter-oral, three-dimensional, fabrication"

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US 2005153257 A (DURBIN DUANE M , DURBIN DENNIS A) 14 JULY 2005 See the abstract; figures 1.	1, 22 31, 245, 254, 263 2-9, 14-15, 17-22, 26-28, 30, 31-37, 74-135, 150-244, 246-253, 255-262, 264-277, 311-347, 384-412
Y	US 06648640 A (Ora Metrix, Inc.) 18 NOVEMBER 2003 See the abstract; claims 1-35; figures 1-120.	1-9, 14-15, 17-22, 26-28, 30, 31-37, 74-135, 150-277, 311-347, 384-412
A	US 2004029078 A (MARSHALL MICHAEL CRAIG) 12 FEBRUARY 2004 See the abstract; figures 1-2.	1-472
A	US 2005170309 A (3M INNOVATIVE PROPERTIES CO) 04 AUGUST 2005 See the abstract; columns 1-2; figures 1-2.	1-472

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
02 JULY 2007 (02.07.2007)	**02 JULY 2007 (02.07.2007)**

Name and mailing address of the ISA/KR

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Telephone No. 82-42-481-8376

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2007/001547

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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US06648640	18.11.2003	US20020015934A1	07.02.2002
		US2002150859A1	17.10.2002
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US2005170309A1	04.08.2005	AU2004316121AA	01.09.2005
		EP1711120A1	18.10.2006
		WO2005079695A1	01.09.2005

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(72) Inventors; and
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Declaration under Rule 4.17:
— *of inventorship (Rule 4.17(iv))*

Published:
— *with international search report*

(54) **Title:** APPARATUS AND METHOD FOR MEDICAL SCANNING

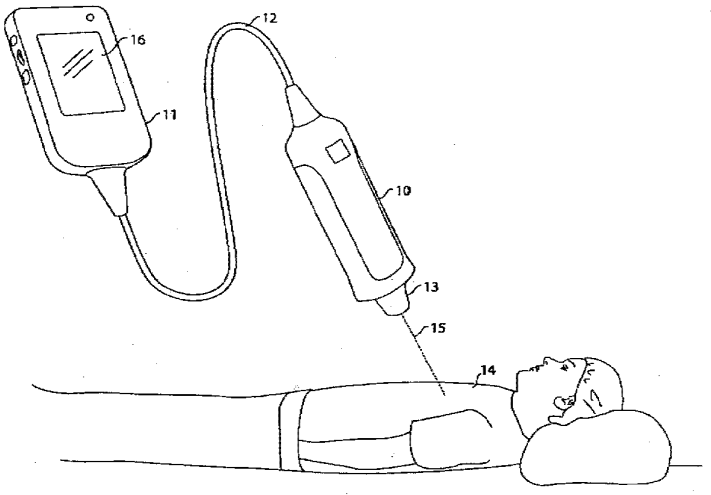


Figure 1

(57) **Abstract:** A hand held ultrasound imaging system with a probe unit having a transducer being adapted to transmit and receive ultrasonic signals and an orientation sensor adapted to sense the rotation of the probe unit, the output of the transducer and of the sensor being combined to produce a set of scanlines having a series of intensity values and a rotation value, the scanlines then being processed to produce a raster image for display on a display unit.

WO 2009/026645 A1

APPARATUS AND METHOD FOR MEDICAL SCANNING

TECHNICAL FIELD

The present invention relates to an improved method and apparatus for ultrasound scanning of a subject, providing cost and range of application advantages. The method has particular application to the field of hand-held ultrasound equipment.

BACKGROUND ART

Ultrasound was first investigated as a medical diagnostic imaging tool in the 1940's. This was based on the use of A-mode (amplitude mode) ultrasound, which is a form of echo ranging. This simply gives a plot of returned echo intensity against time, which, by knowing the speed of sound in the target media, gives the distance of the features returning the echo from the transducer. In order to obtain valid information from such a scanline it is necessary that the direction of the transmitted ultrasound beam be constant and known.

In order to provide an imaging system, it is necessary to insonify a larger area, at least a two dimensional slice of the target. It is also necessary to receive returned echoes from this area and to display this information in correct spatial relationship.

Since the only information received by an ultrasound transducer is echo intensity over time, spatial information can most easily be added by knowing the direction from which the echo was received. This means knowing the position and orientation of the transducer at all times and this was most easily achieved by controlling the movement of the transducer.

This led to B-mode (brightness mode) scanning, where the ultrasound output is pulsed and the transducer is mechanically scanned over the target. The transducer detects the echo from each pulse as intensity versus time, called a scanline. The scanlines are displayed with brightness being proportional to echo intensity, thus forming an image.

In the early 1950's Wild and Reid constructed a B-mode scanning system using a mechanically mounted rotating transducer.

Ultrasound technology developed significantly in the 1960's with the development of articulated arm B-mode scanners by Wright and Meyerdirk. Articulated arm scanners, also known as static mode scanners, connect the ultrasonic transducer to a moveable arm, with movement of the arm mechanically measured using potentiometers. The articulated arm also ensures that the degree of freedom of movement of the transducer is limited to a defined plane. This allowed the position of the transducer to be known with considerable accuracy, thus allowing the scanlines recorded by the transducer to be accurately located in space relative to each other for display.

Static mode ultrasound scanners were in wide use until the early 1980s. The static mode scanners were large cumbersome devices, and the techniques used are not readily suited to a handheld ultrasound system.

In the mid 1970's real-time scanners were developed where an ultrasonic transducer was rotated using a motor. Krause (US Patent No. 3470868 – Ultrasound diagnostic apparatus) describes an invention where a motor rotates an ultrasonic transducer in order to produce images in real-time.

Motor driven transducers removed the need for precise knowledge of the position of the transducer housing, since the operator needed only to hold the transducer housing still and the motor would sweep the transducer rapidly to produce a scan arc. This resulted in an evenly distributed set of scanlines, in a single plane, whose spatial relationship was known because the sweep characteristics were known.

These devices brought their own problems. The motor driving circuitry added size, power consumption, complexity and cost to the device. Additionally, the motor itself and associated moving parts reduced the reliability of the device.

A solution to these problems has been sought in electronic beam steering transducers. Wilcox (US Patent No. 3881466) describes an invention consisting of a number of electronic crystals where the transmitting pulse can be delayed in sequence to each crystal and thus effect an electronic means to steer the ultrasound beam. The basic technique is still in wide use today, with nearly all modern medical ultrasound equipment using an array of ultrasonic crystals in the transducer. The early designs used at least 64 crystals, with modern designs sometimes using up to a thousand crystals or more.

Electronic beam steering removes the need for a motor to produce real time images. The scanlines resulting from the use of an array transducer are contained within a defined plane, or in the case of 2-D arrays within a defined series of planes. The scanlines may therefore be readily mapped onto a flat screen for display.

However, the cost of producing transducers with arrays of crystals is high. There is also a high cost in providing the control and processing circuitry, with a separate channel being required for each crystal. The transducers are usually manually manufactured, with the channels requiring excellent channel to channel matching and low cross-talk. The power consumption for electronic systems is also high, and is generally proportional to the number of channels being simultaneously operational.

In parallel, solutions to the problem of tracking a transducer without using articulated arms were pursued. These involved tracking the transducer, or a component with a fixed relationship to the transducer, in relation to an external reference frame. These generally involved electromagnetic tracking using one or more fixed transmitters separate from the transducer unit, and a receiver on the transducer unit. Visual tracking using cameras was also employed.

These all suffered from the need to establish the frame of reference, in some cases only being of use in specifically equipped rooms. They also suffered from the problem of interference with the tracking signals by people and equipment moving in the field of reference. These problems, in particular made these systems unsuitable for hand-held use.

Much of the prior art in ultrasound technology is directed to improving the performance of ultrasound systems enabling them to be used for an ever increasing range of diagnostic applications. The result has seen significant advances in ultrasound systems with transducers using ever increasing numbers of crystals, and host systems with ever increasing processing power. The result has seen systems with 3D and real-time 3D (or 4D) capability.

These high cost, high power consumption devices are unsuitable for broad point-of-care application outside of specialist sonography facilities. In particular, these systems are unsuitable for application to hand-held devices.

DISCLOSURE OF THE INVENTION

In order to put ultrasound capability into the hands of point of care personnel, factors of cost, size, form factor and usability need to be considered. Power usage is also important, since a hand held device is most conveniently battery powered. A simple, single beam transducer, manually swept over a region of interest provides advantages.

Therefore, in one form of this invention although this may not necessarily be the only or indeed the broadest form of this there is proposed an ultrasound imaging system adapted for hand held use including

a probe unit having a transducer in a fixed spatial relationship with the probe unit, said transducer being adapted to transmit and receive ultrasonic signals,

an orientation sensor adapted to sense the rotation of the probe unit about at least one axis,

electronics adapted to apply a pulsed voltage to the transducer and to process the electrical output signal of the transducer and of the sensor to produce a plurality of scanlines each having a series of intensity values and a rotation value,

a processor adapted to process the scanlines to produce a raster image,

a display adapted to display the resultant raster image.

In preference the sensor is an inertial sensor.

An advantage of using an inertial sensor is that it is self contained. The sensor can be fully contained in the probe unit, without the need for an external reference.

In a further form the invention may be said to lie in a method of ultrasound imaging including the steps of

applying a probe unit including an ultrasound transducer adapted to transmit and receive ultrasonic signals into and from a target body,

transmitting ultrasonic pulses into said target body and receiving return signals

rotating said probe unit substantially in a single plane such that a two dimensional section of the target body is scanned

using a sensor to provide rotation information about the rotation of the probe unit about at lest one axis,

combining the return signals with the rotation information to produce

scanlines,
processing the scanlines to produce a raster image,
displaying the raster image on a display.

It has always been considered in the prior art that inertial sensors suffer from calibration problems which render them unsuitable for this use. However, the apparatus and method of the invention allow medically useful data to be extracted without calibration being a significant issue.

In preference, the sensor includes a gyroscope.

In preference, the sensor includes two or more orthogonally mounted gyroscopes.

In preference, the sensor includes an accelerometer.

In preference, the sensor includes two or more orthogonally mounted accelerometers.

In preference, the rotation is relative to a selected scanline.

The method and apparatus of the invention allow very useful information can be obtained by sensing only orientation and/or changes in orientation of the probe unit, without sensing linear displacement.

An advantage of the invention is that a low cost transducer adapted to scan only in a single direction at any instant and low cost orientation detection devices can be used to produce diagnostically very useful 2D tomographic images of a body to be scanned.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig 1 illustrates an ultrasonic scan system including an embodiment of the invention;

Fig 2 illustrates a probe unit showing the relationship to the orientation sensor;

Fig 3 illustrates a block diagram of a hand held ultrasound system of the invention;

Fig 4 illustrates a time gain compensation diagram;

Fig 5 illustrates a scan data set;

Fig 6 illustrates a partial block diagram of the functional blocks of a probe unit controller;

Fig 7 illustrates an ultrasound scan space, with the pixel grid of a display overlaid upon it.

Fig 8 illustrates a partial ultrasound scan space, with the pixel grid of a display overlaid upon it, illustrating scanline/rowline intersection;

Fig 9 illustrates an ultrasound pulse and an exemplary echo return;

Fig 10 illustrates the selection of a scan data point as a pixel value.

Fig 11 illustrates an example of an idealised scan and its practical realisation in a system of the invention.

Fig 12 illustrates an enveloping function applied to a return signal.

BEST MODE FOR CARRYING OUT THE INVENTION

Referring now to Fig 1, there is illustrated an ultrasonic scan system according to an embodiment of the invention. There is a hand held ultrasonic probe unit 10, a display and processing unit (DPU) 11 with a display screen 16 and a cable 12 connecting the probe unit to the DPU 11.

The probe unit 10 includes an ultrasonic transducer 13 adapted to transmit pulsed ultrasonic signals into a target body 14 and to receive returned echoes from the target body 14.

In this embodiment, the transducer is adapted to transmit and receive in only a single direction at a fixed orientation to the probe unit, producing data for a single scanline 15.

As shown in Fig 2, the probe unit further includes an orientation sensor 20 capable of sensing orientation or relative orientation about one or more axes of the probe unit. Thus, in general, the sensor is able to sense rotation about any or all of the axes of the probe unit, as indicated by rotation arrows 24, 25, 26.

The sensor may be implemented in any convenient form. In an embodiment the sensor consists of three orthogonally mounted gyroscopes. In further embodiments the sensor may consist of two gyroscopes, which would provide

information about rotation about only two axes, or a single gyroscope providing information about rotation about only a single axis.

Since the distance between the mounting point of the sensor 20 and the tip of the transducer 13 is known, it would also be possible to implement the sensor with one, two or three accelerometers.

A block diagram of the ultrasonic scan system is shown in Fig 3. There is a probe unit 10 and a DPU 11. The probe unit includes a controller 351 which controls all of the functions of the probe. In this embodiment, the controller is implemented as a combination of a field programmable gate array (FPGA) 315 and a microcontroller 330.

The DPU includes a main CPU 340 and a communications controller 352.

The probe unit 10 communicates with the DPU 11 via a low speed message channel 310 and a high speed data channel 320. The message channel is a low power, always on connection. In an embodiment, it is implemented as a direct connection between the microcontroller 330 on the probe unit and the main CPU 340 of the DPU. In this embodiment, it is implemented using I^2C bus technology.

The data channel is a higher speed and hence higher power consumption bus which is on only when required to transmit data from the probe unit to the DPU. In this embodiment, it is implemented as a low voltage, differential signal (LVDS) bus. In this embodiment, it is a single channel. Multiple channels may be used in other embodiments, to carry higher data rates or separate sensor channels.

The probe unit includes a transducer 13 which acts to transmit and receive ultrasonic signals. A diplexer 311 is used to switch the transducer between transmit and receive circuitry.

On the transmit side the diplexer is connected to high voltage generator 312, which is controlled by controller 351 to provide a pulsed voltage to the transducer 13. The transducer produces an interrogatory ultrasonic pulse in response to each electrical pulse.

This interrogatory pulse travels into the body and is reflected from the features of the body to be imaged 14 as an ultrasonic response signal. This

response signal is received by the transducer and converted into an electrical received signal.

A plot of the transducer pulse in the time domain is shown in Fig 9a. An exemplary response signal is shown in Fig 9b. This response signal is the intensity value of the returned echo.

The depth from which the echo is received can be determined by the time delay between transmission and reception, with echoes from deeper features being received after a longer delay. Since the ultrasound signal attenuates in tissue, the signal from deeper features will be relatively weaker than that from shallower features.

The diplexer 311 connects the electrical receive signal to time gain compensation circuit (TGC) 313 via a pre-amp 316. The TGC applies amplification as shown in Fig 4, to the received signal. This shows a plot of amplification against time to be applied to the returned echo for each pulse. The characteristics of the amplification are selected to compensate for the depth attenuation, giving a compensated receive signal where the intensity is proportional to the reflectiveness of the feature which caused the echo. In general, the amplification characteristics may take any shape.

This compensated signal is passed to an analogue to digital converter (ADC) 314, via an anti-aliasing filter 317. The output of the ADC is a digital data stream representing the intensity of the received echoes over time for a single ultrasonic pulse.

There is an orientation sensor 20 which is adapted to provide information about angular rotation of the probe unit.

The DPU includes a touchscreen user interface device 16. This gives the user control of a user interface which allows parameters for an ultrasound scan to be set. Further user input devices 362 may be provided. These include but are not limited to, a scroll wheel, numeric or alpha numeric keypad and voice recognition means.

The parameters which may be set may be any variable affecting the ultrasound. They include the sample rate for the ADC, the number of values to be taken, the length of a scan in time or in angle travelled by the probe unit.

The set up parameters for the TGC as shown in Fig 4 may also be set. These include the initial amplification 40, and the time 41 to which this should be applied, and the final amplification 42 and the time 43 at which this should be reached. This defines the slope of the TGC ramp 44. This control allows the TGC to be set appropriately for the attenuation profile of the material being imaged.

Returning to Fig 2, in use, a user applies the probe unit 10 to a body to be imaged 14. The communication button 23 is pressed to initiate a scan. The button press is detected by the microcontroller and communicated to the DPU via the message channel 310.

The DPU responds with a message which includes the parameters which have been selected for the scan. The controller 351 controls the high voltage driver to produce the required pulse sequence to be applied via the diplexer to the transducer in order to perform a scan according to the parameters set by the user, or set as defaults in the DPU.

The user rotates the probe as required to sweep the ultrasound beam over the desired area, keeping linear displacement to a minimum.

In embodiments where rotation about all axes is not sensed, the user will also keep rotation about unsensed axes, that is axes about which rotation is not detected by the sensor of the embodiment, to a minimum.

At the same time, data is received from the orientation sensor 20. This is the rotation about the sensed axes of the probe unit. It may be the angular change in the position of the probe unit since the immediately previous transducer pulse, or the orientation of the probe unit in some defined frame of reference. One such frame of reference may be defined by nominating one transducer pulse, normally the first of a scan sequence, as the zero of orientation.

The sensor data and the response signal are passed to the controller 351 and in particular the field programmable gate array (FPGA) 315 where they are combined to give a scanline. A scanline is a dataset which comprises a sequential series of intensity values of the response signal combined with orientation information. A scan dataset is a plurality of sequentially received scanlines.

A scan data set is built up by a user rotating the probe unit about at least one sensed axis while keeping the positional displacement to a minimum. The high voltage generator 312 continues to provide the pulsed voltage to the transducer under control of the microcontroller and each pulse results in a scanline.

More than one transducer may be used, such that more than one scanline is produced at a time. In an alternative embodiment, three transducers are mounted at a fixed angle of fifteen degrees to each other. Other numbers or transducers and angles of separation are possible. All three transducers are driven together. The angle of orientation received from the orientation sensor is adjusted by the amount of the angular offset of the transducers from each other in order to produce scanlines with consistent angular data. This results in a denser coverage of the area of interest, or allows for a slower pulse rate of the transducer, or a faster movement of the probe for the same density of coverage.

The result is a scan data set, as illustrated in Fig 5. The scan data set may be seen to consist of a series of scanlines 51, each of which has an origin 52, a direction, and a depth. Taken together, these constitute the echo data for some geometric region in the target body. Since only orientation data is collected, the origins of all of the scanlines are co-incident, since no information about any linear displacement which may have occurred is available. They are not, in general, co-planar.

In embodiments where rotation about only a single axis is sensed by the sensor, the scanlines will be co-planar, since no information about rotation out of the plane orthogonal to the sensed axis will be available.

The scanline is generated in the controller 351. A partial block diagram of the functional blocks provided by the FPGA 315 is shown in Fig 6. There is a FIFO buffer 61 which allows the scanlines to be asynchronously processed. Echo intensity data from the ADC data is received into the FIFO buffer via filter 65 and passed to a scanline generator 62. It is combined with orientation data from the orientation sensor 20 and has a CRC added for error correction over the data link. The data is then passed to a protocol converter 64 to be converted to a protocol suitable for transmission via the data channel. Any

suitable protocol may be used. In this embodiment the protocol chosen for use on the data channel is 8b10b, which is well known in the art.

The 8b10b data is passed to an LVDS transmitter 338 and is transmitted via the data channel 320 to the DPU 11.

Referring to Fig 3, the LVDS data channel is received by the DPU via LVDS receiver 321 and phase locked loop 322. The 8b10b data is passed to the DPU FPGA 341. Protocol conversion is performed by controller 352 to recover the original scanline data.

An application is now run by the DPU CPU 340 to process the scanlines for display as an ultrasound image on the display 16 of the DPU 11.

The scanline data at this point is still in the form as shown in Fig 9b. This is not suitable for display. There is more information contained in the signal than can be displayed on a practical display. In order to provide scanlines with an information content compatible with display, an enveloping function is applied to each scanline, as shown in Fig 12. Thus the raw scanline signal 123 is enveloped to produce a scanline which has the characteristics of the envelope 125. Any suitable enveloping function may be used. In an embodiment, a Hilbert transform is applied as the enveloping function.

The frequency of the enveloped data is less than that of the raw data signal allowing the enveloped data to be down sampled, that is, use fewer samples per time period than the raw signal, without loss of imaging information.

The application processes the scanlines in order to map the vector scanlines to a pixel buffer which may then be mapped to the physical pixels used by the display. Any suitable method of mapping vector data to a Cartesian grid may be employed. Interpolation is required in order to fill in pixels that do not coincide with scanlines.

Since no information concerning the linear displacement of the probe unit is sensed, all scanlines have a common, arbitrary origin. In embodiments where rotation about only one axis is sensed, the scanlines will also be co-planar in an arbitrary plane. In embodiments where rotation about more than one axis is sensed, it is necessary to choose a "plane of best fit" which will correspond to the plane of the display screen.

It is also necessary to choose a forward direction for the scan which will correspond to the vertical centreline of the screen display.

Any suitable method may be used to make these choices. In an embodiment, the forward direction is chosen by bisecting the angle which is the largest angle between any two scanlines.

The plane of best fit may be chosen by any means which minimises the degree to which scanlines deviate from the chosen plane. In an embodiment a mathematical process employing principal component analysis is undertaken to find this plane. The scanlines are then mapped to this plane.

In a preferred embodiment a process we have called pixel row-wise scan interpolation is now applied to the scanline data to implement the process of mapping the scanlines to a pixel grid. As shown in Fig 7, the scanline dataset is a series of scanlines 71, with a common origin. Each scanline consists of a number of data points 72. In the case of an ultrasound scan these are intensity of reflection values. For the purposes of display these are brightness values.

Fig 7 also shows a pixel buffer pixel grid superimposed on the data. As can be seen, a display screen is a regular grid 73 of individual pixels 74. Each pixel can have only one brightness value. It can be seen that there are pixels 75 which are associated with more than one scan point and other pixels 76, which are associated with none. Pixel row-wise scan interpolation is applied to produce a data set with one and only one brightness value associated with each pixel.

Pixel row-wise interpolation begins by intersecting the scan lines with the pixel buffer one pixel row at a time.

Looking at Fig 8, there is a pixel row 81 and a scanline 82. We define a rowline 83 as the midline of the pixel row. There is one intersection point 84 between the rowline and the scanline.

Each of these intersection points is calculated for a given row. This gives an array of values sorted in the order of the received scanlines. This may not be the order of the column of the pixel grid. This can occur because the ultrasound probe unit, being hand scanned, may briefly wobble in a direction

against the predominant direction of rotation, or indeed may have been swept back over already scanned areas by a user.

The calculated intersection points are now sorted into pixel column order, and order within each pixel.

The value which is assigned to each pixel is chosen as that of the data point which is closest to the intersection point. This is shown on Fig 10. Scanline 101 intersects rowline 102 at intersect point 103 in pixel 104. Scan data point 105 is closest to the intersection point and becomes the value for pixel 104. Scan data points 106, in the same pixel, are ignored and do not contribute to the displayed image.

There may be more than one intersect point in a pixel, when the angle between scanlines is sufficiently small that more than one scanline crosses a pixel. In this case, the pixel value is the mean of the value of the data points which are closest to each of the intersect points.

Also in Fig 10, there are shown pixels 107 which are "holes", that is they do not have a scanline intersect. In order to display a smooth image, these holes must be filled with values which are consistent with the filled pixels around them.

This is done by interpolation between pixels having defined values. Where linear interpolation is employed, the brightness value for the holes is defined such that there is a constant increment between the brightness values of the holes and adjacent pixels.

Other interpolation formulae may be used to fill in the values for the holes. The interpolation of the preferred embodiment is linear but quadratic, cubic or other higher order interpolations may be used.

Along each row, pixel values are interpolated between intersection points, which is computationally efficient as pixels along a row are contiguous in memory. Intersection points are computed and stored in fractional pixel index and fractional scan line index coordinates. After the first row of pixels, subsequent intersection points are determined simply by adding a constant offset to the fractional pixel and fractional scan line coordinates.

The result of this repeated processing is an array of values in the pixel grid buffer. These values are brightness values for the related pixel. This array is mapped to the physical pixels of display 16 and the result is a conventional ultrasound image where brightness corresponds to the intensity of echo, compensated for depth attenuation, and a picture of the internal features of the subject is formed.

Fig 11a shows a scanline dataset as it would be if all movement of the probe unit were able to be sensed. As illustrated in Fig 11a, the origin for each of the scanlines will not actually be the same, despite the best efforts of the user to make it so. Some small displacement is likely to occur in each of the three spatial dimensions. There may also be some small rotation about axes other than the sensed axis or axes.

The prior art attempts to exactly map these origin points 113 in a fixed, external frame of reference.

However, we have discovered that very useful information can be obtained by neglecting these movements. By sensing only orientation, without sensing displacement, the origin points are inherently mapped to a single point.

The distortion of the resultant image caused by this is minimal, as illustrated in Fig 11. Fig 11a shows a perfectly circular target 110 which is isonified and scanned by a manual sweep as described above to produce scanlines 111.

In this idealised diagram, each scanline has zero intensity values, except at the points 112 where the target perimeter 110 is encountered.

Due to hand movement, the origin points 113 of the scanlines are not coincident.

However, if only the rotation of each scanline is measured, as shown in Fig 11b, the scanlines are inherently mapped to a single origin point 115. If rotation about only a single axis is sensed, the scanlines are also inherently mapped to co-planarity. The angles and the intensity values of the scanlines are unaltered.

When the target perimeter scan points are joined, we have the scanned feature perimeter 116. As can be seen, the perimeter 116 is not perfectly circular, but the distortion is minimal.

In other embodiments, information sensed about errant rotation about an axis which is not the axis about which the user is attempting to rotate the probe unit can be made use of without using it to calculate a plane of best fit. In an embodiment, the magnitude of such rotation for each scanline is monitored by the CPU in the DPU. If the magnitude exceeds a selected value, which is calculated to introduce unacceptable distortion, the user is warned and the scan is not displayed. If the errant rotation is within acceptable limits, it is ignored, and the scanlines treated as if rotation about only a single axis has been sensed.

In an embodiment, the probe unit is shaped to assist the user to rotate the unit about only a single axis. This shaping may apply to the main body of the probe unit or to a transducer housing, or to both.

Although the invention has been herein shown and described in what is conceived to be the most practical and preferred embodiment, it is recognised that departures can be made within the scope of the invention, which is not to be limited to the details described herein but is to be accorded the full scope of the appended claims so as to embrace any and all equivalent devices and apparatus.

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS

1. An ultrasound imaging system adapted for hand held use including
   a probe unit having a transducer in a fixed spatial relationship with the probe unit, said transducer being adapted to transmit and receive ultrasonic signals in substantially only one direction,
   an orientation sensor adapted to sense a rotation of the probe unit about at least one axis,
   electronics adapted to apply a pulsed electrical signal to the transducer and to process the electrical output signal of the transducer and of the sensor to produce a plurality of scanlines each having a series of intensity values and a rotation value,
   a processor adapted to process the scanlines to produce a raster image,
   a display adapted to display the resultant raster image.
2. The system of claim 1 wherein the sensor is an inertial sensor.
3. The system of claim 1 wherein the sensor includes a gyroscope.
4. The system of claim 1 wherein the sensor includes two or more orthogonally mounted gyroscopes.
5. The system of claim 1 wherein the sensor includes an accelerometer.
6. The system of claim 1 wherein the sensor includes two or more orthogonally mounted accelerometers.
7. The system of claim 1 wherein the rotation is relative to a selected scanline.
8. The system of claim 7 wherein the selected scanline is the first scanline of a scan data set.
9. The system of claim 1 wherein the rotation is relative to the immediately preceding scanline.
10. The system of claim 1 wherein the processor when processing the scanlines to produce a raster image is adapted to map the scanlines to a plane of best fit.
11. The system of claim 10 wherein the processor is further adapted to map the scanlines to a pixel grid.

12. The system of claim 11 wherein the process of mapping includes pixel row-wise interpolation.

13. The system of claim 1 wherein the sensor is adapted to separately rotation about at least two axes, with rotation about axes other than a selected axis being considered to be errant rotation.

14. The system of claim 13 wherein a user is warned if the errant rotation exceeds a selected level, said selected level being chosen to limit distortion of the resultant image to an acceptable level.

15. The system of claim 1 wherein the probe unit is shaped to assist a user to perform a sweep in which rotation about other than a selected axis is minimised.

16. A method of ultrasound imaging including the steps of
applying a probe unit including an ultrasound transducer adapted to transmit and receive ultrasonic signals into and from a target body,
transmitting ultrasonic pulses into said target body and receiving return signals
rotating said probe unit substantially in a single plane such that a two dimensional section of the target body is scanned
providing a sensor at the probe adapted to provide rotation information about the rotation of the probe unit about at least one axis,
receiving rotation information from said sensor,
combining the return signals with the rotation information to produce scanlines,
processing the scanlines to produce a raster image,
displaying the raster image on a display.

17. The method of claim 16 wherein the sensor is an inertial sensor.

18. The method of claim 16 wherein the sensor includes a gyroscope.

19. The method of claim 16 wherein the sensor includes two or more orthogonally mounted gyroscopes.

20. The method of claim 16 wherein the sensor includes an accelerometer.

21. The method of claim 16 wherein the sensor includes two or more orthogonally mounted accelerometers.

22. The method of claim 16 wherein the step of producing a raster image includes mapping the scanlines to a plane of best fit.

23. The method of claim 22 wherein the process further includes mapping the scanlines to a pixel grid.

24. The method of claim 16 wherein the step of producing a raster image includes applying row wise pixel interpolation to the scanlines.

25. The method of claim 16 wherein the probe unit is shaped to assist a user to rotate the probe unit substantially in a single plane.

26. The method of claim 25 wherein a transducer cover which is part of the probe unit is shaped to assist a user to rotate the probe unit substantially in a single plane.

27. A method of ultrasound imaging including providing a probe unit having a transducer adapted to scan substantially only in a single direction at any instant, providing an orientation detection sensor integral with the probe unit, combining an output of the transducer with the output of the sensor to produce diagnostically useful 2D tomographic images of a body to be scanned.

28. An ultrasound imaging system substantially as described in the specification with reference to and as illustrated by any one or more of the accompanying drawings.

29. A method of ultrasound imaging substantially as described in the specification with reference to and as illustrated by any one or more of the accompanying drawings.

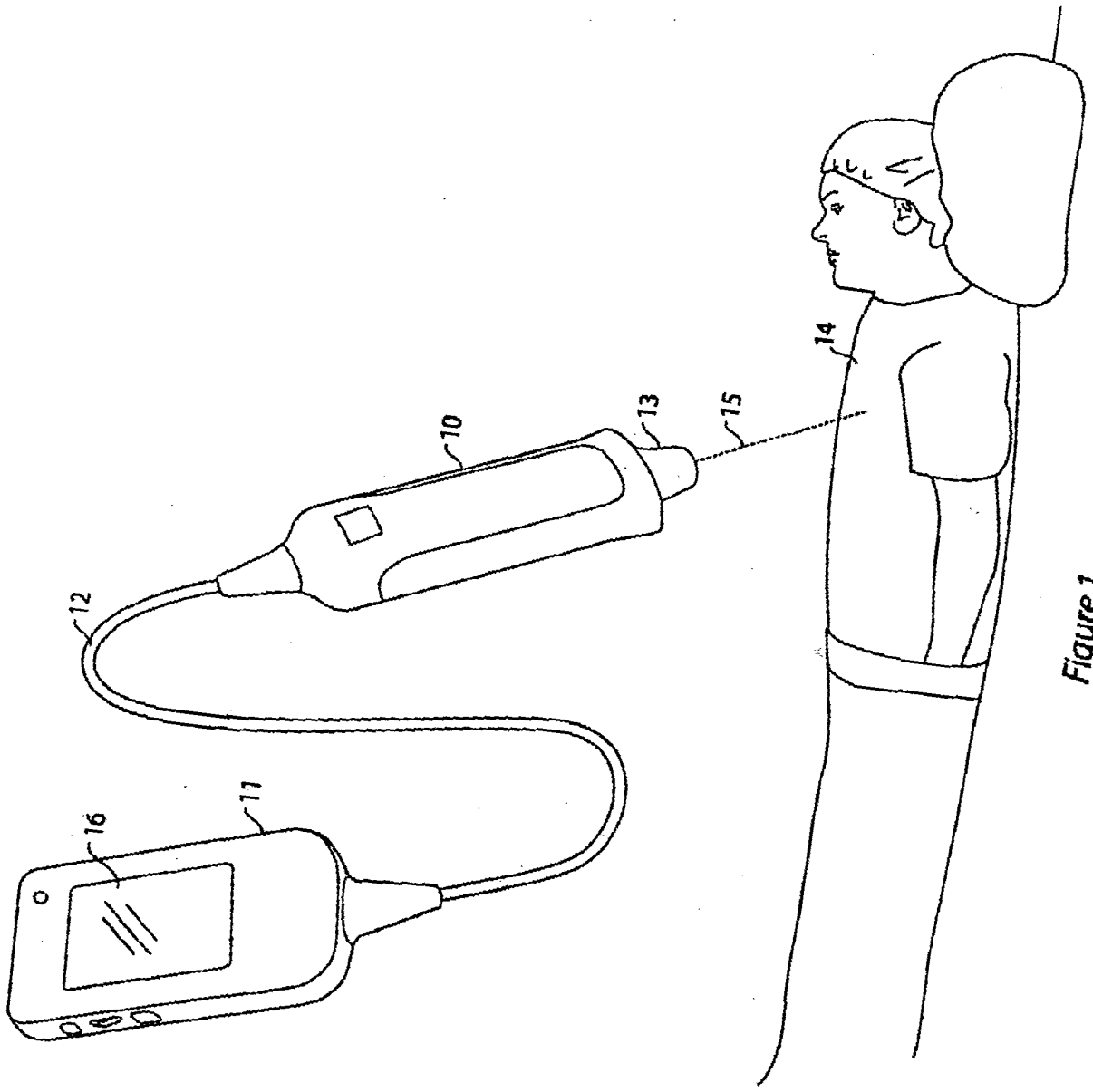


Figure 1

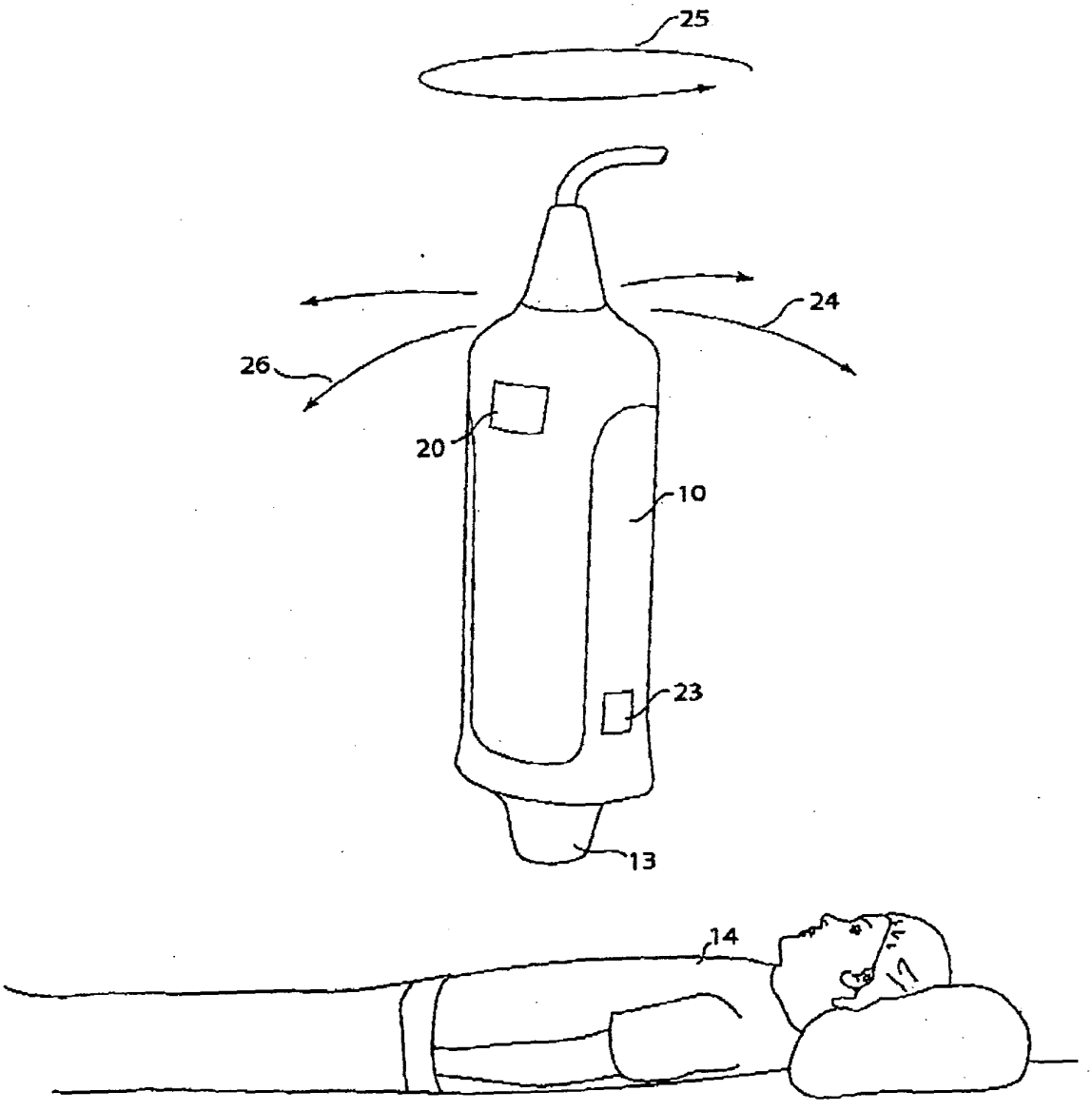


Figure 2

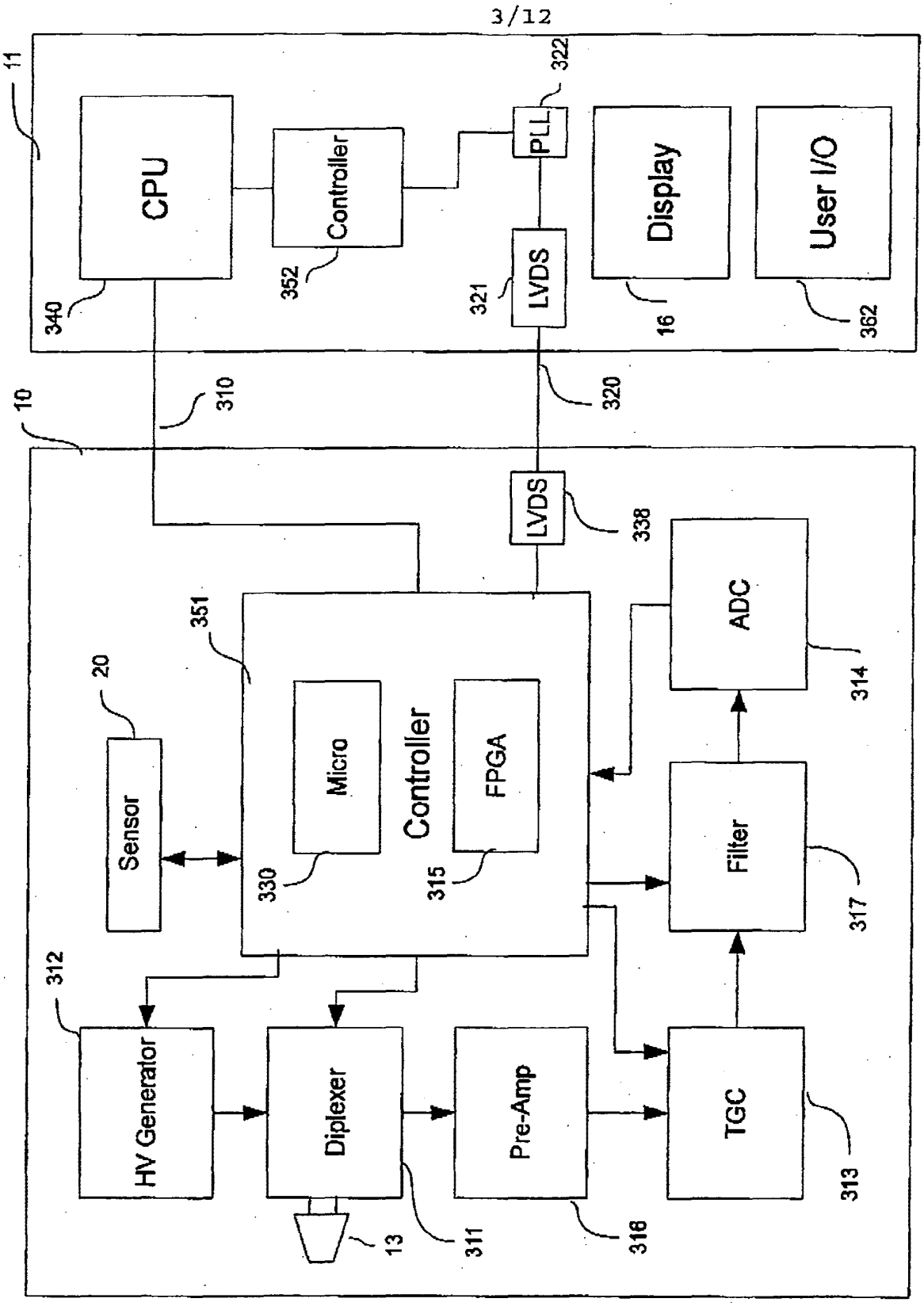

11
CPU
340
Controller
352
PLL
322
LVDS
321
Display
16
User I/O
362
10
310
320
LVDS
338
351
20
Sensor
Micro
330
Controller
FPGA
315
ADC
314
Filter
317
312
HV Generator
Diplexer
13
311
Pre-Amp
316
TGC
313

Figure 3

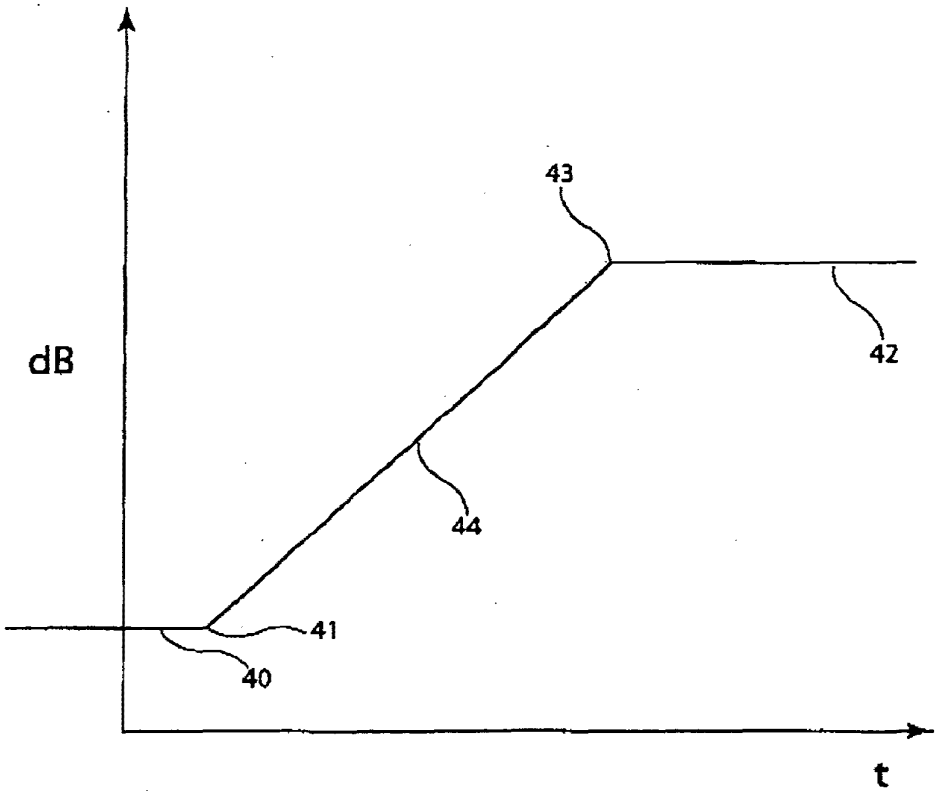


Figure 4

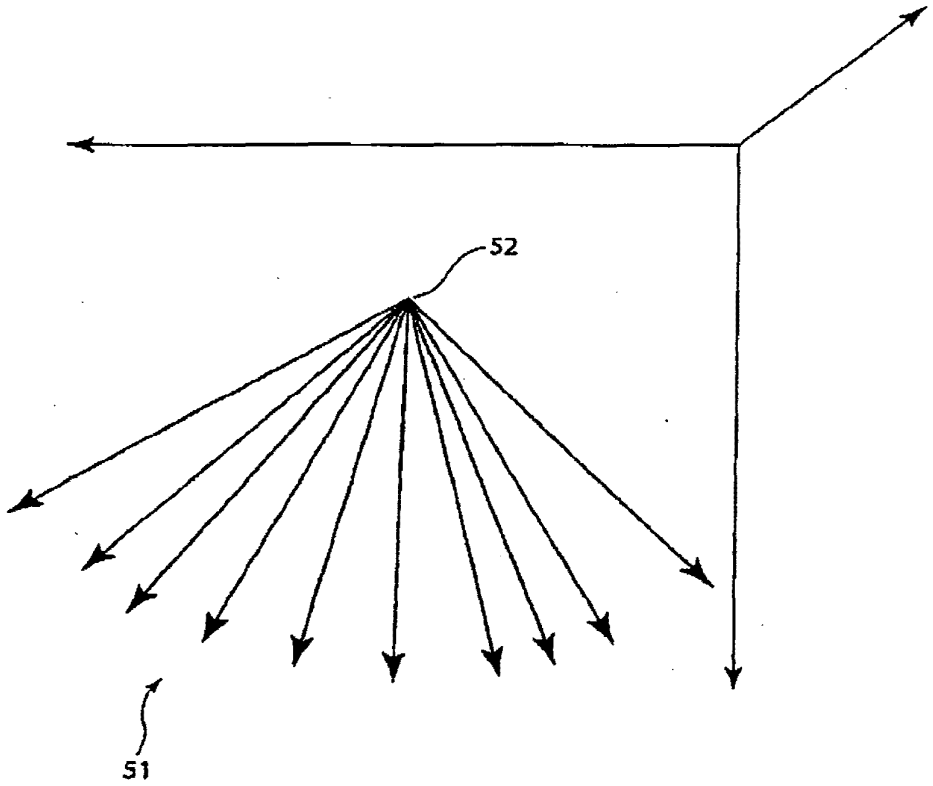


Figure 5

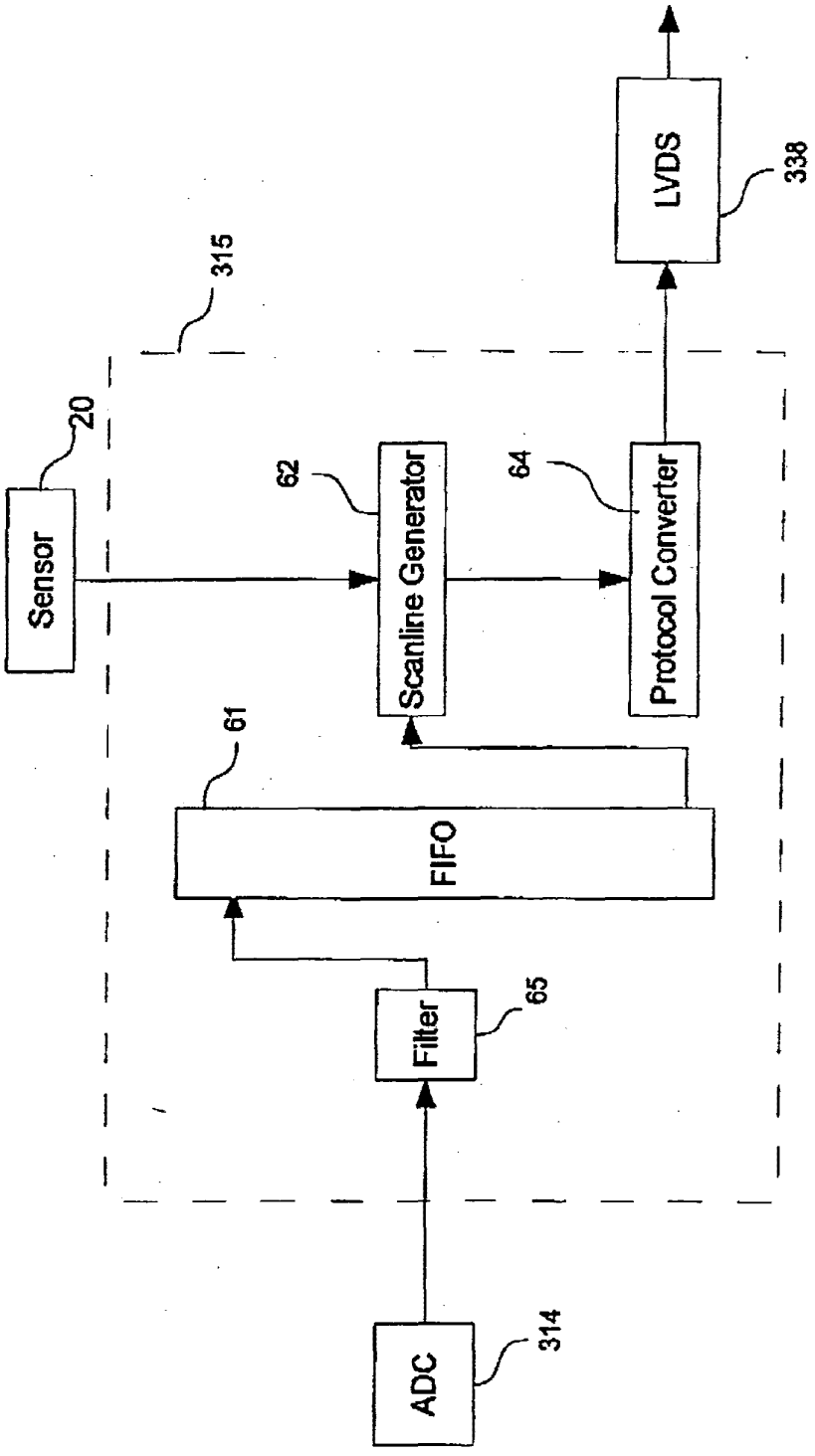

LVDS
338
315
20
Sensor
62
Scanline Generator
64
Protocol Converter
61
FIFO
Filter
65
ADC
314

Figure 6

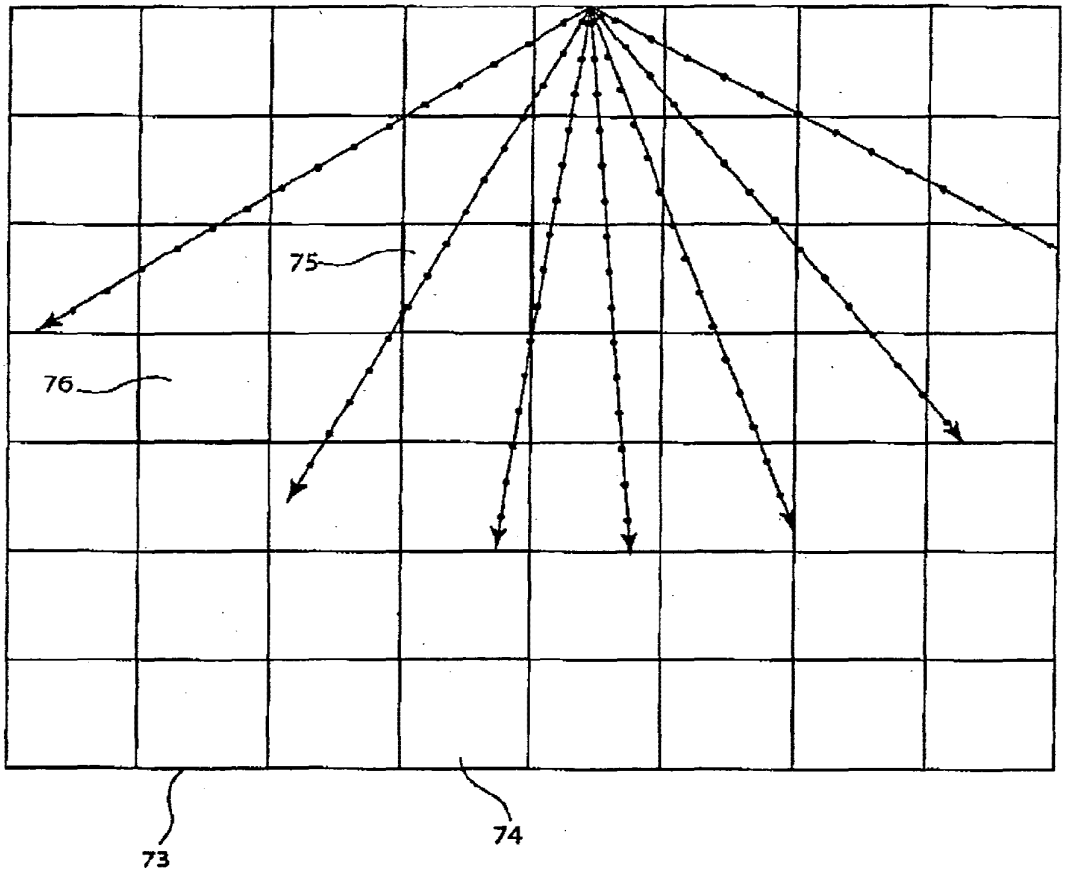


Figure 7

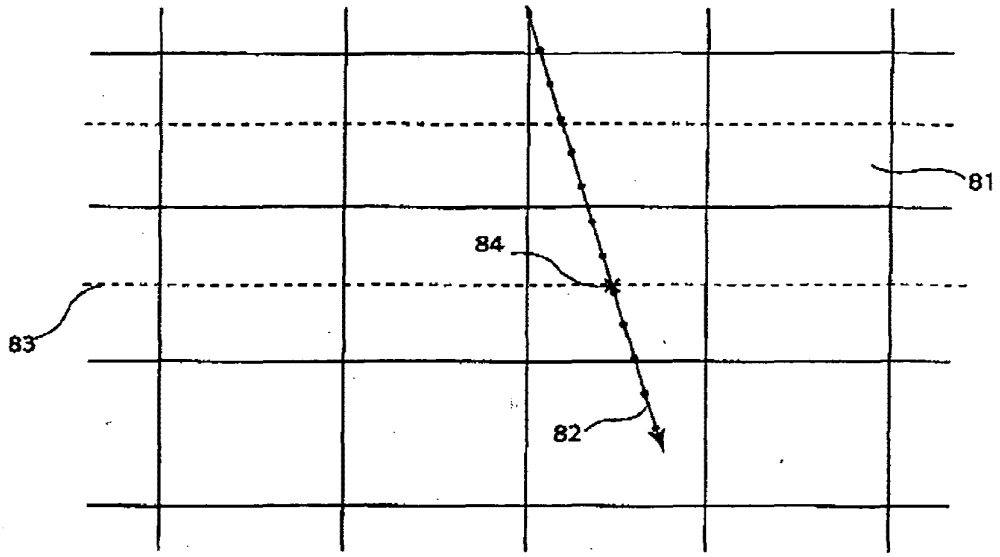


Figure 8

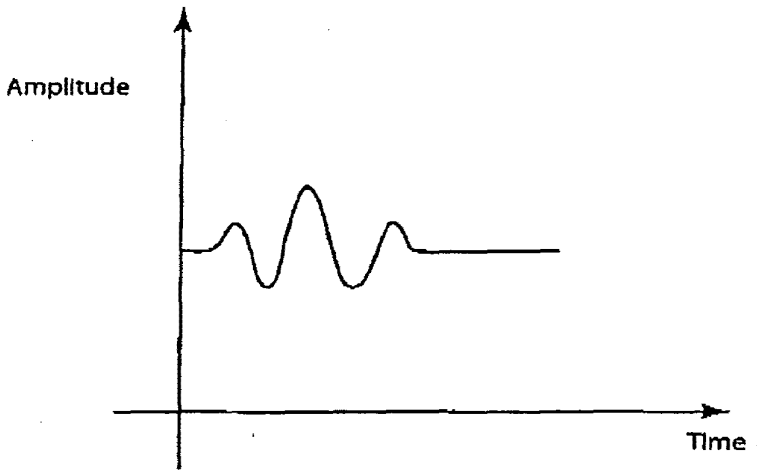


Figure 9a

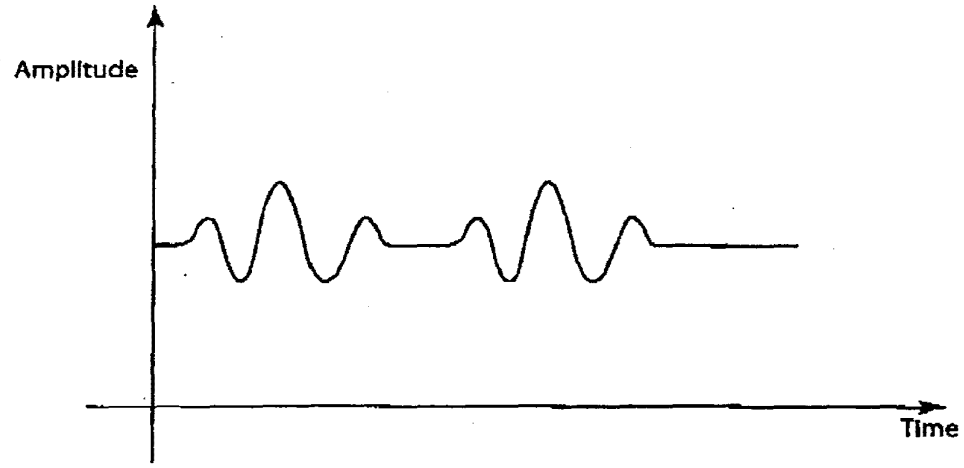


Figure 9b

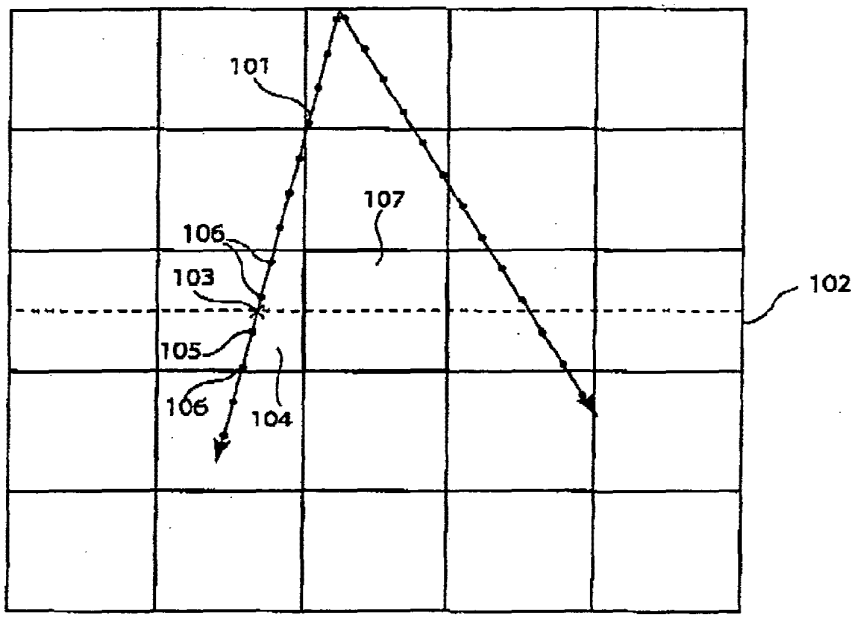


Figure 10

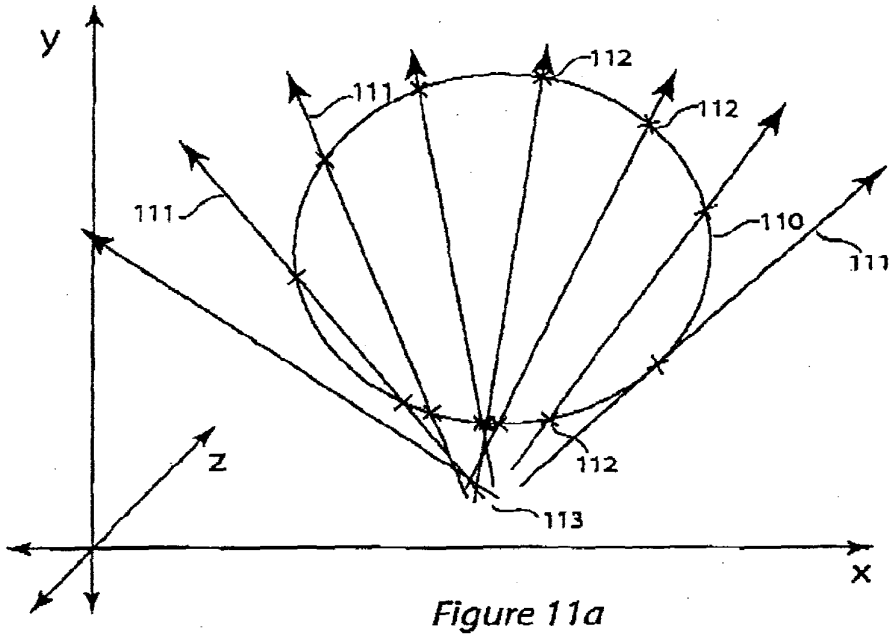


Figure 11a

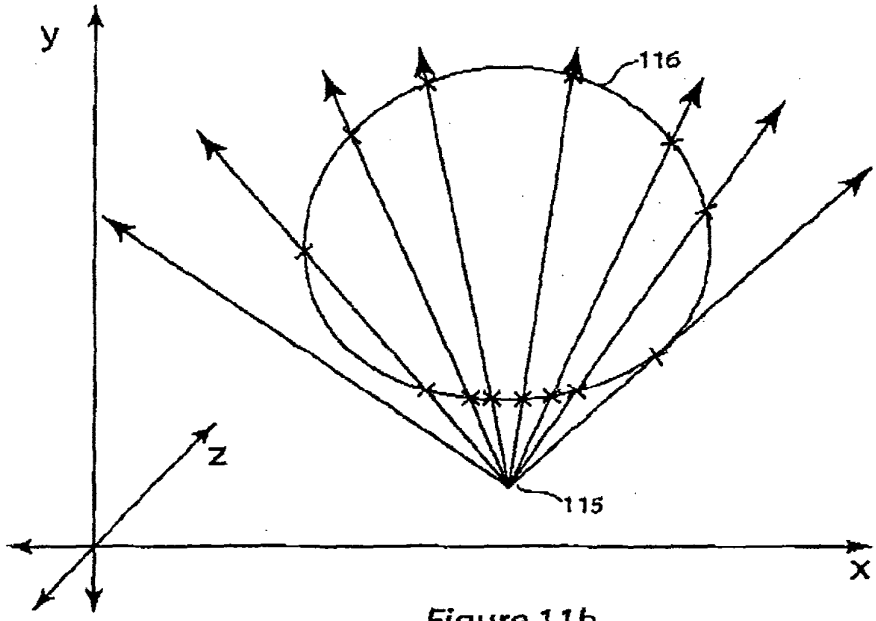


Figure 11b

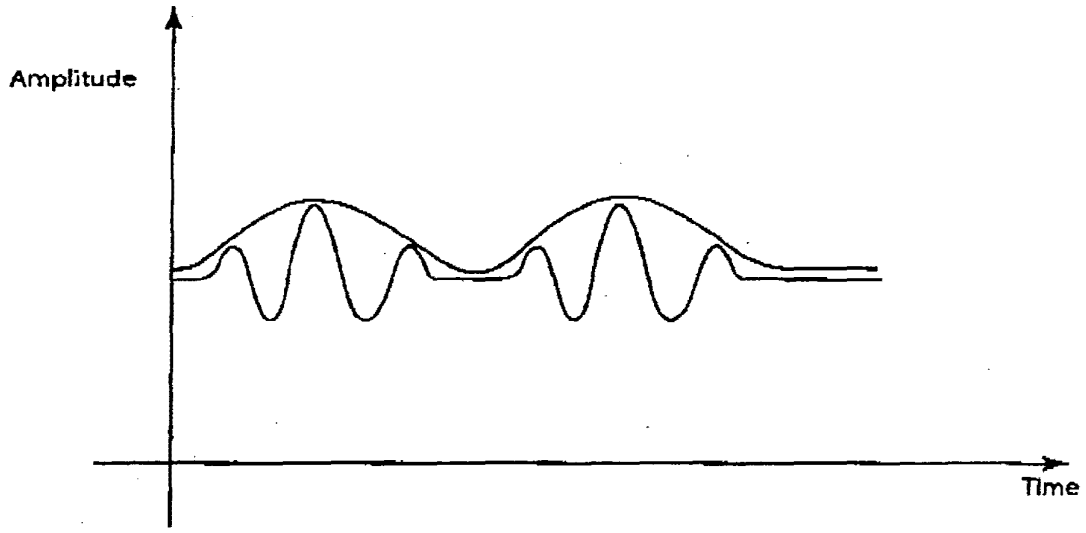


Figure 12

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU2008/001278

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl.

A61B 8/00 (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
WPI: USPTO: ESPACE: GOOGLE: IPC (A61B/IC) & keywords (ULTRASOUND, ORIENT, ROTATE, MEASURE, PROCESS, SCAN, RASTER, PIC, DISPLAY, GYROSCOPE, ACCELERO, HANDHELD, PROBE) & similar terms

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5690113 A (SLIWA, JR. et al) 25 November 1997 See Column 1; Line 5 – Column 7; Line 48	1-27
A	US 2003/0078501 A1 (BARNES et al.) 24 April 2003 See abstract & fig. 1	1, 16 & 27
A	US 2004/0127796 A1 (CHALANA et al.) 1 July 2004 See abstract & fig. 1	1, 16 & 27
A	US 5538004 A (BAMBER) 23 July 1996 See abstract & figs. 1 & 2	1, 16 & 27

☐ Further documents are listed in the continuation of Box C ☒ See patent family annex

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
20 October 2008	10 NOV 2008
Name and mailing address of the ISA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustralia.gov.au Facsimile No. +61 2 6283 7999	Authorized officer **MOUHAMMAD HABLAS** AUSTRALIAN PATENT OFFICE (ISO 9001 Quality Certified Service) Telephone No : +61 2 6225 6143

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU2008/001278

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. [X] Claims Nos.: **28-29**

because they relate to subject matter not required to be searched by this Authority, namely:

Claims 28-29 do not comply with Rule 6.2(a) because they rely on references to the description and/or drawings.

2. [ ] Claims Nos.:

because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. [ ] Claims Nos.:

because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a)

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. [ ] As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. [ ] As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. [ ] As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. [ ] No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

[ ] The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

[ ] The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

[ ] No protest accompanied the payment of additional search fees.

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member					
US	5690113	NONE					
US	2003078501	AU	55672/99	AU	59718/98	AU	68099/98
		AU	2002305258	BR	9801212	BR	9801670
		CA	2341099	CN	1170560	CN	1212146
		CN	1242978	EP	0815793	EP	0875203
		EP	0881492	EP	0884606	EP	1119293
		JP	10057375	JP	10277035	JP	11047131
		JP	11056838	NO	981475	NO	982389
		US	5722412	US	5782769	US	5817024
		US	5893363	US	6135961	US	6203498
		US	6383139	US	6416475	US	6569101
		US	6575908	US	6962566	US	2002177774
		US	2003009102	US	2003013965	US	2003013966
		US	2003195418	US	2004138564	US	2006025684
		US	2007232910	WO	0019905	WO	03071919
US	2004127796	AU	2003237819	AU	2003254372	AU	2003261357
		AU	2003296928	CA	2526297	CA	2534287
		CA	2541798	CA	2587137	CA	2598335
		CA	2616541	CA	2617622	CA	2626226
		CA	2631937	EP	1521548	EP	1538986
		EP	1551305	EP	1596718	EP	1689298
		EP	1781176	EP	1784129	EP	1809178
		EP	1819279	EP	1909648	GB	2391625
		KR	20040057077	US	6676605	US	6803308
		US	6884217	US	7004904	US	7041059
		US	7087022	US	2003229281	US	2004024302
		US	2004024315	US	2004121578	US	2004127797
		US	2004267123	US	2005215896	US	2005228278
		US	2005251039	US	2006006765	US	2006025689
		US	2006079775	US	2006111633	US	2006235301
		US	2007004983	US	2007100236	US	2007232908
		US	2007276247	US	2007276254	US	2008139934

		US	2008139938	US	2008146932	US	2008146939
		US	2008181479	US	2008242985	US	2008249414
		US	2008262356	WO	03103499	WO	2004012584
		WO	2004017834	WO	2004041094	WO	2005000390
		WO	2005044109	WO	2005079487	WO	2005107581
		WO	2005112773	WO	2006017168	WO	2006026605
		WO	2006031526	WO	2006047554	WO	2006062867
		WO	2007016369	WO	2007103737	WO	2008073560
		WO	2008083386				
US	5538004	NONE					

Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.

END OF ANNEX

(12) NACH DEM VERTRAG ÜBER DIE INTERNATIONALE ZUSAMMENARBEIT AUF DEM GEBIET DES PATENTWESENS (PCT) VERÖFFENTLICHTE INTERNATIONALE ANMELDUNG

(19) Weltorganisation für geistiges Eigentum
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(81) Bestimmungsstaaten *(soweit nicht anders angegeben, für jede verfügbare nationale Schutzrechtsart)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

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[Fortsetzung auf der nächsten Seite]

(54) **Title:** METHOD FOR DETERMINING THE POSITION OF AN INTRAORAL MEASURING DEVICE

(54) **Bezeichnung:** VERFAHREN ZUR POSITIONSBESTIMMUNG EINES INTRAORAL MESSENDEN MESSGERÄTES

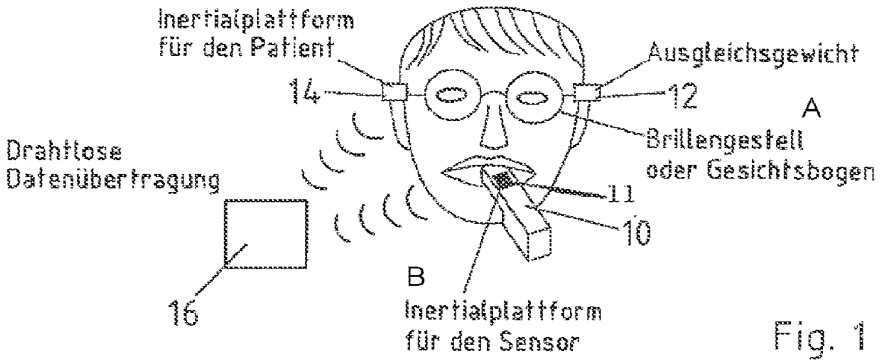


Fig. 1

14... inertial platform for patient
12... counterbalance
16... wireless data transmission
A... spectacle frame or face bow
B... inertial platform for sensor

(57) **Abstract:** The invention relates to a method for determining the position of an intraoral measuring device which is to be moved relative to an organ of mastication of a patient and with which positions in the organ of mastication or areas of the organ of mastication are measured. To be able to carry out measurements without a fixed reference, it is proposed that, independently of a reference that is independent of the patient, the position of the measuring device is measured by means of a position-determining sensor that is in a fixed relationship to the measuring device.

[Fortsetzung auf der nächsten Seite]

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MC, MT, NL, NO, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Veröffentlicht:
— *mit internationalem Recherchenbericht*

(57) Zusammenfassung: Die Erfindung bezieht sich auf ein Verfahren zur Positionsbestimmung eines relativ zu einem Kauorgan eines Patienten zu bewegenden intraoral messenden Messgeräts, mit dem Positionen im Kauorgan oder Bereiche des Kauorgans gemessen werden. Um ohne ortsfeste Referenzierung messen zu können, wird vorgeschlagen, dass unabhängig von einer von dem Patienten unabhängigen Referenzierung die Position des Messgerätes mittels eines in ortsfester Beziehung zu dem Messgerät stehenden Positionsbestimmungssensors gemessen wird.

Verfahren zur Positionsbestimmung eines intraoral messenden Messgerätes

Die Erfindung bezieht sich auf ein Verfahren zur Positionsbestimmung eines relativ zum Kauorgan eines Patienten zu bewegenden intraoral messenden Messgerätes, mit dem Positionen im Kauorgan oder Bereiche des Kauorgans gemessen werden, wobei die Position des Messgerätes mittels eines in ortsfester Beziehung zu dem Messgerät stehenden Positionsbestimmungssensors gemessen wird. Auch bezieht sich die Erfindung auf Verfahren und Anordnungen zum Bewerten wie Messen der Position und Taschentiefe einer parodontalen Zahnfleischtasche.

Aus der EP-A-1733 693 (Goldbach) ist ein medizinisches Tracking System bekannt, das auf Infrarot Basis arbeitet. Es benötigt jedoch wie andere Systeme (z. B. EP-A-1 523 950 (Foley)) einen zusätzlichen Ständer mit Infrarot Sendern und Empfängern im Operationsraum zur Referenzierung. Diese Systeme verknüpfen Daten aus bildgebenden Verfahren und die Positionsinformation des Navigationssystems zur Positionierung von Instrumenten für stereotaktische Operationen z. B. in der Neurochirurgie.

In der Zahnheilkunde berichten erste Veröffentlichungen über Anwendung oben genannter Systeme zur Implantatpositionierung (Mischkowski et al.: Comparison of static and dynamic computer-assisted guidance methods in implantology, in Int. J. Comput. Dent. 2006 Jan; 9(1):23-35). Auch hier werden Bilddaten mit Navigationsdaten verknüpft, um die Bohrrichtung für das Implantat zu bestimmen.

Marmulla R. et al: Intraoperative precision of mechanical, electromagnetic, infrared and laser-guided navigation systems in computer-assisted surgery, in Mund Kiefer Gesichtschir. 1998 May; 2 Suppl 1: S145-8, beschreibt die Anwendung eines Navigationssystems auf elektromagnetischer Basis. Dabei werden die unpräzisen Resultate in Gegenwart metallischer Gegenstände bemängelt.

Beim intraoralen Scannen von Zähnen ist der sichtbare Teilbereich eines Zahns oder Kieferabschnitts, von dem die 3D-Daten gemessen werden, zumeist viel kleiner als der gesamte Zahn oder Kiefer, so dass die Notwendigkeit entsteht, mehrere Bilder aus verschiedenen Blickrichtungen zu einem Gesamtdatensatz des Zahns oder Kieferabschnitts zu vereinigen.

Die Schwierigkeit der genauen Ortsbestimmung der Bereiche des Kauorgans, also Unter- und Oberkiefer, der Zähne sowie sonstiger interessierender Bereiche wie Taschen liegt zudem in dem Umstand begründet, dass sich nicht nur Ober- und Unterkiefer zueinander bewegen, sondern der Patientenkopf selbst und zusätzlich der von Hand geführte Scanner zum Kiefer selbst bewegt wird. Dabei erfolgen Aufnahmen von Kieferbereichen in unterschiedlichen Stellungen und Winkeln, so dass sich ungeachtet ausgereifter Software zum Mergen Fehler ergeben können.

Nach dem Stand der Technik wird das softwaremäßige Zusammenfügen bzw. -setzen der Einzelaufnahmen auch dadurch erschwert, dass die Zähne keine klaren Kanten und Ecken aufweisen. Wenn man zudem die Positionsbeziehung der Aufnahmen zueinander (die Kameraposition) nicht kennt, entsteht ein erheblicher Rechenaufwand, der z. B. bei dem Intraoral Scanning System der Firma CaDent deutlich länger als 30 Minuten beträgt, da die Algorithmen bei völlig unbekannter Kameraposition und der nicht kooperativen Zahngeometrien nur langsam konvergieren.

Dies führt zu inakzeptablen Wartezeiten für Behandler und Patient bei der Beurteilung des elektronischen Abdrucks und der Entscheidung, ob der Vorgang ggf. wiederholt werden muss.

Um dieses Problem zu lösen, können Referenzobjekte in den Mund eingebracht werden (US-B-7,065,243). Dabei wird durch intraorales Messen eines oder mehrerer Zähne bei gleichzeitiger Gegenwart einer Referenz durch diese die Position einer Kamera bestimmt, mittels der der Zahn bzw. die Zähne gemessen werden. Nach Kenntnis der Kameraposition in Bezug auf den Zahn bzw. die Zähne wird sodann aus den Messungen ein 3D-Modell erzeugt, das für die Herstellung von Zahnersatz benötigt wird. Ein entsprechendes Verfahren ist aufwändig und zeigt zudem den Nachteil, dass die als quaderförmiger offener Kasten ausgebildete Referenz den Zahn bzw. die Zähne abschattet.

Auch die US-A-2003/0219148 bezieht sich auf ein Verfahren zur Generierung eines dreidimensionalen Modells eines Zahnbogens unter Zuhilfenahme dreidimensionaler Referenzierungen.

Aus der US-A-2006/0212260 ist ein Verfahren bekannt, um intraoral zu scannen. Hierzu wird ein Scanner benutzt, der ein Inertial- oder Trackingsystem umfasst, um Lage und Position zu bestimmen.

Die US-A-2005/0020910 sieht bei einem intraoralen Messsystem die Möglichkeit vor, bei dem sowohl ein Scanner als auch ein am Kopf eines Nutzers befestigter Empfänger mit einem dreidimensionalen Trackingsystem versehen wird.

Die DE-B-100 45 381 bezieht sich auf eine Vorrichtung zur Bestimmung der Position eines medizinischen Instruments oder Gerätes oder Körperteils. Hierzu weist der Gegenstand, dessen Position bestimmt werden soll, aktive und passive Referenzkörper auf, um mit Navigationssystemen eine Positionsbestimmung vorzunehmen. Dabei können Neigungs- und Magnetfeldsensoren eingesetzt werden.

Aus der EP-A-1 088 525 sind ein Verfahren sowie eine Vorrichtung zur Justierung medizinischer Bilder auf einem Patienten zu entnehmen. Hierzu sind mit dem Patientenkörper verbindbare Halteelemente vorgesehen, die mit Markier- bzw. Lokalisiermitteln versehen sind. Hierdurch soll für die computergestützte Chirurgie ein dreidimensiona-

les Lokalisierungssystem geschaffen werden, um die Ausrichtung zu medizinisch-chirurgischen Handlungen zu ermöglichen.

Bei der Messung parodontaler Taschentiefen oder bei der Kariesdiagnostik wird dem Stand der Technik entsprechend keine Augmentation mit Positionsdaten genutzt. Damit sind keine automatischen Verfahren zur Überführung der Messdaten in das Patienten-verwaltungsprogramm der Praxis möglich.

Zur Feststellung von Parodontalerkrankungen erfolgt heutzutage ein Arbeiten dahingehend, dass in die Zahnfleischtaschen manuell eine Messsonde eingeführt und die Tiefe mittels einer Skala der Sonde durch Ablesen bestimmt wird. Vom Ort der Messung wird sodann vom Arzt einer Assistentin der Wert mitgeteilt, die die entsprechenden Daten in Abhängigkeit von dem Zahn bzw. Position der Messung zu einem Zahn notiert. Dies ist zeit- und personalaufwändig.

Bei der Kariesdiagnostik wird ebenso die Diagnose mit Angabe der Lokalität am Zahn verbal übermittelt oder vom Behandler selbst manuell in den Praxiscomputer eingegeben. Neben Zeitverlust ist dies zudem hygienisch bedenklich, da parallel zur Arbeit am Patienten eine Tastatur zu bedienen ist, die oft nicht hinreichend keimfrei zu halten ist.

Dem Stand der Technik nach ist lediglich ein elektromechanisches Gerät zur Erfassung der Taschentiefe bekannt, das aber keine Positionsdaten ermittelt. (Florida probe www.floridaprobe.de). Die Taschentiefe wird durch einen mechanischen Anschlag ermittelt, durch den die stiftförmige Sonde gleitet, bis sie den Taschenboden berührt. Die Wegstrecke, die der Stift bis zum Taschenfundus benötigt, wird über eine Winkeländerung einer mechanischen Spreizvorrichtung in ein elektrisches Signal konvertiert, das zu einem PC übertragen wird. Eine Spracheingabe in den PC reduziert zumindest bei der Florida-Probe das Kontaminationsrisiko bei der Tastatur.

Aus der DE-A-37 12 054 ist ein Messtaster zur Erfassung der Taschentiefe des Zahnfleisches bekannt. Dabei können induktive oder optische Messwertgeber zum Einsatz gelangen, wobei auch Lichtleiter Verwendung finden.

Die Taschentiefe des Zahnfleisches wird nach der US-A-5,100318 mittels Ultraschall gemessen. Gleiches gilt für die US-A-5,755,571, die ein Ultraschallmessgerät zur Taschentiefenmessung vorschlägt. Dabei besteht auch die Möglichkeit, die Lage der Spitze des Messgerätes zu der Tasche mittels eines Sensors zu messen.

Die DE-C-38 36 743 sieht ein kapazitives Messverfahren vor, um die Passgenauigkeit von Kronen- und Brücken-Zahnersatz zu bestimmen.

Um den Abstand zwischen Krone und Spitze einer Zahnwurzel zu ermitteln, wird nach der DE-A-198 54 223 ein Gerät vorgeschlagen, mit dem erste und zweite Messsignale erzeugt werden, aus denen eine Positionsbestimmung erfolgt.

Der vorliegenden Erfindung liegt die Aufgabe zu Grunde, ein Verfahren zur Positionsbestimmung eines relativ zu einem Kauorgan eines Patienten zu bewegenden ersten Sensors, mit dem Positionen im Kauorgan oder Bereiche des Kauorgans gemessen werden, insbesondere Positionen an bzw. von Zähnen und/oder Bereiche von Zahntaschen, so weiterzubilden, dass eine unabhängig von dem Patienten vorhandene Referenzierung, insbesondere ein auf einem Ständer zu positionierendes Referenzsystem im Behandlungsraum nicht notwendig ist. Auch soll das Verfahren unempfindlich gegen Metalle im Mundraum sein. Ferner soll im Vergleich zum Stand der Technik die zu verarbeitende Datenmenge reduziert werden, ohne Einbußen der Genauigkeit hinnehmen zu müssen. Die Bewegung des Patienten während des Messens soll zu Messverfälschungen nicht führen.

Bei Verwendung eines intraoralen Scanners als Sensor soll durch Bereitstellung von Grobpositionsdaten die Zusammenführung von Teilmessdaten zu einem einheitlichen 3D Datensatz beschleunigt werden.

Eine weitere Aufgabe ist es, bei Taschentiefenmessungen und/oder einer Karies- / Zahnsteindetektion ein vorzugsweise vollautomatisches Erfassen der Daten zu ermöglichen, insbesondere dann, wenn eine Startposition für die Messungen bekannt ist.

Erfindungsgemäß werden zumindest Teilaspekte des zuvor beschriebenen Problems im Wesentlichen dadurch gelöst, dass Positionsdaten des Messgeräts unter ergänzender Berücksichtigung zumindest eines in ortsfester Beziehung zum Oberkiefer des Kauorgans angeordneten zweiten Positionsbestimmungssensors bestimmt werden, wobei insbesondere nach Auslösen eines Startsignals die Positionsdaten der zwei Positionsbestimmungssensoren synchron ausgewertet werden.

Auch sieht die Erfindung nach einem unabhängigen Lösungsvorschlag vor, dass die Bestimmung der Position des Messgerätes mittels des Positionsbestimmungssensors zu einem als Ausgangspunkt gewählten Startsignal erfolgt. Dabei kann das Startsignal räumlich sein, also zu dem Kauorgan eine ortsfeste Beziehung aufweisen.

Ausgehend von einer ersten Positionsmessung, die beispielsweise an einem vorgegebenen Ausgangspunkt als Referenzpunkt erfolgen kann, werden sodann Positionsdatenänderungen des Messgerätes mittels weiterer zeitlich versetzter Messungen bestimmt.

Dabei werden die Positionsänderungen des Messgerätes mittels in dem Messgerät integrierter bzw. vorhandener oder zu diesem in bekannter Ortsbeziehung stehender Inertialplattform bestimmt. Es werden drei translatorische und drei rotatorische Freiheitsgrade gemessen, die die Ortspositionsänderung des scannenden Sensors zum Kauorgan des Patienten bestimmt. Bevorzugterweise kann die Positionsänderung unter Berücksichtigung der Daten eines zweiten Positionsbestimmungssensors (Inertialplattform) erfolgen, der in fester Ortsbeziehung zum Oberkiefer angeordnet ist.

Erfindungsgemäß wird durch Aufintegrieren der Bewegungsänderungen eine neue Relativposition im Vergleich zur ersten Messung berechnet. Die Verkippung im Raum kann ggfs. direkt gemessen werden.

Dabei arbeitet die erfindungsgemäße Lösung nicht unter Einbeziehung von Daten, die mittels bildgebender Verfahren gewonnen wurden, sondern ist sogar in der Lage, selbst dreidimensional bildgebende Daten zu liefern.

Die Verwendung einer Intertialplattform kann zwar den Nachteil zeigen, dass ein zeitliches Driften auftreten kann, wie es von Gyrosystemen in der Luftfahrt bekannt ist. Dies bedarf grundsätzlich eines Nachkalibrierens zu einem festen Koordinatensystem von Zeit zu Zeit. Dieses Driften ist jedoch innerhalb der kurzen Messzeiten, in der die 3D-Daten des Kauorgans aufgenommen werden, so gering, dass dem Grunde nach von einer Korrektur Abstand genommen werden kann.

Für Messungen, bei denen die Bewegung des Patienten als vernachlässigbar im Vergleich zur Messgerät- bzw. Sensorposition angenommen werden kann, reicht die Inertialplattform im Messgerät aus.

Ist die Patientenbewegung nicht vernachlässigbar, ist erfindungsgemäß vorgesehen, dass der weitere Positionsbestimmungssensor (Inertialplattform) am Kopf des Patienten, also in einer ortsfesten Beziehung zum Oberkiefer des Kauorgans, die im Messzeitraum erfolgte Bewegung erfasst. Somit kann die Kopfbewegung des Patienten von der eigentlichen Messgerätebewegung getrennt erfasst werden.

Hierzu kann ein Gestell wie Brillengestell benutzt werden. Auch ein Gesichtsbogen kann zum Befestigen des zweiten Sensors eingesetzt werden. Alternativ kann eine Bissgabel mit einer Inertialplattform am Ober- oder Unterkiefer befestigt werden.

Eine andere Möglichkeit besteht darin, dass ein Beißblock, der die zumindest eine zweite Inertialplattform enthält, zwischen die Zahnreihen gelegt wird und der Patient aufgefordert wird, die Zahnreihen zu schließen.

Dabei ist insbesondere vorgesehen, dass die Positionsdaten als erste Koordinaten des ersten Positionsbestimmungssensors, also ersten Sensors (Inertialplattform) und die Positionsdaten des optionalen zumindest zweiten Positionsbestimmungssensors, also zweiten Sensors (Inertialplattform) als zweite Koordinaten verknüpft werden und dass aus den verknüpften Daten Koordinaten für den ersten Sensor und den zumindest einen

zweiten Sensor in einem gemeinsamen Koordinatensystem erzeugt werden, in dem Koordinaten von Positionen oder Bereichen des Kauorgans bestimmt werden.

Bei Messungen am Unterkiefer sollte bevorzugterweise zumindest eine weitere Inertialplattform in fester Ortsbeziehung zum Unterkiefer angebracht werden. Dies kann beispielsweise mit einem Beißblock oder einer am Unterkiefer angebrachten Bissgabel erfolgen. Ungünstige Platzverhältnisse können es im klinischen Einsatz jedoch erfordern, auf eine zum Unterkiefer ortsfeste Positionierung der zumindest einen Inertialplattform zu verzichten. Dies ist dann möglich, wenn die Positionsbestimmung innerhalb der Kauebene ausreichend ist. In diesem Fall kann man, um die Bewegung des Unterkiefers zum Oberkiefer zu berücksichtigen, von der Kenntnis ausgehen, dass der Unterkiefer zu dem Oberkiefer entlang einer bogenförmigen Bewegungsbahn bewegt wird, die vom Kiefergelenk bestimmt wird. Misst man während der Öffnungsbewegung des Unterkiefers einen Messpunkt, beispielsweise zwischen Zahn 31 und 41, weiß man, wie sich der Unterkiefer bewegt. Jeder andere Punkt des Unterkiefers wird sich in einer im mathematischen Sinn ähnlichen Kurve bewegen. Ergänzend kann die typische Mundöffnung berücksichtigt werden, um eine weitere Grobbestimmung vornehmen zu können.

Eine Zahnfleischtaschenposition wird sich in erster Näherung immer auf der gleichen Bogenbahn bewegen.

Durch die mit dem Messgerät (Intraoral-Scanner) fest verbundene Inertialplattform, die Positionsänderungsdaten liefert (ohne oder deutlich genauer mit weiterer ortsfest zum Oberkiefer angeordneter Inertialplattform), kennt man die aktuelle Grobposition des scannenden Sensors zum Kauorgan und die Positionsänderung zu zeitlich früheren Positionen. Damit wird es möglich, das Zusammenfügen von Einzel-3D-Datensätzen zu beschleunigen und in manchen Fällen kritischer Geometrie dies erst möglich zu machen, da die verwendeten Algorithmen gerade bei der groben Bestimmung der Position zweier oder mehrerer Einzeldatensätze zueinander Schwierigkeiten haben. Ist die Grobposition bekannt, kann die folgende Feinjustage der Datensätze zueinander wesentlich

einfacher und schneller erfolgen, so dass die Scanndaten mit relativ geringem Rechenaufwand verknüpft werden können.

Erfindungsgemäß steht ein intraorales Scannsystem zur Verfügung, das eine Vorrichtung zur Grobpositionsbestimmung und deren Änderung relativ zum Kauorgan umfasst.

Nach einem eigenerfinderischen Vorschlag kann das intraoral messende Messgerät nicht nur zum Scannen eines Zahnbogens bzw. eines Abschnitts von diesem verwendet werden, um die Position von Zähnen bzw. Bereichen, die mit Zahnrekonstruktionen zu versorgen sind, zu bestimmen, sondern auch zur Bestimmung von Zahntaschentiefen oder Lage und Erstreckung von Karies oder Zahnstein benutzt werden.

Letzteres ist insbesondere dann von Bedeutung, wenn z. B. Zahnfleischtaschen bzw. deren Tiefe gemessen werden sollen, ohne dass ein übliches Erfassen der Daten durch Aufrufen der Messpunkte erfolgt. Vielmehr sind dann, wenn eine Ausgangsposition einer zu messenden Zahntasche bzw. eines Bereichs einer Zahntasche eines Zahns bekannt ist, anschließend automatisch Messungen von Bereichen der Zahntasche desselben Zahns und angrenzender Zähne durchführbar und somit abspeicherbar, da sich die Positionen der sich hieraus ergebenden Ortskoordinaten aus der Stellung des Messgerätes, also des ersten Sensors (Inertialplattform) zu dem in Bezug auf den Oberkiefer ortsfest zumindest einen zweiten Sensor ergibt.

Erfindungsgemäß kann dies voll- bzw. halbautomatisch durchgeführt werden. Wird ein die Taschentiefe messender Abschnitt des Messgerätes in die Tasche geschoben, so kann aufgrund der erfindungsgemäßen Lehre automatisch die Position des Messgerätes ermittelt und abgespeichert werden. Sodann ist es beim halbautomatischen Messen allein erforderlich, dass die Taschentiefen am Messgerät abgelesen werden (z. B. an der Skala einer von dem Messgerät ausgehenden Sonde) und z. B. mittels Spracherkennungssystem an das Patientendokumentationsprogramm im PC übermittelt werden. Die Position des Messgerätes selbst wird automatisch erfasst. Um die automatische Positionserfassung zu ermöglichen, muss eine Ausgangsposition angegeben werden, z. B. Berühren der Gingiva zwischen Zahn 31 und 41 approximal. Ist diese Position bekannt,

so wird aufgrund der erfindungsgemäßen Lehre beim Bewegen des Messgerätes die neue Position automatisch relativ zur ersten Position ermittelt, so dass jede Messposition automatisch erfassbar ist. Bei der halbautomatischen Erfassung ist es erwähntermaßen nur erforderlich, dass die Taschentiefe bei jeder Messung z. B. über eine Tastatur eines Rechners eingegeben oder per Spracherkennung übermittelt wird, wohingegen die Position selbst automatisch abgespeichert wird.

Neben der automatischen Positionserfassung des Messortes kann auch der Messvorgang selbst automatisch durchgeführt werden, ohne dass es eines Ablesens von Daten bedarf. Auch hierin ist ein eigenerfinderischer Vorschlag zu sehen. Dies kann auf verschiedene Weise erfolgen, z. B. mit einem Drag-Indikator mit elektronischer Auslesung (z. B. Florida probe), Ultraschalltaschentiefenmessung, optoelektronisch oder mit Impedanzänderungsverfahren.

Messergebnisse, die mit einem entsprechenden Verfahren ermittelt werden, können sodann automatisch mit der Ortsposition in einem Patientenmanagementsystem abgespeichert werden.

Insbesondere erfolgt die Taschentiefenmessung mittels eines optischen Lichtleiters in Form einer oder mehrerer Fasern eines für elektromagnetische Strahlung transparenten Materials z. B. aus Glas, Saphir oder Kunststoff, der in die Tasche eingeführt wird. Dabei kann der Durchmesser des optischen Leiters z. B. im Bereich zwischen 50 µm und 1.000 µm liegen, ohne dass hierdurch eine Einschränkung der erfindungsgemäßen Lehre erfolgt. Von dem Moment an, zu dem der optische Leiter in die Tasche eindringt, ändert sich die von dem Lichtleiter über dessen Stirnfläche gesammelte und einem Empfänger zugeleitete Lichtintensität bzw. spektrale Verteilung aufgrund der optischen Eigenschaften des Zahnfleisches und des Zahnes. Hieraus kann die Eindringtiefe der Spitze des Lichtleiters in die Tasche bestimmt werden, wobei die Messung dann beendet ist, wenn die Stirnfläche des Lichtleiters den Boden der Tasche berührt. Die Taschentiefe berechnet sich dann aus der Differenz zwischen der Position, an der der Eintritt in die Tasche festgestellt wurde und der Position, in der keine weitere Bewegung in z-Richtung (in die Tiefe der Tasche) erfolgt.

Das von dem Lichtleiter erfasste Licht kann Umgebungslicht sein, das z. B. von der Beleuchtung eines Behandlungsstuhles abgegeben wird. Es kann jedoch auch Licht durch den Lichtleiter selbst geleitet und das am Faserende reflektierte Licht mittels einer Photodiode oder eines anderen Lichtdetektors gemessen werden.

Es besteht auch die Möglichkeit, dass das ins Cladding des Lichtleiters rückreflektierte Licht bzw. dessen Veränderung gemessen wird.

Ein weiterer Vorschlag sieht vor, dass in die Tasche zumindest zwei optische Leiter eingeführt werden, wobei über einen oder mehrere der Leiter Licht emittiert und über mindestens einen anderen Leiter Licht empfangen und sodann ausgewertet wird. Hierdurch wird die Nachweisempfindlichkeit des reflektierten Signals erhöht und es kann durch unterschiedliche numerische Aperturen, Durchmesser der Lichtleiter und Abstände zwischen den Lichtleitern zueinander eine Auswahl des Bereiches erfolgen, von wo das in den Lichtleiter reflektierte Licht vorzugsweise empfangen werden soll. Der Abstand zwischen den Lichtleitern beim Einsatz mehrerer Lichtleiter sollte vorzugsweise zwischen dem 0,5- und 3-fachem Durchmesser eines Lichtleiters sein, ohne darauf begrenzt zu sein.

Auch kann eine koaxiale Anordnung eines Lichtleitröhrchens und eines in das Röhrchen lose eingeführten Lichtleiters benutzt werden.

Nach einem anderen Vorschlag ist vorgesehen, dass ein Lichtleiter benutzt wird, dessen Cladding und Coating entfernt sind und der Kern aufgeraut ist. Sodann wird der aufgeraute Lichtleiter von einem Luftmantel oder zumindest einer Beschichtung aus einem Material mit einem geringen Brechungsindex x mit $x << 1,3$ umgeben. Eine solche Konstruktion stellt sicher, dass die optische Faser in dem aufgerauten Bereich nahezu isotrop abstrahlt.

Alternativ kann an das Ende einer Faser ein Stäbchen aus streuendem Medium angebracht werden, das bei adäquater Wahl des Streukoeffizienten ($0,1/mm<\mu s<100/mm$)

ebenfalls eine über die Länge des Stäbchens verteilte möglichst homogene Lichtintensität erzeugt.

Sodann besteht die Möglichkeit, die Faser mit Licht einer oder mehrerer Wellenlängen mittels z. B. einer LED, einer Laserdiode oder einer anderen Lichtquelle zu beaufschlagen. Gegebenenfalls besteht auch die Möglichkeit, dass kein Beleuchten der Faser erfolgt, sondern dass diese allein Umgebungslicht aufnimmt. Diesbezügliche Messungen sind möglicherweise mit einem Fehler behaftet.

Wird die Faser mit Licht beaufschlagt, so wird dieses mehr oder weniger isotrop von dem aufgerauten Ende abgestrahlt und entsprechend reflektiertes Licht gesammelt. Sobald der aufgeraute Bereich in die Tasche eindringt, ändert sich die Reflektionsrate von Faser zu Luft gegenüber Faser zum Gewebe und umgekehrt. Dies resultiert in einer Veränderung der Intensität und spektralen Verteilung des reflektierten Lichtes. Der Grad der Veränderung entspricht der Tiefe des Eindringens des Sensors in die Zahntasche. Der Sensor ist zu jeder Zeit aktiv und erfasst unmittelbar das Eindringen in die Tasche. Je tiefer sich der Sensor in der Tasche befindet, umso stärker macht sich eine Signaländerung bemerkbar.

Um die Empfindlichkeit zu erhöhen, können auch zwei entsprechende Fasern, die von Luft oder einer Ummantelung sehr niedrigen Brechungsindexes umgeben sind, verwendet werden, wobei eine Faser als Sensor und die andere Faser als Empfänger in Bezug auf ihre aufgerauten Bereiche dienen. Ein unmittelbarer Lichtübergang vom Sender zum Empfänger wird dadurch verhindert, dass eine Abschirmung zwischen den Sensoren erfolgt. In diesem Fall nimmt der als Empfänger dienende Lichtleiter allein vom Zahn bzw. Gewebe reflektiertes Licht wahr, wobei das reflektierte Licht für jede Wellenlänge unterschiedlich gedämpft und gestreut ist, so dass Rückschlüsse auf die Eigenschaften des Gewebes bzw. des Zahnes erfolgen können, die das Licht reflektieren bzw. von dem Licht durchsetzt sind. Die Unterschiede zwischen den Wellenlängen nehmen in Abhängigkeit von der Eindringtiefe der Faser in das Material zu.

Über die Messung des Spektrums des zurückgestreuten Lichts kann auch festgestellt werden, ob das Gewebe bzw. Zahnfleisch entzündet ist. So ändert sich die Perfusion des Gewebes mit Blut in Abhängigkeit von dem Umfang der Entzündung. Blut hat abweichende optische Eigenschaften zum Gewebe. Werden geeignete Wellenlängen des applizierten Lichtes benutzt, so kann der Umfang der Perfusion ermittelt werden. Zwei Komponenten des Gewebes, und zwar Proteine und Wasser, können als Referenz benutzt werden, wobei für Proteine eine Absorption von Wellenlängen unter 350 nm und für Wasser für Wellenlängen über 1.500 nm bemerkbar ist. Blut hat ein Absorptionsmaximum bei ungefähr 400 nm und eine moderate Absorption im Bereich zwischen 650 nm und 1.000 nm. Wird nun das Verhältnis zwischen reduzierter Blutabsorption im Wellenlängenbereich ‹ 350 nm und Wellenlänge › 1.500 nm zur signifikanten Blutabsorption im Wellenlängenbereich 400 nm bis 1.000 nm gemessen, sind Rückschlüsse auf die Blutperfusion im Gewebe möglich. Diesbezügliche Verfahren können mit jedweder Form zur Bestimmung der Zahntaschentiefe mittels optischer Fasern kombiniert werden.

Die Taschentiefe kann jedoch auch durch Impedanzmessungen ermittelt werden. So kann eine elektrisch leitende Spitze wie beispielsweise eine Parodontalsonde in die Tasche eingeführt werden, wobei gleichzeitig der Gewebewiderstand gemessen wird. Sobald die Sondenspitze die Tasche gefüllt mit Crevicular Flüssigkeit berührt, nimmt der Widerstand ab, z. B. auf einen Wert kleiner als 200 kΩ. In Luft liegt der Widerstand bei größer als 1 MΩ . Die Eindringtiefe der Spitze in die Tasche wird sodann durch die Bewegung des Sensors ermittelt, um auf diese Weise die Taschentiefe zu berechnen. Es kann auch eine Bipolarnadel benutzt werden, die mit einer speichelabweisenden Oberfläche wie Teflon beschichtet ist.

Alternativ besteht die Möglichkeit, einen nichtleitenden Sondengrundkörper zu verwenden, der abschnittsweise leitende Ringabschnitte in unterschiedlichen Abständen von der Sondenspitze aufweist. Während des Eindringens der Sonde in die Tasche wird ein Ring nach dem anderen mit Flüssigkeit bedeckt und die Impedanz zwischen den Ringen ändert sich. Auch kann eine kapazitive Messung durchgeführt werden.

Über einen mittleren oder hohen Widerstandsbelag aufgebracht als Schicht auf die Sonde kann auch das graduelle Eintauchen der Sonde in die Parodontaltasche gemessen werden. Die Eigenschaften eines Potentiometers werden genutzt.

Eine eigenerfinderische Lehre ermöglicht auch die Ortsbestimmung bzw. Flächenerstreckung von Karies bzw. Zahnstein mittels des ersten Positionsbestimmungssensors. Hierbei macht man sich die unterschiedlichen Reflektionseigenschaften von Karies bzw. Zahnstein im Vergleich zum gesunden Zahnbereich zueigen.

Ebenfalls möglich ist die Erfassung der Unterkieferbewegung gegen den Oberkiefer, falls ein Positionsbestimmungssensor (Inertialplattform) am Kopf des Patienten und ein weiterer Positionsbestimmungssensor (Intertialplattform) am Unterkiefer befestigt werden. Insbesondere können hierdurch dynamische Okklusalmessungen durchgeführt werden.

Weitere Einzelheiten, Vorteile und Merkmale der Erfindung ergeben sich nicht nur aus den Ansprüchen, den diesen zu entnehmenden Merkmalen -für sich und/oder in Kombination-, sondern auch aus der nachfolgenden Beschreibung von der Zeichnung zu entnehmenden bevorzugten Ausführungsbeispielen.

Es zeigen:

Fig. 1 eine Prinzipdarstellung von ersten und zweiten Positionsbestimmungssensoren, die auf ein Kauorgan ausgerichtet werden,

Fig. 2 ein Flussdiagramm,

Fig. 3 eine erste Ausführungsform einer Anordnung zum Messen der Tiefe einer Zahntasche,

Fig. 4 eine weitere Prinzipdarstellung von Messsensoren,

Fig. 5 eine dritte Ausführungsform zur Messung einer Zahnfleischtaschentiefe,

Fig. 6 eine vierte Ausführungsform zur Messung einer Zahnfleischtaschentiefe,

Fig. 7 eine fünfte Ausführungsform zur Messung einer Zahnfleischtaschentiefe,

Fig. 8 eine sechste Ausführungsform zur Messung einer Zahnfleischtaschentiefe und

Fig. 9 eine siebte Ausführungsform zur Messung einer Zahnfleischtaschentiefe .

In Fig. 1 ist rein prinzipiell ein als Intraoral-Scanner 10 zu bezeichnendes Messgerät dargestellt, in dem eine Inertialplattform (erster Sensor) integriert ist, durch die die Position des Messgerätes abhängig von dessen Bewegungen in X-, Y- und Z-Richtung sowie Drehung um die jeweiligen Achsen erfassbar ist. Die Inertialplattform kann z. B. mit einem ADIS 16355 aufgebaut sein.

Die Position des Messgerätes 10 und damit des ersten Positionsbestimmungssensors 11 wird zu der Position von zumindest einem zweiten Positionsbestimmungssensor 14 mittels eines Rechners 16 ermittelt, dem die Daten des ersten Positionsbestimmungssensors 10 und des zweiten Positionsbestimmungssensors 14 idealerweise drahtlos übergeben werden. Auch der zweite Sensor 14 beinhaltet eine Inertialplattform. Der zweite Positionsbestimmungssensor 14 kann dabei an dem Bügel einer Brille oder an einem Gesichtsbogen oder in Bissblöcken integriert sein, die zwischen Unter- und Oberkiefer positionierbar sind. Ein Ausgleichsgewicht 12 ist zur symmetrischen Gewichtsverteilung am Brillengestell angebracht.

Somit werden von dem Rechner aus den Daten des ersten Positionsbestimmungssensors 11 und des ortsfest in Bezug auf den Oberkiefer positionierten zweiten Positionsbestimmungssensors 14 die Positionen des Intraoral-Scanners ermittelt und mit den 3D Daten, die an den jeweiligen Positionen gemessen wurden, verknüpft. Damit wird die Grobpositionierung der einzelnen Datensets innerhalb eines gemeinsamen Koordinatensystems beschleunigt (Schritt 20 in Fig. 2). Nach Schritt 20 befinden sich die 3D-Datensets in einem gemeinsamen Koordinatensystem (Schritt 22). Anschließend werden Feinkorrekturen durchgeführt, die die Datensets zueinander in bestmögliche zueinander passende Position bringen (Schritt 24). Der so gewonnene einheitliche 3D-Datensatz 26 kann nun durch weitere bekannte Schritte zur Herstellung von Zahnersatz verwendet werden.

Insbesondere zur digitalen Darstellung von Bereichen des Unter- und/oder Oberkiefer bietet das erfindungsgemäße Verfahren erhebliche Einsparungen in der Rechenzeit und vermeidet Fehldarstellungen; denn mittels der Inertialplattformen oder entsprechend technisch gleichwirkender Ortsbestimmungsmittel werden die Positionen des Intraoral-Scanners in Bezug auf einen zu scannenden Bereich zumindest grob ermittelt, wodurch das Registrieren der Teildatensätze aus unterschiedlichen Aufnahmewinkeln erleichtert wird. Fehlzuordnungen, die bei völlig unbekannter Scannerposition möglich sind, werden hierdurch ausgeschlossen.

Nach dem Ausführungsbeispiel unter Verwendung von zwei Positionsbestimmungssensoren übermittelt der erste Positionsbestimmungssensor Daten (Beschleunigungswerte), mit denen die Ortsveränderungen des Messgerätes in Bezug auf die vorherige Messposition berechnet werden. Der zweite Positionsbestimmungssensor übermittelt Daten, aus denen auf die Ortsveränderungen des Patienten bezügliche dessen Ausgangslage geschlossen werden können.

Selbstverständlich wird die Erfindung nicht verlassen, wenn nur ein Positionsbestimmungssensor eingesetzt wird, dessen Daten Ortsveränderungen zwischen den einzelnen Messorten ermitteln. Dies erfolgt aufgrund der mit der Inertialplattform ermittelten Da-

ten, also der Aufnahme von Beschleunigungswerten, die in Verbindung mit ihrem zeitlichen Verlauf die Berechnung der sich ergebenden Positionsänderungen ermöglichen.

Grundsätzlich werden keine absoluten Positionen in allen 6 Freiheitsgeraden erfasst. Absolute Positionen können jedoch in Bezug auf eine bekannte Startposition bestimmt werden.

Um insbesondere die Tiefe von Zahnfleischtaschen an verschiedenen Orten eines Zahns zu messen, kann das erfindungsgemäße Verfahren, also die Bestimmung der Ortsposition des Messgerätes 10 mit dem ersten Positionsbestimmungssensor allein oder in Verbindung mit einem bzw. dem zweiten Positionsbestimmungssensor 14 benutzt werden, wobei von dem Messgerät 10 ein Sensorelement wie Stift oder optischer Leiter ausgeht, mittels dessen die Taschentiefe gemessen wird. Es besteht jedoch auch die Möglichkeit, mittels Ultraschall die Taschentiefe zu bestimmen. Sender und Empfänger gehen sodann von dem Sensor aus. Ebenso kann mittels einer Impedanzmessung die Taschentiefe gemessen werden.

Vorzugsweise kann jedoch opto-elektronisch gemessen werden. Hierzu ist entsprechend der Fig. 3 ein optischer Leiter in Form vorzugsweise einer aus Kunststoff oder Glas bestehenden Lichtleitfaser 28 von einem lichtleitenden Mantel (Coating) 30 umgeben. Der Lichtleiter wird sodann in eine Zahntasche 32 eingeführt. Über den Lichtleiter 28 wird Licht eines Lichtemitters wie mindestens einer Leuchtdiode oder Laserdiode 34 emittiert, um sodann die in der Tasche 32 reflektierte Strahlung über die Faser 28 zurück an den Lichtsensor 36 zu leiten. Ebenso ist über kurze Entfernungen die Rückleitung des reflektierten Lichts über Einkopplung in die Stirnfläche 34 des Coatings 30 zu einem Empfänger möglich. Dies hat den Vorteil der räumlichen Entkopplung von Sender- und Empfängerlichtpfad. Zu dem Zeitpunkt, zu dem die Stirnfläche der Faser die Gingiva berührt bzw. in die Zahnfleischtasche eintaucht, ändert sich das reflektierte Licht in Intensität und im Falle der Verwendung von mehr als einer Wellenlänge auch das Spektrum. Damit ist der Zeitpunkt des Eintritts in die Zahnfleischtasche bekannt. Am Taschenboden stoppt die Bewegung in Taschenrichtung. Die seit dem Eintrittszeit-

punkt zurückgelegte Wegstrecke entspricht der Taschentiefe, und kann mittels der bekannten Positionsdaten aus der Inertialplattform ermittelt werden.

Es besteht auch die Möglichkeit, zwei optische Leiter 38, 40 nebeneinander in eine Tasche einzuführen, wobei über einen Leiter, z. B. den optischen Leiter 38, Licht zugeführt wird, um in der Tasche bzw. von dem Gewebe bzw. von dem Zahn, der die Tasche begrenzt, reflektierte Strahlung von dem optischen Leiter bzw. der Faser 40 zu sammeln und einem Empfänger zur Auswertung zuzuleiten. Der Abstand d zwischen den Leitern 38, 40 sollte dabei vorzugsweise 0,5- bis 3-facher Durchmesser eines jeden Leiters 38, 40 sein.

Wie in Fig. 5 dargestellt kann eine koaxiale Ausführungsform genutzt werden. In einem Glas-Saphir oder Quarzröhrchen 40 ist ein Lichtleiter 42 so eingebracht, dass er die Innenfläche des Glasröhrchens nicht berührt. Sobald die Anordnung die Gingiva berührt oder in die Zahnfleischtasche eintaucht, ändert sich das im Material des Röhrchens zurückgeleitete Licht hinsichtlich Intensität und spektraler Verteilung. Damit keine Flüssigkeit in den Luftspalt 40a eindringt, ist die Anordnung mit einem transparenten Fenster aus dem gleichen Material wie das Röhrchen verschlossen.

Nach dem Ausführungsbeispiel der Fig. 6 wird ein Lichtleiter 44 benutzt, der in seinem Endbereich 46 aufgeraut ist. Hierzu ist sowohl das Cladding 48 als auch das Coating 50 des Lichtleiters entfernt. Der aufgeraute Endbereich 46 wird sodann in eine Umhüllende 50a und beabstandet zu deren Innenfläche angeordnet, wobei der Zwischenraum mit Luft gefüllt ist. Somit ergibt sich ein Brechungsindexsprung, der eine annähernd gleichmäßige Abstrahlung des Lichts ermöglicht. Anstelle der Umhüllenden 50a mit Luftspalt kann der aufgeraute Abschnitt 46 auch z. B. mit einem Material niedrigen Brechungsindex wie Teflon beschichtet sein.

Der aufgeraute Bereich zeigt den Vorteil, das Licht annähernd isotrop abgestrahlt und reflektiertes Licht annähernd isotrop gesammelt wird. Sobald der aufgeraute Bereich in die Tasche hinein geschoben wird, ändert sich durch die optischen Eigenschaften des Parodontalgewebes, das vom Licht durchquert wird, die Menge und spektrale Vertei-

lung des rückgestreuten Lichts, in Abhängigkeit von der Eindringtiefe in die Parodontaltasche.

Auf diese Weise kann nicht nur die Taschentiefe, sondern auch mögliche Entzündungen des Zahnfleisches ermittelt werden. Hierzu wird der Lichtleiter mit Strahlung über einen Wellenlängenbereich beaufschlagt, in dem die das Gewebe charakterisierenden Komponenten Protein und Wasser bzw. Blut Strahlung besonders stark absorbieren. Anschließend werden die Intensitäten der charakteristischen Absorptionsbereiche ins Verhältnis gesetzt, um Aussagen über Art und Umfang der Entzündung zu treffen.

Fig. 7 sieht eine Ausführungsform vor, bei der entsprechend der Fig. 6 am Ende vom Coating und Cladding befreiter und aufgerauter Lichtleiter 54 Strahlung in den interessierenden bzw. zu messenden Bereich leitet bzw. abstrahlt und ein ebenso vorbereiteter Lichtleiter 56 aus dem Gebiet reflektierte Strahlung sammelt und einem Empfänger zuführt. Dabei sollten die Lichtleiter 54, 56 in ihren aktiven, also aufgerauten Bereichen optisch voneinander getrennt bzw. abgeschattet sein. Wegen dieser Abschirmung muss das Licht innerhalb des Gewebes einen längeren Weg zurücklegen. Die Anordnung wird somit empfindlicher auf Unterschiede in den optischen Eigenschaften des Gewebes und der Eindringtiefe in die Parodontaltasche.

Auch Impedanzmessungen können zur Bestimmung der Taschentiefe vorgenommen werden. Hierzu kann eine leitende Spitze wie beispielsweise einer Parodontalsonde benutzt werden, deren Impedanz sich in Abhängigkeit von dem Kontakt mit Crevicularflüssigkeit ändert. Berührt die Spitze keine Flüssigkeit, sondern wird in Luft bewegt, so beläuft sich der Widerstand auf mehr als ein 1 MΩ. In dem Moment, wo ein Kontakt mit der Flüssigkeit in der Zahntasche erfolgt, bricht der Widerstand auf Werte kleiner als 200 kΩ zusammen. Diese Widerstandsänderung wird als Indikator für das Eindringen in die Tasche benutzt. Sodann wird die Spitze in die Tasche hinein bis zu deren Boden verstellt und mittels des die Inertialplattform aufweisenden ersten Sensors der Verstellweg bestimmt, um die Tiefe automatisch zu ermitteln. Als Endpunkt dient der Stopp der Bewegung in die Tasche.

Es besteht auch die Möglichkeit, eine Spitze in die Tasche zu führen, die in parallel verlaufenden und gegeneinander elektrisch isolierten Ebenen Elektroden aufweist, die durch das Gewebe und die in der Tasche befindliche Flüssigkeit elektrisch leitend verbunden werden. Ein entsprechender Aufbau ist in Fig. 8 dargestellt. Um einen leitenden Kern 60 gruppieren sich abwechselnd Isolationsschichten 59 und leitende Schichten 62. So werden leitfähige Ringe erzeugt, die je eine eigene Anschlusselektrode 61 erhalten. Wird die Isolationsschicht zwischen den Elektroden von einer leitfähigen Flüssigkeit benetzt bzw. kommt Gewebe mit zwei benachbarten Elektroden in Berührung, sinkt der Widerstand zwischen den beiden Elektroden deutlich ab. Somit kann die Eindringtiefe der Sonde in eine Flüssigkeit bzw. in die parodontale Tasche schrittweise gemessen werden. Eine sinnvolle Ausführung kann 0,5 mm – 1 mm Eindringtiefenänderung auflösen. Die freien Enden des leitenden Kerns 60 bzw. der leitenden Schichten enden in unterschiedlichen Ebenen, wie sich aus der Zeichnung ergibt, um die Tiefenmessung durchzuführen.

Auch eine kapazitive Messung zur Taschenmessung ist möglich. Hierzu werden auf ein Trägerstäbchen 63 aus einem Material mit niedriger Dielektrizitätskonstante z. B. Teflon, oder Polypropylen gegenüberliegend zwei oder mehrere Elektroden 64 aufgebracht, die mit dem Gewebe, in das die Sonde eintaucht, einen Kondensator bilden. Die Elektroden 64 sind mit einer vorzugsweise hydrophoben Isolierschicht überzogen und mit Verbindungsleitungen 67 mit der Auswerteelektronik verbunden. Abhängig von der Eintauchtiefe 65 ändert sich die Kapazität der Gesamtanordnung.

Lässt man die Isolation 66 in der Ausführung gemäß Fig. 9 weg und führt die Elektroden 64 mit einem mittel- bis hochohmigen Material aus, kann die Eintauchtiefe auch aus der kontinuierlichen Widerstandsänderung der Anordnung bestimmt werden.

Mittels des intraoralen Scannens 10 können nicht nur Positionen im Kauorgan oder Bereiche des Kauorgans wie örtliche Anordnung von Zähnen oder Messpunkte mit gleichzeitiger Tiefenmessung einer Zahntasche automatisch ermittelt werden, sondern es besteht auch die Möglichkeit, Karies bzw. Zahnstein und dessen Erstreckung und Lage zu messen. Hierzu nutzt man die unterschiedlichen Reflexionsspektren von gesundem

Zahn im Vergleich zu Bereichen, die von Karies befallen sind bzw. Zahnstein aufweisen, die bei der Ortsbestimmung des ersten Sensors mit ausgewertet werden können.

Patentansprüche

Verfahren zur Positionsbestimmung eines intraoral messenden Messgerätes

1. Verfahren zur Positionsbestimmung eines relativ zu einem Kauorgan eines Patienten zu bewegenden intraoral messenden Messgeräts, mit dem Positionen im Kauorgan oder Bereiche des Kauorgans gemessen werden, insbesondere zur Taschentiefenmessung von Zahnfleisch und/oder Karies- bzw. Zahnsteindetektion, wobei die Position des Messgerätes mittels eines in ortsfester Beziehung zu dem Messgerät stehenden Positionsbestimmungssensors gemessen wird,
   d a d u r c h g e k e n n z e i c h n e t ,
   dass Positionsdaten des Messgeräts unter ergänzender Berücksichtigung zumindest eines in ortsfester Beziehung zum Oberkiefer des Kauorgans angeordneten zweiten Positionsbestimmungssensors bestimmt werden, wobei insbesondere nach Auslösen eines Startsignals die Positionsdaten der zwei Positionsbestimmungssensoren synchron ausgewertet werden.

2. Verfahren zur Positionsbestimmung eines relativ zu einem Kauorgan eines Patienten zu bewegenden intraoral messenden Messgeräts, mit dem Positionen im Kauorgan oder Bereiche des Kauorgans gemessen werden, insbesondere zur Taschentiefenmessung von Zahnfleisch und/oder Karies- bzw. Zahnsteindetektion, wobei die Position des Messgerätes mittels eines in ortsfester Beziehung zu dem Messgerät stehenden Positionsbestimmungssensors gemessen wird,
   d a d u r c h g e k e n n z e i c h n e t ,
   dass die Bestimmung der Position des Messgerätes mittels des Positionsbestimmungssensors zu einem als Ausgangspunkt gewählten Startsignal erfolgt, das insbesondere in ortsfester Beziehung zu dem Kauorgan steht.

3. Verfahren nach Anspruch 1,
d a d u r c h g e k e n n z e i c h n e t ,
dass die Positionsdaten des ersten Positionsbestimmungssensors als erste Koordinaten und die Positionsdaten des zumindest einen zweiten Positionsbestimmungssensors als zweite Koordinaten verknüpft werden und dass aus den verknüpften Daten Koordinaten für den ersten Positionsbestimmungssensor und den zumindest einen zweiten Positionsbestimmungssensor in einem gemeinsamen Koordinatensystem erzeugt werden, in dem Koordinaten von Positionen oder Bereichen des Kauorgans bestimmt werden.

4. Verfahren nach einem der Ansprüche 1 bis 3, ,
d a d u r c h g e k e n n z e i c h n e t ,
dass der erste und/oder der zumindest eine zweite Positionsbestimmungssensor als Inertialplattform ausgebildet wird oder mit einer solchen versehen ist.

5. Verfahren nach zumindest einer der vorhergehenden Ansprüche,
d a d u r c h g e k e n n z e i c h n e t ,
dass die Positionen bzw. Koordinaten des ersten Positionsbestimmungssensors mittels mindestens eines zweiten Positionsbestimmungssensors bestimmt werden, der vorzugsweise am Kopf des Patienten angeordnet wird.

6. Verfahren nach zumindest einer der vorhergehenden Ansprüche,
d a d u r c h g e k e n n z e i c h n e t ,
dass der zumindest eine zweite Positionsbestimmungssensor an einem Gestell wie Brillengestell oder an einem Gesichtsbügel oder in einen Bissblock befestigt wird, der zwischen Unter- und Oberkiefer angeordnet wird.

7. Verfahren nach zumindest einer der vorhergehenden Ansprüche,
d a d u r c h g e k e n n z e i c h n e t ,
dass zur Bestimmung von Ortskoordinaten von Bereichen des Unterkiefers dessen Bewegung entlang eines vom Oberkiefer ausgehenden Bogens ergänzend berücksichtigt wird.

8. Verfahren nach zumindest einer der vorhergehenden Ansprüche,
d a d u r c h g e k e n n z e i c h n e t ,
dass zur Bestimmung von Ortskoordinaten von Bereichen des Unterkiefers und/oder Oberkiefers ein weiterer oder der erste Positionsbestimmungssensor ortsfest zu dem Unter- bzw. Oberkiefer angeordnet wird.

9. Verfahren nach zumindest einer der vorhergehenden Ansprüche,
d a d u r c h g e k e n n z e i c h n e t ,
dass zur Bestimmung einer Position des Unterkiefers bzw. deren Koordinaten dem Unterkiefer ein dritter Positionsbestimmungssensor ortsfest zugeordnet wird, der eine Intertialplattform aufweist.

10. Verfahren nach zumindest einer der vorhergehenden Ansprüche,
d a d u r c h g e k e n n z e i c h n e t ,
dass mit dem Messgerät die Taschentiefe eines Zahns gemessen wird.

11. Verfahren vorzugsweise nach zumindest einer der vorhergehenden Ansprüche,
d a d u r c h g e k e n n z e i c h n e t ,
dass die Taschentiefe mittels Ultraschall, Drag-Indikator, optoelektronisch, induktiv, kapazitiv oder durch Widerstandsmessung bestimmt wird.

12. Verfahren nach zumindest einer der vorhergehenden Ansprüche,
d a d u r c h g e k e n n z e i c h n e t ,
dass das Messgerät ein stiftförmiges Element aufweist, mit dem Zahntaschen gemessen werden.

13. Verfahren nach zumindest einer der vorhergehenden Ansprüche,
d a d u r c h g e k e n n z e i c h n e t ,
dass mittels des stiftförmigen Elements Tiefe und/oder Zustand der Zahntasche durch Ortsveränderung des Messgerätes elektrisch und/oder optoelektronisch gemessen wird.

14. Verfahren nach vorzugsweise zumindest einer der vorhergehenden Ansprüche,
d a d u r c h g e k e n n z e i c h n e t ,
dass mit dem Messgerät die Taschentiefe in Abhängigkeit von der Position des ersten Positionsbestimmungssensors zu dem zweiten Positionsbestimmungssensor gemessen wird.

15. Verfahren nach zumindest einer der vorhergehenden Ansprüche,
d a d u r c h g e k e n n z e i c h n e t ,
dass ein optischer Lichtleiter in die Tasche eingeführt wird und dass die Tiefe der Tasche in Abhängigkeit von über den Lichtleiter einem Empfänger zugeführtem Licht bestimmt wird.

16. Verfahren nach zumindest einer der vorhergehenden Ansprüche,
d a d u r c h g e k e n n z e i c h n e t ,
dass Änderungen von Intensität und/oder spektrale Verteilung des über den optischen Lichtleiter dem Empfänger zugeleiteten Lichts zur Bestimmung der Taschentiefe ausgewertet wird.

17. Verfahren nach vorzugsweise zumindest einer der vorhergehenden Ansprüche,
d a d u r c h g e k e n n z e i c h n e t ,
dass ein optischer Leiter zur Beleuchtung und Rückleitung des rückgestreuten Lichts zur Messung der Taschentiefe verwendet wird.

18. Verfahren nach zumindest einer der vorhergehenden Ansprüche,
d a d u r c h g e k e n n z e i c h n e t ,
dass vom optischen Leiter empfangenes Umgebungslicht zur Messung der Taschentiefe ausgewertet wird.

19. Verfahren nach zumindest einer der vorhergehenden Ansprüche,
d a d u r c h g e k e n n z e i c h n e t ,
dass der optische Leiter von einem lichtleitenden Mantel umgeben ist, über dessen Stirnfläche eingekoppeltes Licht zur Messung der Taschentiefe ausgewertet wird.

20. Verfahren nach zumindest einer der vorhergehenden Ansprüche,
d a d u r c h g e k e n n z e i c h n e t ,
dass in die Tasche zumindest zwei optische Leiter eingeführt werden, wobei über einen der Leiter Licht zugeführt und über den anderen Leiter empfangenes Licht ausgewertet wird.

21. Verfahren nach zumindest einer der vorhergehenden Ansprüche,
d a d u r c h g e k e n n z e i c h n e t ,
dass als optischer Leiter eine Faser oder ein Faserbündel verwendet wird, wobei der optische Leiter einen Durchmesser D mit vorzugsweise 50 µm ≤ D ≤ 1000 µm aufweist.

22. Verfahren nach zumindest einer der vorhergehenden Ansprüche,
d a d u r c h g e k e n n z e i c h n e t ,
dass bei der Verwendung von zwei optischen Leitern diese einen lichten Abstand D einnehmen, der vorzugsweise 0,5 D ≤ d ≤ 3 D mit D gleich Durchmesser des optischen Leiters ist.

23. Verfahren nach zumindest einer der vorhergehenden Ansprüche,
d a d u r c h g e k e n n z e i c h n e t ,
dass ein optischer Leiter in einer koaxialen Anordnung innerhalb eines transparenten Röhrchens z. B. aus Saphir positioniert wird, ohne dieses zu berühren.

24. Verfahren nach vorzugsweise zumindest einer der vorhergehenden Ansprüche,
d a d u r c h g e k e n n z e i c h n e t ,
dass als optischer Leiter eine in ihrem freien Ende von Cladding und Coating befreite aufgeraute lichtleitende Faser verwendet wird, dass der optische Leiter mit Licht vorzugsweise ausgewählter Wellenlänge oder ausgewählten Wellenlängenbereichs, insbesondere im Bereich von 350 nm ≤ λ ≤ 10.000 nm, vorzugsweise 400 nm ≤ λ ≤ 2000 nm beaufschlagt wird, und dass das über das aufgeraute Ende in den optischen Leiter zurückreflektierte Licht zur Bestimmung der Taschentiefe ausgewertet wird.

25. Verfahren nach zumindest einer der vorhergehenden Ansprüche,
d a d u r c h g e k e n n z e i c h n e t ,
dass die Intensitätsänderung und/oder Änderung der spektralen Verteilung des empfangenen Lichts zur Bestimmung der Taschentiefe ausgewertet wird.

26. Verfahren nach zumindest einer der vorhergehenden Ansprüche,
d a d u r c h g e k e n n z e i c h n e t ,
dass zwei bereichsweise aufgeraute optische Leiter in die Tasche eingeführt werden, dass über einen Leiter Licht in die Tasche und über den anderen Leiter in der Tasche reflektiertes Licht zu einem Empfänger geleitet wird.

27. Verfahren nach zumindest einer der vorhergehenden Ansprüche,
d a d u r c h g e k e n n z e i c h n e t ,
dass die optischen Leiter in ihren aufgerauten Bereichen gegeneinander abgeschirmt werden.

28. Verfahren nach zumindest einer der vorhergehenden Ansprüche,
d a d u r c h g e k e n n z e i c h n e t ,
dass das über den optischen Leiter dem Empfänger zugeführtes Licht in Bezug auf das Absorptionsverhalten der Tasche ausgewertet wird.

29. Verfahren nach zumindest einer der vorhergehenden Ansprüche,
d a d u r c h g e k e n n z e i c h n e t ,
dass das Absorptionsverhältnis von Strahlung im Wellenlängenbereich λ_1, λ_2 mit $\lambda_1 \leq 350$ nm und $\lambda_2 > 1500$ nm zur Strahlung im Wellenlängenbereich $\Delta\lambda$ mit $400\text{ nm} \leq \Delta\lambda \leq 1000$ nm bestimmt wird.

30. Verfahren nach zumindest einer der vorhergehenden Ansprüche,
d a d u r c h g e k e n n z e i c h n e t ,
dass Widerstandsänderung eines in die Tasche eingeführten leitenden Messsensors in Abhängigkeit von dessen Eindringtiefe in die Tasche gemessen wird.

31. Verfahren nach zumindest einer der vorhergehenden Ansprüche,
d a d u r c h g e k e n n z e i c h n e t ,
dass ein Messsensor aus elektrisch isolierendem Material mit zueinander beabstandeten Elektrodenabschnitten in Ebenen gleichen Querschnitts des Messsensors in die Tasche eingeführt wird und dass Impedanzänderung zwischen den Elektrodenabschnitten zur Bestimmung der Taschentiefe gemessen wird.

32. Verfahren nach vorzugsweise zumindest einer der vorhergehenden Ansprüche,
d a d u r c h g e k e n n z e i c h n e t ,
dass ein Messsensor aus elektrisch isolierendem Material mit zueinander beabstandeten in Sensorlängsrichtung streifenförmigen Elektrodenabschnitten des Messsensors in die Tasche eingeführt wird und dass Impedanzänderung zwischen den Elektrodenabschnitten zur Bestimmung der Taschentiefe gemessen wird.

33. Verfahren nach Anspruch 31 oder 32,
d a d u r c h g e k e n n z e i c h n e t ,
dass der Messsensor mit einer hydrophoben Beschichtung überzogen ist.

34. Verfahren nach vorzugsweise zumindest einer der vorhergehenden Ansprüche,
d a d u r c h g e k e n n z e i c h n e t ,
dass spektrale Verteilung der empfangenen Strahlung von dem Messgerät zur Ortsbestimmung und/oder Erstreckung von Karies und/oder Zahnstein ausgewertet wird.

35. Verfahren nach vorzugsweise zumindest einer der vorhergehenden Ansprüche,
d a d u r c h g e k e n n z e i c h n e t ,
dass die Unterkieferbewegung gegenüber dem Oberkiefer gemessen wird, wobei ein Positionsbestimmungssensor am Kopf des Patienten und ein weiterer Positionsbestimmungssensor am Unterkiefer befestigt werden.

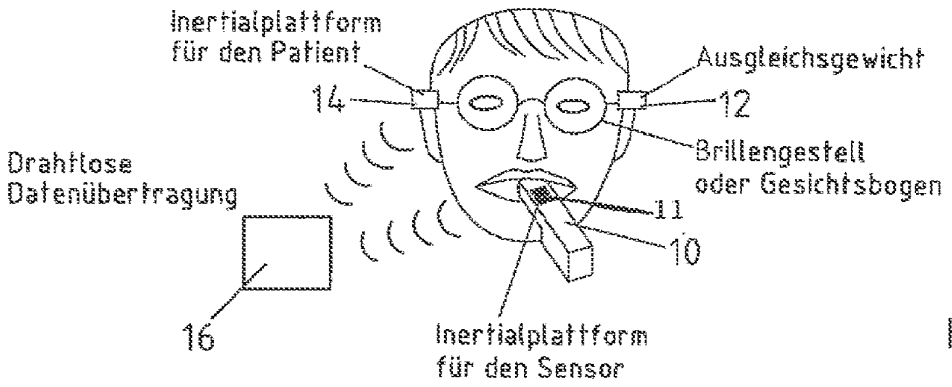

Inertialplattform
für den Patient
14
Ausgleichsgewicht
12
Brillengestell
oder Gesichtsbogen
Drahtlose
Datenübertragung
11
10
16
Inertialplattform
für den Sensor

Fig. 1

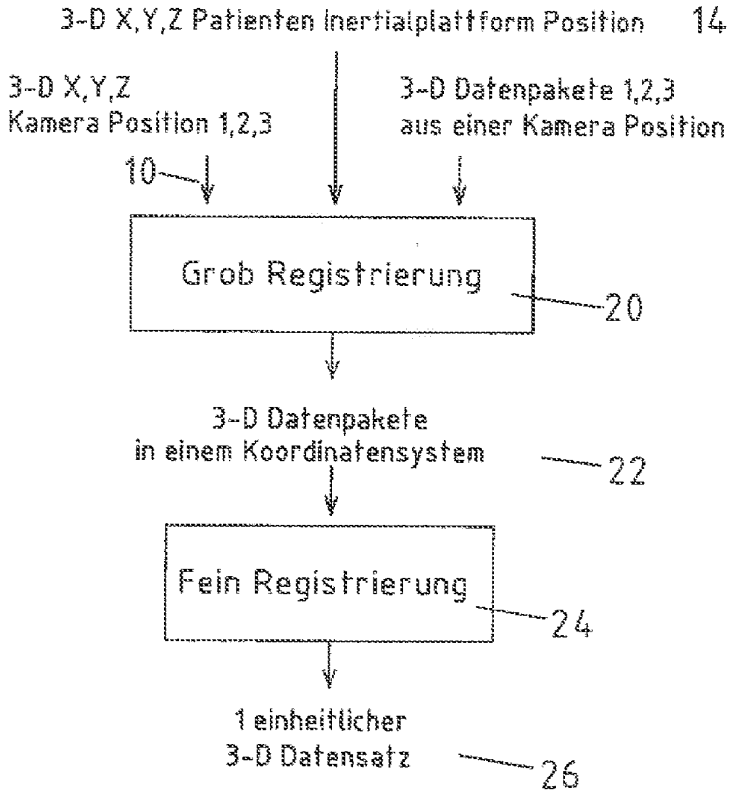

3-D X,Y,Z Patienten Inertialplattform Position
14
3-D X,Y,Z
Kamera Position 1,2,3
10
3-D Datenpakete 1,2,3
aus einer Kamera Position
Grob Registrierung
20
3-D Datenpakete
in einem Koordinatensystem
22
Fein Registrierung
24
1 einheitlicher
3-D Datensatz
26

Fig. 2

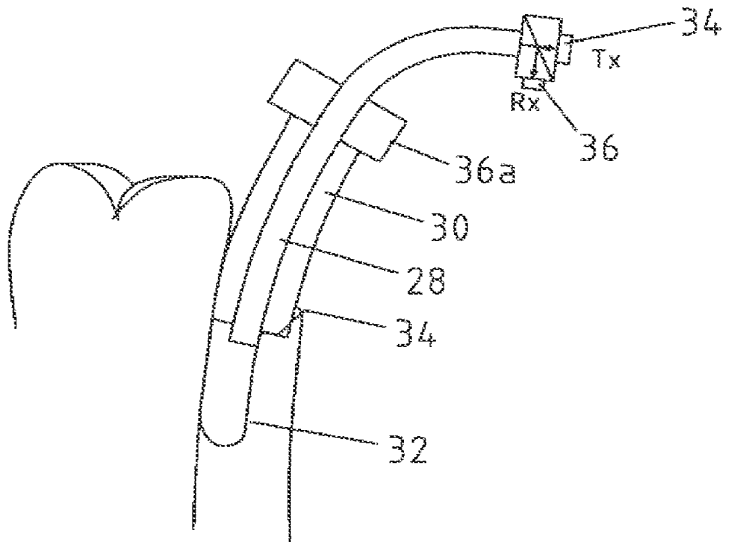


Fig. 3

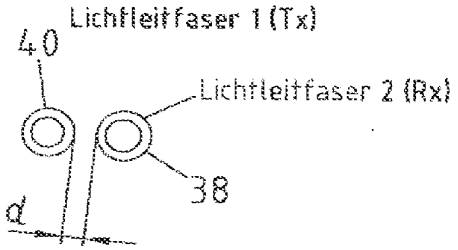


Fig. 4

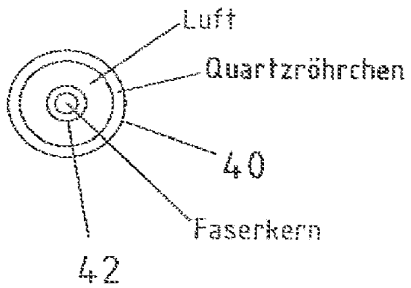


Fig. 5

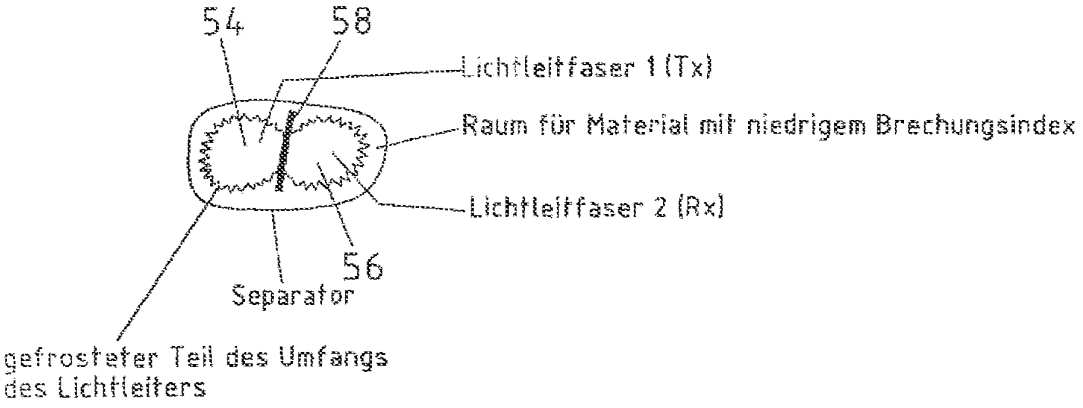

54
58
Lichtleitfaser 1 (Tx)
Raum für Material mit niedrigem Brechungsindex
Lichtleitfaser 2 (Rx)
56
Separator
gefrosteter Teil des Umfangs
des Lichtleiters

Fig. 7

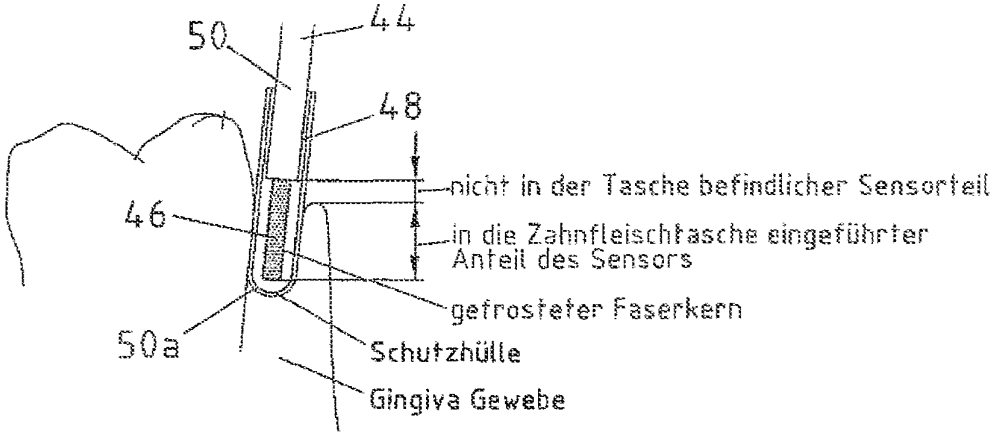

50
44
48
nicht in der Tasche befindlicher Sensorteil
46
in die Zahnfleischtasche eingeführter
Anteil des Sensors
gefrosteter Faserkern
50a
Schutzhülle
Gingiva Gewebe

Fig. 6

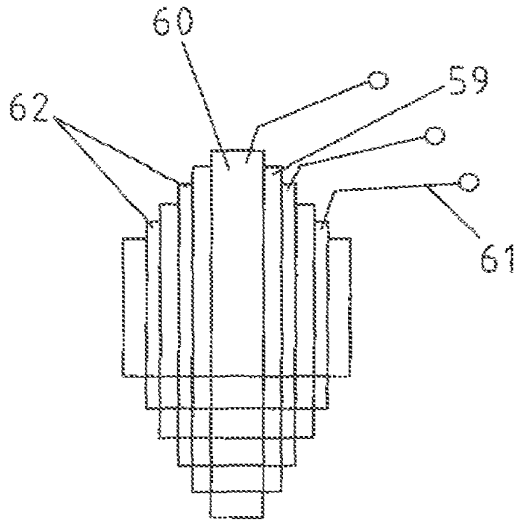


Fig. 8

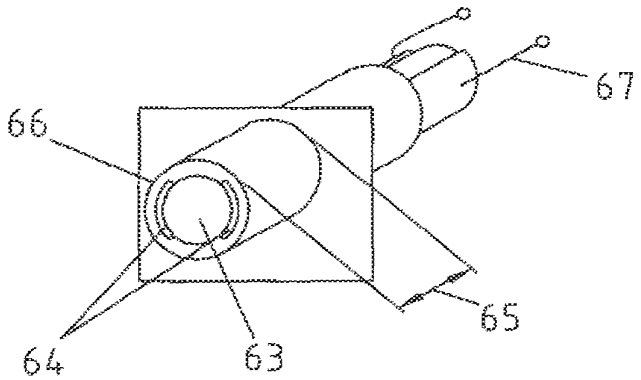


Fig. 9

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2008/062116

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61C1/00 A61C19/04
ADD. A61B19/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
A61B A61C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US 4 673 352 A (HANSEN MARKUS [DE]) 16 June 1987 (1987-06-16) column 3, line 50 - column 5, line 41; claim 1	1,3-6,8, 9,35 10-15, 17,18, 20,25-27
Y	US 5 897 509 A (TODA MASATAKA [JP] ET AL) 27 April 1999 (1999-04-27) column 3, line 13 - column 5, line 45; claim 1	10-15, 17,18, 20,25-27
X	US 6 381 485 B1 (HUNTER MARK W [US] ET AL) 30 April 2002 (2002-04-30) columns 5-7	1,2,5

-/--

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
8 Dezember 2008	18/12/2008

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Chopinaud, Marjorie

Form PCT/ISA/210 (second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2008/062116

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 741 994 A (TRUPPE MICHAEL [AT]) 13 November 1996 (1996-11-13) column 7, lines 11-58; figure 1	1
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2008/062116

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INTERNATIONALER RECHERCHENBERICHT

Internationales Aktenzeichen
PCT/EP2008/062116

A. KLASSIFIZIERUNG DES ANMELDUNGSGEGENSTANDES
INV. A61C1/00 A61C19/04
ADD. A61B19/00

Nach der Internationalen Patentklassifikation (IPC) oder nach der nationalen Klassifikation und der IPC

B. RECHERCHIERTE GEBIETE

Recherchierter Mindestprüfstoff (Klassifikationssystem und Klassifikationssymbole)
A61B A61C

Recherchierte, aber nicht zum Mindestprüfstoff gehörende Veröffentlichungen, soweit diese unter die recherchierten Gebiete fallen

Während der internationalen Recherche konsultierte elektronische Datenbank (Name der Datenbank und evtl. verwendete Suchbegriffe)
EPO-Internal

C. ALS WESENTLICH ANGESEHENE UNTERLAGEN

Kategorie*	Bezeichnung der Veröffentlichung, soweit erforderlich unter Angabe der in Betracht kommenden Teile	Betr. Anspruch Nr.
X Y	US 4 673 352 A (HANSEN MARKUS [DE]) 16. Juni 1987 (1987-06-16) Spalte 3, Zeile 50 - Spalte 5, Zeile 41; Anspruch 1	1,3-6,8, 9,35 10-15, 17,18, 20,25-27
Y	US 5 897 509 A (TODA MASATAKA [JP] ET AL) 27. April 1999 (1999-04-27) Spalte 3, Zeile 13 - Spalte 5, Zeile 45; Anspruch 1	10-15, 17,18, 20,25-27
X	US 6 381 485 B1 (HUNTER MARK W [US] ET AL) 30. April 2002 (2002-04-30) Spalten 5-7	1,2,5

-/--

[X] Weitere Veröffentlichungen sind der Fortsetzung von Feld C zu entnehmen [X] Siehe Anhang Patentfamilie

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"&" Veröffentlichung, die Mitglied derselben Patentfamilie ist

Datum des Abschlusses der internationalen Recherche	Absendedatum des internationalen Recherchenberichts
8. Dezember 2008	18/12/2008

Name und Postanschrift der Internationalen Recherchenbehörde	Bevollmächtigter Bediensteter
Europäisches Patentamt, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Chopinaud, Marjorie

Exhibit 1004 page 615 of 1621
DENTAL IMAGING

C. (Fortsetzung) ALS WESENTLICH ANGESEHENE UNTERLAGEN

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INTERNATIONALER RECHERCHENBERICHT

Angaben zu Veröffentlichungen, die zur selben Patentfamilie gehören

Internationales Aktenzeichen
PCT/EP2008/062116

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[Fortsetzung auf der nächsten Seite]

(54) Title: METHOD FOR OPTICAL MEASUREMENT OF OBJECTS USING A TRIANGULATION METHOD

(54) Bezeichnung: VERFAHREN ZUR OPTISCHEN VERMESSUNG VON OBJEKTEN UNTER VERWENDUNG EINES TRIANGULATIONSVERFAHRENS

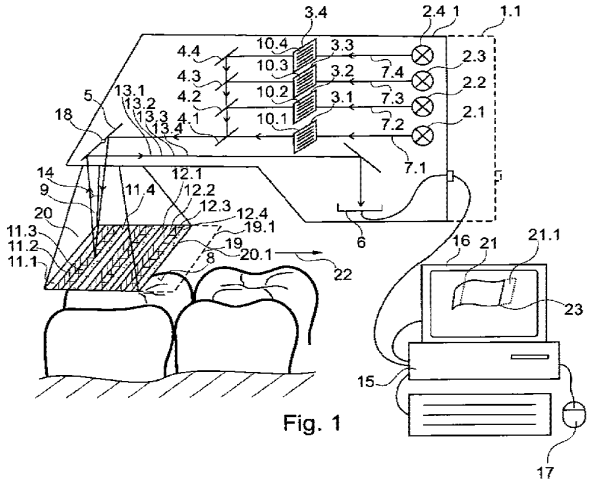


Fig. 1

(57) Abstract: The invention relates to a method for optical measurement of an object using a triangulation method, by means of an optical recording apparatus (1). A first shutter means (3.1) is used to produce a first pattern (11.1) and to project this as a first projection beam (7.1) onto the object (8) to be recorded. At least one further shutter means (3.1-3.4) is used to produce a further pattern (11.2-11.4) and to project this onto the object (8) to be recorded, as a further projection beam (7.2-7.4). The first pattern (11.1) and the further pattern (11.2-11.4) are passed back from the object (8) as observation beams (13.1-13.4) and are recorded by at least one recording means (6, 6.1, 6.2) in order to obtain a 3D data record (21) of the object. The projected first pattern (11.1) and the further pattern (11.2-11.4) are recorded at the same time in at least one triangulation recording (20, 53, 54), using the at least one recording means (6, 6.1, 6.2).

(57) Zusammenfassung: Die Erfindung betrifft ein Verfahren zur optischen Vermessung eines Objekts unter Verwendung eines Triangulationsverfahrens mittels einer optischen Aufnahmevorrichtung (1). Mittels eines ersten Blendenmittels (3.1) wird ein erstes Muster (11.1) erzeugt und auf das aufzunehmende

[Fortsetzung auf der nächsten Seite]

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(84) Bestimmungsstaaten *(soweit nicht anders angegeben, für jede verfügbare regionale Schutzrechtsart)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), eurasisches (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), europäisches (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL, NO, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Erklärung gemäß Regel 4.17:

— *Erfindererklärung (Regel 4.17 Ziffer iv)*

Veröffentlicht:

— *ohne internationalen Recherchenbericht und erneut zu veröffentlichen nach Erhalt des Berichts*

Objekt (8) als ein erster Projektionsstrahl (7.1) projiziert. Mittels mindestens eines weiteren Blendenmittels (3.1-3.4) wird ein weiteres Muster (11.2-11.4) erzeugt und auf das aufzunehmende Objekt (8) als ein weiterer Projektionsstrahl (7.2-7.4) projiziert. Das erste Muster (11.1) und das weitere Muster (11.2-11.4) werden vom Objekt (8) als Beobachtungsstrahlen (13.1-13.4) zurückgestrahlt und von mindestens einen Aufnahmemittel (6, 6.1, 6.2) aufgenommen, um einen 3D-Datensatz (21) des Objekts zu gewinnen. Das projizierte erste Muster (11.1) und das weitere Muster (11.2-11.4) werden in mindestens einer Triangulationsaufnahme (20, 53, 54) unter Verwendung des mindestens einen Aufnahmemittels (6, 6.1, 6.2) gleichzeitig aufgenommen.

Beschreibung

Verfahren zur optischen Vermessung von Objekten unter Verwendung eines Triangulationsverfahrens

Technisches Gebiet

Die Erfindung betrifft ein Verfahren zur optischen Vermessung der dreidimensionalen Geometrie von Objekten und befasst sich mit der Aufgabenstellung der 3D-Vermessung bei relativer Bewegung zwischen der Kamera und dem Objekt während des Messprozesses, insbesondere für zahnmedizinische Zwecke.

Stand der Technik

Durch eine optische 3D-Vermessung eines oder mehrerer Zähne im Mund eines Patienten können digitale Konstruktionsdaten für die rechnergesteuerte Anfertigung von Zahnersatz ohne die Erstellung eines herkömmlichen Abdrucks gewonnen werden.

Für diese Vermessung werden oft Messmethoden verwendet, die auf dem Prinzip der Triangulation basieren. Aus der EP 0 160 797 ist eine Phase-Shifting-Triangulation (Phasenschiebeverfahren) bekannt, bei der aus mehreren Aufnahmen mit einem jeweils von einer Aufnahme zum anderen versetzt angeordneten Raster ein 3D-Datensatz gewonnen wird.

Bei bekannten Triangulationsverfahren wird von einer Projektionseinrichtung ein einzelner gerader Lichtstrich auf das aufzunehmende Objekt aufprojiziert und das projizierte Bild wird unter einem in Beobachtungsrichtung liegenden Parallaxe-Winkel mit einer Kamera aufgenommen, sodass eine Aufnahme vorliegt.

Abhängig von der Oberflächenstruktur des Objekts erscheint der Lichtstrich nicht mehr gerade, sondern gegenüber dem

geraden Verlauf gekrümmt und verschoben. Aus der Lage und aus dem Verlauf des Lichtstrichs kann auf die Oberflächenstruktur des Aufnahmeobjekts geschlossen werden.

Durch ein Verschieben des Lichtstrichs in einer Richtung senkrecht zur Erstreckungsrichtung des Lichtstrichs kann das gesamte Aufnahmeobjekt abgetastet werden, sodass Aufnahmen entstehen. Die aus jeder der Aufnahmen gewonnenen Höheninformationen des Aufnahmeobjekts können in einem zweidimensionalen Raster im Speicher eines Rechners abgespeichert werden, was einer Projektion der Höheninformationen der Oberfläche des Aufnahmeobjekts auf eine Grundfläche als Referenzebene entspricht. Nach dem Messvorgang liegt ein digitales 3-dimensionales Datenmodell des Aufnahmeobjekts vor, welches z.B. auf einem Monitor als Videostandbild dargestellt werden kann.

Aus der Schrift WO 2004/085956 A2 ist ein Verfahren zur Erstellung eines 3-dimensionalen Bildes eines Aufnahmeobjekts bekannt, welches die zuletzt beschriebene Messmethode dahingehend verbessert, dass während einer Aufnahme Pi die Oberflächenstruktur des Aufnahmeobjekts vollständig vermessen wird.

Der Lichtstrich kann z.B. durch schnelles Bewegen des Lichtstrahls eines Lasers während der Dauer einer Aufnahme erzeugt werden, d.h. der Lichtstrich ist eigentlich aus Lichtpunkten aufgebaut. Während einer Aufnahme Pi wird also ein punktförmiger Lichtstrahl eines Lasers entlang eines 2-dimensionalen Lichtstreifenmusters, bei dem zumindest ein Teil der Lichtstreifen im wesentlichen parallel zueinander, also in einer Richtung R1, verlaufen, über das Aufnahmeobjekt geführt. Zwischen den Lichtstreifen ist dabei ein Zwischenraum vorgesehen.

Während einer Aufnahme werden im wesentlichen die Höheninformation des Aufnahmeobjekts entlang mehrerer paralleler, beabstandeter Lichtstreifenstücke oder Striche erfasst.

Damit liegen nach einer Aufnahme bereits die Höheninformationen des Aufnahmeobjekts in einer ersten Gruppe von mehreren, beabstandeten Zeilen des 2-dimensionalen Rasters des zu erstellenden 3D-Datensatzes vor.

Bei den beiden beschriebenen Verfahren der während jeweils einer Aufnahme quasi-statischen Streifenprojektion mit einem Strich pro Aufnahme oder mit mehreren beabstandeten Strichen pro Aufnahme, wie aus der WO 2004/085956 A2 bekannt, werden die mittels der einzelnen Aufnahmen gewonnenen unabhängigen Höheninformationen zu einem Gesamtfeld zusammengeführt, welches die Gesamtheit der gewonnenen 3D-Daten des Aufnahmeobjekts beschreibt bzw. beinhaltet.

Die beschriebenen Messmethoden unter Verwendung von Triangulation haben den Nachteil, dass bedingt durch den Umstand, dass die einzelnen Aufnahmen in zeitlich aufeinanderfolgender Reihenfolge aufgenommen werden und anschließend aus einem Satz von mindestens zwei Aufnahmen eine gesamte Aufnahme zusammengesetzt wird, ein Verwackeln der Aufnahmevorrichtung relativ zum Objekt zwischen den einzelnen Aufnahmen zu Bildfehlern führen kann. Die Aufnahmevorrichtung muss also während der Aufnahme eines Satzes von Aufnahmen gegenüber dem Objekt in ihrer Lage unverändert bleiben und kann erst im nächsten Schritt zur Aufnahme eines nächsten Satzes in ihrer Lage verändert werden. Eine Überflugmessung (on-the-fly-Messung) des Objekts, bei der in kurzen Zeitintervallen mehrere vollständige Aufnahmen vom Objekt aufgenommen werden, ist dadurch unmöglich.

Die sich ergebende Aufgabe besteht also darin, ein Verfahren zur optischen Vermessung von Objekten unter Verwendung

eines Triangulationsverfahrens, insbesondere für zahnmedizinische Zwecke, zur Verfügung zu stellen, welches eine Überflugmessung ermöglicht.

Darstellung der Erfindung

Diese Aufgabe wird durch die im Folgenden angegebenen Merkmale der Erfindung gelöst.

Gemäß der Erfindung wird ein Verfahren zur optischen Vermessung der dreidimensionalen Geometrie eines Objekts unter Verwendung eines Triangulationsverfahrens mittels einer optischen Aufnahmevorrichtung zur Verfügung gestellt. Die Aufnahmevorrichtung umfasst mindestens eine Lichtquelle, mindestens ein Blendenmittel zur Erzeugung von strukturierten Mustern und mindestens ein Aufnahmemittel. Mittels eines ersten Blendenmittels wird ein erstes Muster erzeugt und auf das aufzunehmende Objekt als ein erster Projektionsstrahl projiziert, wobei mittels mindestens eines weiteren Blendenmittels ein weiteres Muster erzeugt wird und auf das aufzunehmende Objekt als ein weiterer Projektionsstrahl projiziert wird, wobei das erste Muster und das weitere Muster vom Objekt als Beobachtungsstrahlen zurückgestrahlt werden und von dem mindestens einen Aufnahmemittel aufgenommen werden, um einen 3D-Datensatz des Objekts zu gewinnen. Das projizierte erste Muster und das weitere Muster in mindestens einer Triangulationsaufnahme werden unter Verwendung des mindestens einen Aufnahmemittels gleichzeitig aufgenommen.

Das bei der vorliegenden Erfindung verwendete Triangulationsverfahren beruht auf dem folgenden Grundprinzip.

Ein bestimmter Messpunkt eines Objekt wird aus einer Richtung von einem Projektionsstrahl beleuchtet und als Beo-

bachtungsstrahl aus einer anderen Richtung durch einen Sensor aufgenommenen.

Dabei erhält man die beiden Winkel zwischen einer Basislänge, die die Lichtquelle mit dem Sensor verbindet, und dem Projektionsstrahl sowie dem Beobachtungsstrahl. Unter Kenntnis der Basislänge kann man dann die Koordinaten des Messpunktes relativ zum Koordinatensystem der Aufnahmevorrichtung bestimmen, die die Lichtquelle und den Sensor umfasst.

Die vorliegende Erfindung verwendet vorteilhafterweise ein Streifenprojektionsverfahren, wobei ein Muster aus parallelen Streifen auf das Objekt projiziert wird und dadurch mehrere Messpunkte gleichzeitig vermessen werden können.

Zur Bestimmung der Koordinate des Messpunktes muss eine Projektionskoordinate bekannt sein, die einem Messpunkt eine Bildkoordinate auf dem Zensor zuordnet. Die Messpunkte müssen also den jeweiligen Streifen zugeordnet sein.

Diese Zuordnung kann durch Abzählen der Streifen erfolgen, indem die Folge von Helligkeitswerte auf den Sensor ausgewertet wird und somit die Nummer des jeweiligen Streifens bestimmt wird.

Diese Zuordnung kann auch durch ein Binär-Kode-Verfahren (z.B. Gray Code) erfolgen, indem jeder Streifen eine binäre Abfolge von Helligkeitswerten enthält, die die Nummer des Streifens repräsentiert. Beim Auswerten dieses binären Kode kann dann die jeweilige Nummer des Streifens bestimmt werden.

Eine höhere Genauigkeit bei der Zuordnung der Projektionskoordinate kann durch das sogenannte Phasenschiebeverfahren (Phase-Shift-Verfahren) erreicht werden, wobei beim Phasenschiebeverfahren die 3D-Daten des Objekts erst nach der

Auswertung von mindestens vier zueinander phasenverschobenen Einzelaufnahmen erzeugt werden können. Die Helligkeitswerte der einzelnen Streifen weisen einen sinusförmigen Verlauf auf, dessen Phase sich in den Mustern der einzelnen Triangulationsaufnahme unterscheidet. Zu jedem Messpunkt ergeben sich demnach mindestens vier Helligkeitswerte aus den einzelnen Triangulationsaufnahmen, woraus nach einem mathematischen Verfahren die Phaselage dieses Messpunktes berechnet werden kann und anschließend aus der Phaselage die Position des Messpunktes auf einer Koordinatenachse senkrecht zu den Streifen bestimmt werden kann.

Der Vorteil der Zuordnung durch das Abzählen und durch das Binär-Kode-Verfahren besteht also darin, dass die 3D-Daten des durch das Muster beleuchteten Messbereichs nach jeder einzelnen Triangulationsaufnahme sofort erzeugt werden können.

Der Vorteil des Phasenschiebeverfahrens ist, dass im Gegensatz zum Abzählen oder zum Binär-Kode-Verfahren ein Messpunkt nicht einem bestimmten Streifen und damit einer diskreten Koordinate zugeordnet wird, sondern eine nicht diskrete Koordinate des Messpunktes bestimmt wird, die auch zwischen zwei Streifen liegen kann. Dadurch wird folglich eine höhere Messgenauigkeit erreicht.

Das Muster kann aus einem einzelnen Streifen oder aus mehreren parallelen Streifen aufgebaut sein.

Die optische Aufnahmevorrichtung kann eine dentale Kamera oder ein sonstiger optischen Aufbau sein.

Die Aufnahmevorrichtung kann mindestens eine Lichtquelle umfassen, die ein herkömmliches Leuchtmittel, eine farbliche LED, eine weiße LED oder ein Laser sein kann. Für das Triangulationsverfahren ist sowohl monochromatische als

auch polychromatisches Licht geeignet. Die Lichtquellen für die einzelnen Muster können sich in ihrer Wellenlänge unterscheiden, damit Sie in einer gemeinsamen Triangulationsaufnahme voneinander getrennt werden können.

Die Aufnahmevorrichtung kann mehrere Blendenmittel zur Erzeugung von strukturierten Mustern umfassen, wobei jedes gen Mittel ein Muster erzeugen kann. Das Blendenmittel kann ein optisches Gitter sein, das strukturierte Schlitze aufweist. Die strukturierten Schlitze können zueinander parallele Streifen sein.

Das aufzunehmende Objekt kann ein beliebiges dreidimensionales Objekt sein, wobei das vorliegende Verfahren insbesondere zur Aufnahme von Zähnen geeignet ist.

Das Licht der Lichtquelle durchstrahlt das Blendenmittel, so dass ein strukturiertes Muster entsteht, welches als ein Projektionsstrahl auf das Objekt projiziert wird. Das Licht des projizierten Musters wird dann vom Objekt als ein Beobachtungsstrahl zurückgestrahlt und von mindestens einem Aufnahmemittel in mindestens einer Triangulationsaufnahme gleichzeitig mit den anderen Mustern aufgenommen. Das Aufnahmemittel kann ein optischer Sensor, insbesondere ein CCD-Sensor, sein. Die projizierten Muster können aus unterschiedlichen Beobachtungsrichtungen in mehreren Triangulationsaufnahmen aufgenommen werden.

Die verschiedenen Muster aus der Triangulationsaufnahme werden getrennt voneinander analysiert und 3D-Daten der Bereiche erzeugt, die von den Mustern erfasst wurden, und anschließend aus den einzelnen 3D-Daten der Muster ein 3D-Datensatz des Objekts zusammengesetzt.

Ein Vorteil des erfinderischen Verfahrens ist, dass die einzelnen auf das Objekt projizierten Muster gleichzeitig

aufgenommen werden. Bei herkömmlichen Verfahren werden die einzelnen Muster in getrennten Aufnahmen in zeitliche Abfolge nacheinander aufgenommen. Dadurch kann die Aufnahmevorrichtung zwischen den Aufnahmen Verwackeln und somit ihre relative Lage zum Objekt ändern. Dieser Verwacklungsfehler kann dann anschließend durch aufwändige computergestützte Verfahren korrigiert werden. Die Gefahr der Verwacklung besteht jedoch wegen der simultanen Aufnahme der Muster beim vorliegenden Verfahren nicht.

Ein weiterer Vorteil des vorliegenden Verfahrens ist, dass eine Überflugmessung (on-the-fly-Messung) ermöglicht wird. Bei den herkömmlichen Verfahren konnte ein bestimmter Messbereich in einem Satz von zeitlich nacheinander folgenden Triangulationsaufnahmen mit versetzten Mustern abgetastet werden, wobei die relativen Lagen der Aufnahmevorrichtung zum Objekt während der Aufnahme eines Satzes möglichst unverändert bleiben sollte. Erst in einem nächsten Schritt konnte ein neuer Messbereich mit einem neuen Satz von Triangulationsaufnahmen aufgenommen werden. Im Gegensatz dazu werden beim vorliegenden Verfahren die Muster eines Satzes gleichzeitig aufgenommen und der Messbereich somit zum gleichen Zeitpunkt vermessen. Im nächsten Schritt kann die Aufnahmevorrichtung relativ zum Objekt bewegt werden und ein benachbarter Messbereich nach einem festgelegten Zeitintervall gleichzeitig aufgenommen werden. Auf diese Weise kann eine Serie von Triangulationsaufnahmen in einer Überflugmessung durchgeführt werden, wobei diese Triangulationsaufnahmen unter Verwendung von computergestützten Methoden zu einer gesamten 3D-Abbildung des Objekts zusammengefügt werden können.

Vorteilhafterweise können das erste Muster und das weitere Muster als Projektionsstrahlen in einer gemeinsamen Projektionsrichtung auf das Objekt projiziert werden.

Die Muster können durch mehrere Blendenmittel erzeugt werden und die Projektionsstrahlen so umgelenkt werden, dass die Muster entlang einer gemeinsamen Projektionsrichtung auf das Objekt projiziert werden. Dadurch kann die Aufnahmevorrichtung kompakter gebaut werden und ein Messbereich des Objekts lückenlos aus einer gemeinsamen Aktionsrichtung erfasst werden.

Vorteilhafterweise können die Beobachtungsstrahlen der Muster aus mindestens zwei Beobachtungsrichtungen aufgenommen werden, wobei die erste Beobachtungsrichtung zu der weiteren Beobachtungsrichtung um einen Winkel versetzt angeordnet ist.

Dadurch können die projizierten Muster aus mehreren Beobachtungsrichtungen gleichzeitig erfasst werden. Der Winkel zwischen den Beobachtungsrichtungen sollte vorteilhafterweise zwischen 20° und 90° betragen. Es ist zu beachten, dass für die Funktionsweise des Triangulationsverfahrens die Streifen des Musters einen Winkel von mindestens 10° zur Triangulationsebene, die durch die Projektionsrichtung und die Beobachtungsrichtung aufgespannt ist, aufweisen sollten.

Vorteilhafterweise können die Beobachtungsstrahlen der Muster mittels mehrerer Aufnahmemittel aus den unterschiedlichen Beobachtungsrichtungen in mehreren einzelnen Triangulationsaufnahmen aufgenommen werden.

Die gleichzeitig projizierten Muster werden folglich von mindestens zwei auseinander liegenden Aufnahmemitteln in mindestens zwei Triangulationsaufnahme erfasst. Durch das

Zusammenführen dieser Triangulationsaufnahmen aus unterschiedlichen Beobachtungsrichtungen wird eine höhere Messgenauigkeit erreicht und insbesondere konkave und konvexe Messbereiche des Objekts können vollständig erfasst werden.

Vorteilhafterweise können die Projektionsstrahlen der Muster aus mindestens zwei verschiedenen Projektionsrichtungen auf das Objekt projiziert werden. Die Beobachtungsstrahlen der Muster werden dabei aus einer einzigen Beobachtungsrichtung aufgenommen, wobei die erste Projektionsrichtung zu der weiteren Projektionsrichtung um einen Winkel versetzt angeordnet ist.

Dadurch werden die Muster aus unterschiedlichen Projektionsrichtungen gleichzeitig auf das Objekt projiziert, so dass die Muster das Objekt aus unterschiedlichen Richtungen erfassen und somit ein vollständigeres Bild des Objekts erzeugt wird. Darüber hinaus müssen die Projektionsstrahlen der unterschiedlichen Muster nicht zu einer gemeinsamen Projektionsrichtung umgelenkt werden.

Vorteilhafterweise können die einzelnen Muster zur Unterscheidung untereinander und zur Identifizierung in der mindestens einen Triangulationsaufnahme codiert sein.

Dadurch können die einzelnen Muster in der Triangulationsaufnahme bei einem Aufnahmemittel aus einer Beobachtungsrichtung oder mehreren Triangulationsaufnahmen bei mehreren Aufnahmemitteln aus unterschiedlichen Beobachtungsrichtungen identifiziert werden und getrennt voneinander analysiert werden.

Vorteilhafterweise können die einzelnen Muster farblich codiert sein, indem das erste Muster eine erste Wellenlänge aufweist und das weitere Muster eine davon abweichende Wellenlänge aufweist, wobei mindestens ein Farbsensor als Auf-

nahmemittel vorhanden ist, dessen Messbereich die Wellenlängen der Muster abdeckt und der eine getrennte Analyse der farblich unterschiedlichen Muster ermöglicht.

Dadurch können die unterschiedlichen Muster gleichzeitig von mindestens einem Farbsensor aufgenommen werden und anhand ihrer Wellenlänge zur getrennten Analyse voneinander unterschieden werden. Das Licht der Muster kann von Lichtquellen unterschiedlicher Wellenlänge ausgestrahlt werden. Dabei kann es sich um monochromatisches Licht mit unterschiedlichen Wellenlängen und um polychromatisches Licht mit unterschiedlichen Spektren handeln.

Vorteilhafterweise können die einzelnen Muster mit einem binären Grauwert-Code versehen sein und anhand dieses Grauwert-Codes die einzelnen Muster in der mindestens einen Triangulationsaufnahme identifiziert werden.

Dadurch können die unterschiedlichen Muster in der gemeinsamen Triangulationsaufnahme identifiziert und getrennt voneinander analysiert werden. Der binäre Grauwert-Code enthält binäre Helligkeitswerte, woraus die Nummer des Musters decodiert werden kann.

Vorteilhafterweise können die Projektionsstrahlen der Muster aus mindestens zwei verschiedenen Projektionsrichtungen auf das Objekt projiziert werden, wobei die Beobachtungsstrahlen der Muster aus mindestens zwei verschiedenen Beobachtungsrichtungen aufgenommen werden.

Dadurch werden die in Muster aus mehreren Projektionsrichtungen auf das Objekt projiziert und der Messbereich des Objekts aus mehreren Beobachtungsrichtungen aufgenommen. Dadurch können mehrere Triangulationsaufnahmen aus verschiedenen Beobachtungsrichtungen erzeugt und überlagert werden, um ein vollständigeres 3D-Modell zu erhalten.

Vorteilhafterweise kann die erste Projektionsrichtung des ersten Musters gegenüber der weiteren Projektionsrichtung des weiteren Musters einen Winkel größer als 10° aufweisen.

Dadurch unterscheiden sich die Projektionsrichtungen um mindestens 10°, so dass die Lichtquellen und die Blendemittel zum Erzeugen der Muster nebeneinander angeordnet werden können.

Vorteilhafterweise kann die erste Beobachtungsrichtung gegenüber der weiteren Beobachtungsrichtung einen Winkel größer als 10° aufweisen.

Dadurch können die Aufnahmemittel, wie CCD-Sensoren, in den Beobachtungsrichtungen nebeneinander angeordnet werden.

Verdachtweise kann die Auswertung der mindestens einen Triangulationsaufnahme nach einem Streifenprojektionsverfahren erfolgen, welches auf dem Triangulationsverfahren beruht.

Beim Streifenprojektionsverfahren ist das Muster aus mehreren parallelen Streifen gebildet, wobei die Streifen vorzugsweise senkrecht zur Triangulationsebene ausgerichtet sind. Die Koordinate des Messpunktes wird mittels der oben genannten Verfahren durch Abzählen der Streifen, durch ein Binär-Kode-Verfahren oder durch ein Phasenschiebeverfahren ermittelt.

Vorteilhafterweise können zusätzlich zu den Triangulationsaufnahmen weiteren Zusatzaufnahmen basierend auf dem Prinzip der Photogrammetrie vom Objekt aus unterschiedlichen Beobachtungsrichtungen aufgenommen werden und bei der Auswertung der Triangulationsaufnahmen berücksichtigt werden.

Bei der Photogrammetrie handelte sich um eine Gruppe von Messmethoden, um aus fotografischen Aufnahmen eines Objekts

aus unterschiedlichen Richtungen seine räumliche Lage und seine dreidimensionale Form zu bestimmen. In der Regel werden hochauflösende digitale Kameras für die fotografischen Aufnahmen verwendet. Die Photogrammetrie ist ein computergestütztes Verfahren, wobei aus den einzelnen fotografischen Aufnahmen durch Mustererkennung und durch die Anwendung der Zentralprojektion 3D-Koordinaten von Objektpunkten ermittelt werden. Die Zusatzaufnahmen werden also aus unterschiedlichen Richtungen aufgenommen und unter Verwendung der Photogrammetrie wird ein zusätzlicher photogrammmetrischer 3D-Datensatz des Objekts erzeugt. Der photogrammmetrische 3D-Datensatz wird mit dem ersten nach dem Triangulationsverfahren erzeugten 3D-Datensatz überlagert, um die Messgenauigkeit zu erhöhen.

Vorteilhafterweise kann sowohl eine Auswertung der Triangulationsaufnahmen nach dem Prinzip der Streifenprojektion als auch eine Auswertung der Zusatzaufnahmen nach dem Prinzip der Photogrammetrie mittels einer Auswerteeinheit erfolgen.

Die Auswertung der Triangulationsaufnahmen nach dem Prinzip der Streifenprojektion sowie der Zusatzaufnahmen nach dem Prinzip der Photogrammetrie können mittels eines Auswertemittels, wie eines Computers, erfolgen.

Vorteilhafterweise können die Aufnahmemittel CCD-Sensoren sein.

Vorteilhafterweise kann die Auswerteeinheit aus den einzelnen Triangulationsaufnahmen 3D-Daten der jeweils erfassten Bereiche des Objekts erzeugt und diese 3D-Daten zu dem gesamten 3D-Datensatz des Objekts zusammensetzt.

Die Auswerteeinheit kann ein Computer sein. Der Messaufbau der optischen Aufnahmevorrichtung ist bekannt, wobei insbe-

sondere die Projektionsrichtungen und die Beobachtungsrichtungen sowie die Basislänge zwischen den Aufnahmemitteln und den Lichtquellen räumlich bekannt sind, so dass unter Verwendung des Triangulationsverfahrens die 3D-Daten aus der Projektion eines Musters mittels der Auswerteeinheit berechnet werden können. Unter Verwendung der Winkeln der Projektionsrichtungen und der Beobachtungsrichtungen der einzelnen Muster zueinander können die 3D-Daten zu einem gemeinsamen 3D-Datensatz zusammengesetzt werden.

Vorteilhafterweise kann eine Anzeigeeinheit vorhanden sein, die den gesamten 3D-Datensatz des Objekts als ein 3D-Modell grafisch anzeigt.

Die Anzeigeeinheit kann ein Computermonitor sein, der den gesamten 3D-Datensatz als ein dreidimensionales Modell darstellen kann.

Vorteilhafterweise können bei der Verwendung des Streifenprojektionsverfahrens die einzelnen Muster aus mehreren parallelen Streifen gebildet sein.

Vorteilhafterweise können die mindestens zwei Triangulationsaufnahmen aus unterschiedlichen Beobachtungsrichtungen analysiert werden, wobei die Triangulationsaufnahmen anhand von übereinstimmenden Bereichen überlagert werden. Als Analyseverfahren zum Auffinden der übereinstimmenden Bereiche wird das ICP-Verfahren oder das Topology-Matching-Verfahren verwendet.

Die auf das Objekt projizierten Muster werden aus unterschiedlichen Beobachtungsrichtungen von beabstandeten Aufnahmemitteln, wie CCD-Sensoren, aufgenommen. Die relative Lage der Aufnahmemittel zueinander und ihre Beobachtungsrichtungen sind bekannt, so dass daraus die Lagebeziehung zwischen den Triangulationsaufnahmen berechnet werden und

diese Triangulationsaufnahmen zu einem gesamten 3D-Datensatz des Objekts zusammengeführt werden.

Alternativ dazu können auch übereinstimmende Bereiche der Muster in den verschiedenen Triangulationsaufnahmen bestimmt werden und anhand dieser übereinstimmenden Bereiche die Triangulationsaufnahmen überlagert werden. Als Analyseverfahren bieten sich das ICP-Verfahren oder das Topology-Matching-Verfahren an.

Das sogenannte ICP-Verfahren (Iterative Closest Point) wird zur Ausrichtung von 3D-Daten mit zumindest in Teilbereichen ähnlicher Form verwendet.

Das Topology-Matching-Verfahren ist ein Verfahren aus der Bildbearbeitung, das zum Vergleich der verschiedenen Topologien MRGs (Multiresolutional Reeb Graphs) verwendet wird. MRGs eignen sich besonders gut als Suchkriterium für ähnliche 3D-Datensätze. Die Berechnung der Ähnlichkeit erfolgt mit diesem Verfahren schnell und effizient, da nach diesem Verfahren die Lageänderung sowie die Rotation nicht berechnet werden muss.

Vorteilhafterweise können die 3D-Daten ausschließlich durch die Analyse der Muster der jeweiligen Triangulationsaufnahme erzeugt werden, wobei die einzelnen Streifen durch das Abzählen der Streifen oder durch ein Binär-Kode-Verfahren identifiziert werden.

Beim Streifenprojektionsverfahren muss die Koordinate eines Messpunktes in den Triangulationsaufnahmen bestimmt werden. Dazu wird einem Messpunkt der jeweilige Streifen zugeordnet, der diesem Messpunkt erfasst hat. Diese Zuordnung kann durch das oben beschriebene Abzählen der Streifen erfolgen, indem die Folge von Helligkeitswerte auf den Sensor ausge-

wertet wird und die Nummer des jeweiligen Streifens somit bestimmt wird.

Diese Zuordnung kann auch durch das oben beschriebene Binär-Kode-Verfahren (z.B. Gray Code) erfolgen, indem jeder Streifen eine binäre Abfolge von Helligkeitswerten enthält, die die Nummer des Streifens repräsentiert. Beim Auswerten dieses binären Kodes kann dann die jeweilige Nummer des Streifens bestimmt werden.

Vorteilhafterweise können die 3D-Daten einer einzelnen Triangulationsaufnahme durch die Analyse von mindestens vier in ihrer Phase unterschiedlichen Mustern in der mindestens einen Triangulationsaufnahme erzeugt werden, wobei ein Phasenschiebeverfahren verwendet wird, um die Koordinate eines Messpunktes zu ermitteln.

Das oben beschriebene Phasenschiebeverfahren (Phase-Shift-Verfahren) erreicht eine höhere Genauigkeit bei der Zuordnung der Projektionskoordinate. Beim Phasenschiebeverfahren werden die 3D-Daten des Objekts erst nach der Auswertung von mindestens vier Einzelaufnahmen von zueinander phasenverschobenen Mustern erzeugt. Die phasenverschobenen Muster werden gleichzeitig auf das Objekt projiziert und in mindestens einer Triangulationsaufnahme aufgenommen. Anschließend werden die einzelnen Muster voneinander separat analysiert. Die Phasenlage der Messpunkte und anschließend ihre Koordinate wird mittels der Auswerteeinheit bestimmt.

Vorteilhafterweise können Projektionsmittel für eine zeitgleiche Projektion von mindestens zwei auf das Objekt projizierten Mustern vorhanden sein.

Diese Projektionsmittel können die Blendenmittel zum erzeugen der Muster und die Umlenkmittel zum Ändern der Projektionsrichtung sein.

Vorteilhafterweise kann in einem ersten Schritt eine erste Gruppe von Mustern in mindestens einer ersten Triangulationsaufnahme unter Verwendung des mindestens einen Aufnahmemittels gleichzeitig aufgenommen werden und in einem weiteren Schritt nach einem festgelegten Zeitintervall eine weitere Gruppe von Mustern in mindestens einer weiteren Triangulationsaufnahme mittels eines weiteren Aufnahmemittels gleichzeitig aufgenommen werden, wobei die Lage der Aufnahmevorrichtung während des Zeitintervalls relativ zum aufzunehmenden Objekt geändert wird.

Es wird folglich eine Überflugmessung (on-the-fly-Messung) durchgeführt. Eine erste Gruppe von Mustern wird gleichzeitig in einer ersten Triangulationsaufnahme aufgenommen, die Aufnahmevorrichtung wird relativ zum Objekt bewegt und eine weitere Gruppe von Mustern wird gleichzeitig in einer weiteren Triangulationsaufnahme aufgenommen. Es werden also Triangulationsaufnahmen in einer zeitlichen Abfolge mit einem festgelegten Zeitintervall aus unterschiedlichen Richtungen aufgenommen.

Vorteilhafterweise kann aus der ersten Gruppe von Mustern in der ersten Triangulationsaufnahme ein erster 3D-Datensatz des Objekts gewonnen werden und aus der weiteren Gruppe von Mustern in der weiteren Triangulationsaufnahme ein weiterer 3D-Datensatz des Objekts gewonnen werden. Anschließend wird der erste 3D-Datensatz und der weitere 3D-Datensatz zu einer gemeinsamen 3D-Abbildung des Objekts zusammengefügt.

Kurzbeschreibung der Zeichnung

Ausführungsbeispiele der Erfindung sind in den Zeichnungen dargestellt. Es zeigt die

Fig. 1 eine Skizze des erfinderischen Verfahrens, umfassend eine dentale intraorale Kamera als eine Aufnahmevorrichtung zu Vermessung mit einer Projektionseinrichtung und einer Beobachtungsrichtung,

Fig.2A eine schematischen Skizze der Aufnahmevorrichtung wie in Fig. 1 in seitliche Ansicht mit einer gemeinsamen Projektionsrichtung von zwei Mustern und einer Beobachtungsrichtung,

Fig. 2B eine schematische Skizze in der Draufsicht der Aufnahmevorrichtung aus Fig. 1 mit einer gemeinsamen Projektionsrichtung von zwei Mustern und einer Beobachtungsrichtung,

Fig. 3 eine schematische Skizze in der Draufsicht mit zwei unterschiedlichen Projektionsrichtungen und einer Beobachtungsrichtung,

Fig. 4 eine schematische Skizze in der Draufsicht mit einer Projektionsrichtung und mit zwei unterschiedlichen Beobachtungsrichtungen,

Fig. 5 eine schematische Skizze in der Draufsicht mit zwei Projektionsrichtungen und mit zwei im Beobachtungsrichtungen.

Fig. 6 eine Skizze eines projizierten Musters auf einem unebenen Objekt bei zwei unterschiedlichen Beobachtungsrichtungen zur Verdeutlichung der Überlagerung von Triangulationsaufnahmen unter Verwendung übereinstimmender Bereiche,

Fig. 7 eine Skizze zur Verdeutlichung der Überflugmessung mit Triangulationsaufnahmen aus unterschiedlichen Richtungen.

Ausführungsbeispiele der Erfindung

Die Fig. 1 zeigt eine Skizze zur Verdeutlichung des erfinderischen Verfahrens. Als eine Aufnahmevorrichtung 1 wird eine intraorale dental Kamera verwendet, die vier Lichtquellen 2.1, 2.2, 2.3, 2.4, vier Blendenmittel 3.1, 3.2, 3.3, 3.4, vier Umlenkmittel 4.1, 4.2, 4.3, 4.4, einen Spiegel 5 und einen CCD-Sensor 6 als ein Aufnahmemittel aufweist. Die Lichtquellen 2.1, 2.2, 2.3, 2.4 senden Projektionsstrahlen 7.1, 7.2, 7.3, 7.4 aus, die die als Gitter 3.1, 3.2, 3.3, 3.4 ausgebildeten Blendenmittel durchleuchten, durch Umlenkmittel 4.1, 4.2, 4.3, 4.4 zum Spiegel 5 umgelenkt werden und vom Spiegel 5 auf ein aufzunehmendes Objekt 8, nämlich die Oberfläche eines Zahns, umgelenkt werden. Die Umlenkmittel 4.2, 4.3, 4.4 lenken die Projektionsstrahlen 7.2, 7.3, 7.4 dabei vollständig um, wobei das Umlenkmittel 4.1 halbtransparent ist und den Projektionsstrahl 7.1 durchlässt und die umgelenkten Projektionsstrahlen 7.2, 7.3 und 7.4 teilweise zum Spiegel 5 umlenkt. Die als optische Gitter 3.1, 3.2, 3.3, 3.4 ausgebildeten Blendenmittel weisen zur Triangulationsebene 9 senkrecht angeordnete Schlitze 10.1, 10.2, 10.3, 10.4 auf, so dass beim Durchstrahlen der Gitter 3.1, 3.2, 3.3, 3.4 strukturierte Muster 11.1, 11.2, 11.3, 11.4 erzeugt werden und auf das Objekt 8 projiziert werden. Die Muster 11.1, 11.2, 11.3, 11.4 sind aus parallel zueinander angeordneten Streifen 12.1, 12.2, 12.3, 12.4 aufgebaut. Zur Verdeutlichung sind die parallelen Streifen 12.1 des ersten Musters 11.1 ohne Strichelung dargestellt, die parallelen Streifen 12.2 des zweiten Musters 11.2 mit einfacher Strichelung dargestellt,

die parallelen Streifen 12.3 des dritten Musters 11.3 mit einer gekreuzten Strichelung und die parallelen Streifen 12.4 des vierten Musters 11.4 gepunktet dargestellt. Die vier strukturierten Muster 11.1, 11.2, 11.3, 11.4 sind schematisch dargestellt und entsprechen nicht den realistischen Projektionen der Lichtstreifen 12.1, 12.2, 12.3, 12.4 auf das aufzunehmende Objekt 8, sondern verdeutlicht lediglich die Anordnung der Muster 11.1, 11.2, 11.3, 11.4 zueinander sowie die Richtung der Projektion. Die Projektionsstrahlen 7.1, 7.2, 7.3, 7.4 werden von der Oberfläche des aufzunehmenden Objekts 8 reflektiert und als Beobachtungsstrahlen 13.1, 13.2, 13.3, 13.4 in einem gemeinsamen Strahlengang zurückgestrahlt und zum CCD -Sensor 6 umgeleitet und von diesem detektiert. Die Triangulationsebene 9 wird von den Projektionsstrahlen 7.1, 7.2, 7.3, 7.4 und den Beobachtungsstrahlen 13.1, 13.2, 13.3, 13.4 aufgespannt. Die Projektionsstrahlen 7.1, 7.2, 7.3, 7.4 weisen zu den zurückgestrahlten Beobachtungsstrahlen 13.1, 13.2, 13.3, 13.4 einen sogenannten Triangulationswinkel 14 auf. Die mittels des CCD-Sensors 6 aufgenommenen Bilddaten werden an einen Computer als Auswerteeinheit 15 weitergeleitet, der einen Monitor als Anzeigeeinheit 16 und eine Tastatur und eine Computermaus als Bedienungseinheiten 17 aufweist.

Beim vorliegenden Verfahren ist der Spiegel 5 nicht verstellbar und die Muster 11.1, 11.2, 11.3, 11.4 werden gleichzeitig auf das Objekt 8 projektiert, wobei die einzelnen Muster 11.1, 11.2, 11.3, 11.4 um eine Streifenbreite zueinander verschoben sind und die Oberfläche des zu vermessenden Objekts 8 innerhalb eines rechteckförmigen Messbereichs 19 lückenlos erfasst wird. Die Beobachtungsstrahlen 13.1, 13.2, 13.3, 13.4 der einzelnen Muster 11.1, 11.2, 11.3, 11.4 werden vom CCD-Sensor gleichzeitig in einer ers-

ten gemeinsamen Triangulationsaufnahme 20 aufgenommen. Die einzelnen Muster 11.1, 11.2, 11.3, 11.4 sind zur Unterscheidung untereinander codiert, indem das erste Muster 11.1 eine erste Wellenlänge, das zweite Muster 11.2 eine zweite Wellenlänge, das dritte Muster 11.3 eine dritte Wellenlänge und das vierte Muster 11.4 eine vierte Wellenlänge aufweist. Der CCD-Sensor ist dabei so ausgelegt, dass sein Messbereich die Wellenlängen der Muster 11.1, 11.2, 11.3, 11.4 abdeckt und eine getrennte Analyse ermöglicht. Die Bilddaten der ersten Triangulationsaufnahme 20 werden an die Auswerteinheit 15 weitergeleitet und dort die Projektionen der einzelnen Muster 11.1, 11.2, 11.3, 11.4 getrennt voneinander analysiert und mittels des Triangulationsverfahrens 3D-Daten der erfassten Bereiche berechnet. Bei der Berechnung der 3D-Daten mittels des Triangulationsverfahrens werden die Koordinaten der Messpunkte relativ zum Koordinatensystem der Aufnahmevorrichtung aus dem bekannten Betrag einer Basislänge sowie den bekannten Winkeln des Projektionsstrahls zur Basislänge und des Beobachtungsstrahls zur Basislänge berechnet, wobei die Basislänge eine Verbindungsstrecke zwischen den Lichtquellen 2.1, 2.2, 2.3, 2.4 und dem CCD-Sensor 6 ist, falls der Projektionsstrahl und der Beobachtungsstrahl geradlinig verlaufen.

Die mittels der Auswerteinheit 15 ermittelten 3D-Daten der einzelnen Muster 11.1, 11.2, 11.3, 11.4 werden zu einem gesamten 3D-Datensatz zusammengesetzt, der in der Anzeigevorrichtung 16 als ein 3D-Modell 21 der innerhalb des Messbereichs 19 aufgenommenen Oberfläche des Objekts 8 angezeigt wird.

Bei herkömmlichen Triangulationsmessverfahren werden die Projektionen der unterschiedlichen Muster in zeitlicher Abfolge nacheinander in mehreren Aufnahmen aufgenommen. Da-

durch entstehen beim Verwackeln der Aufnahmevorrichtung zwischen den Aufnahmen Bildfehler. Beim vorliegenden Verfahren sind solche Bildfehler jedoch ausgeschlossen, da die Muster 11.1, 11.2, 11.3, 11.4 in einer gemeinsamen Triangulationsaufnahme gleichzeitig aufgenommen werden. Dies ermöglicht eine Überflugmessung (On-the-fly-Messung), wobei nach der ersten Triangulationsaufnahme 20 die Aufnahmevorrichtung 1 in Richtung 22 zu einer zweiten Position 1.1 bewegt wird und in einer zweiten Triangulationsaufnahme 20.1 ein benachbarter Bereich der Oberfläche des Objekts 8 innerhalb eines in die Richtung 22 verschobenen Messbereichs 19.1 aufgenommen wird. Aus der ersten Triangulationsaufnahme wird der erste 3D-Datensatz und aus der zweiten Triangulationsaufnahme 20.1 wird ein zweiter 3D-Datensatz erzeugt. Der zweite 3D-Datensatz wird ebenfalls in der Anzeigevorrichtung als ein 3D-Modell 21.1, das gestrichelt dargestellt ist, mittels der Anzeigevorrichtung 16 angezeigt. Der erste 3D-Datensatz 21 wird mit dem zweiten 3D-Datensatz 21.1 zu einer gemeinsamen 3D-Abbildung 23 zusammengefügt, die mittels der Anzeigevorrichtung 16 angezeigt wird. Bei der Überflugmessung werden in festgelegten Zeitintervallen Triangulationsaufnahmen solange durchgeführt, bis das gesamte aufzunehmende Objekt 8 lückenlos erfasst ist.

Die Figur 2A zeigt eine schematische Skizze der Aufnahmevorrichtung 1 wie in Fig. 1, wobei die Projektionsstrahlen 7.1, 7.2 der Muster 11.1 und 11.2 entlang einer gemeinsamen Projektionsrichtung 30 auf das Objekt 8 projiziert werden und die Beobachtungsstrahlen 13.1 und 13.2 in einer gemeinsamen Beobachtungsrichtung 31 vom CCD-Sensor 6 aufgenommen werden. Die Muster 11.1 und 11.2 werden von den Blendenmitteln 10.1 und 10.2 erzeugt und mittels der Umlenkmittel 4.1, 4.2 so umgelenkt, dass die Muster entlang einer ge-

meinsamen Projektionsrichtung 30 auf das Objekt 8 projiziert werden. Dies hat den Vorteil, dass die Auffangvorrichtung 1 kompakter gebaut werden kann und dass der Messbereich 19 lückenlos aus Mustern 11.1 und 11.2 mit gemeinsamer Projektionsrichtung erfasst werden kann. Zur schematischen Vereinfachung sind nur zwei Muster dargestellt. Die Anzahl der Muster kann jedoch beliebig abhängig von der gewünschten Auflösung erhöht werden.

Die Figur 2B zeigt den schematischen Aufbau aus Fig. 2A in der Draufsicht. Die Muster 11.1 und 11.2 werden auf das Objekt 8 projiziert und bilden Projektionen in Form von zueinander parallelen Streifen 12.1 und 12.2. Anschließend werden die Muster in einer gemeinsamen Triangulationsaufnahme 20 aus Fig. 1 mittels des CCD-Sensors 6 in der gemeinsamen Beobachtungsrichtung 31 aufgenommen.

Die Fig. 3 zeigt den schematischen Aufbau in der Draufsicht. Die Muster 11.1 und 11.2 als Projektionsstrahlen 7.1 und 7.2 entlang unterschiedlicher Projektionsrichtungen 40 und 41 auf das Objekt 8 innerhalb des Messbereichs 19 als parallele Streife 12.1 und 12.2 projiziert werden. Die Beobachtungsstrahlen 13.1 und 13.2 der projizierten parallelen Streifen 12.1 und 12.2 werden entlang einer gemeinsamen Beobachtungsrichtung 31 mittels des CCD-Sensors 6 aufgenommen. Die erste Projektionsrichtung 40 weist zur zweiten Projektionsrichtung 41 einen Winkel 42 auf. Dadurch wird das Objekt 8 aus unterschiedlichen Projektionsrichtungen 40 und 41 gleichzeitig erfasst und somit ein vollständigeres Bild des Objekts erzeugt. Die Projektionsstrahlen 7.1 und 7.2 müssen also nicht wie in Fig. 1, Fig. 2 und Fig. 2B in aufwendiger Weise zur einer gemeinsamen Projektionsrichtung 30 umgelenkt werden.

Die Fig. 4 zeigt in schematischer Weise eine weitere Ausführungsform in der Draufsicht, wobei die Projektionsstrahlen 7.1, 7.2 der Muster 11.1, 11.2 entlang einer gemeinsamen Projektionsrichtung 30 auf das Objekt 8 innerhalb eines Messbereichs 19 als parallele Streifen 12.1, 12.2 projiziert werden und anschließend die parallelen Streifen 12.1, 12.2 mittels eines ersten CCD-Sensors 6.1 in einer ersten Beobachtungsrichtung 50 und mittels eines zweiten CCD-Sensors 6.2 in einer zweiten Beobachtungsrichtung 51 aufgenommen werden. Die erste Beobachtungsrichtung 50 weist zur zweiten Beobachtungsrichtung 51 einen Winkel 52 auf. Der Winkel 52 kann größer als 10° sein, so dass die CCD-Sensoren 6.1 und 6.2 nebeneinander angeordnet werden können. Der Vorteil dieser Ausführungsform ist, dass die parallelen Streifen 12.1 und 12.2 aus zwei verschiedenen Beobachtungsrichtungen 50 und 51 gleichzeitig aufgenommen werden und insbesondere bei einer unebenen Oberfläche des Objekts 8 durch Überlagerung einer mittels des ersten CCD-Sensors 6.1 aufgenommen Triangulationsaufnahme 53 und einer zweiten mittels des zweiten CCD-Sensors 6.2 aufgenommenen Triangulationsaufnahme 54 erstellt werden kann.

Ergänzend zu den Triangulationsaufnahme 53 und 54 werden aus den Beobachtungsrichtungen 55 und 56 weitere Zusatzaufnahmen 57 und 58 aufgenommen, die auf dem Prinzip der Photogrammetrie basieren. Dabei werden die gleichen CCD-Sensoren 6.1 und 6.2 verwendet, die neben dem Streifenmuster für die Triangulationsaufnahmen auch fotografische Aufnahmen des Objekts 8 registrieren können. Die Auflösung der CCD-Sensoren 6.1 und 6.2 muss für fotografische Aufnahmen geeignet sein. Die fotografischen Zusatzaufnahmen 57, 58 des Objekts aus den beiden Beobachtungsrichtungen 55, 56 werden mittels der Auswerteeinheit 15 aus Fig. 1 unter Ver-

wendung computergestützter Verfahren, wie der Mustererkennung und der Zentralprojektion, ausgewertet und ein photogrammetrischer 3D-Datensatz des Objekts 8 ermittelt. Der aus den Zusatzaufnahmen 57 und 58 erzeugte photogrammmetrische 3D-Datensatz wird mit dem ersten nach dem Triangulationsverfahren erzeugten 3D-Datensatz überlagert und somit die Messgenauigkeit erhöht.

Die Fig. 5 zeigt den schematischen Aufbau einer weiteren Ausführungsform in der Draufsicht, wobei die Projektionsstrahlen 7.1, 7.2 der Muster 11.1, 11.2 entlang unterschiedlicher Projektionsrichtungen 40, 41 auf das Objekt 8 innerhalb des Messbereichs 19 projiziert werden und anschließend die projizierten parallelen Streifen 12.1, 12.2 entlang einer ersten Beobachtungsrichtung 50 und einer zweiten Beobachtungsrichtung 51 mittels der CCD-Sensoren 6.1 und 6.2 aufgenommen werden. Die erste Projektionsrichtung 40 weist den Winkel 42 zur zweiten Projektionsrichtung 41 auf und die erste Beobachtungsrichtung 50 weist zur zweiten Beobachtungsrichtung 51 den Winkel 52 auf.

Bei den Ausführungsformen aus Fig. 1, Fig. 2A, Fig. 2B und Fig. 4 werden die Projektionsstrahlen 7.1, 7.2 entlang einer gemeinsamen Projektionsrichtung auf das Objekt 8 projiziert. Im Gegensatz dazu werden bei der Ausführungsform aus Fig. 3 und Fig. 5 die Projektionsstrahlen 7.1, 7.2 entlang unterschiedlicher Projektionsrichtungen 40, 41 auf das Objekt 8 projiziert, so dass der Abstand der Aufnahmevorrichtung 1 und somit der Blendemittel 3.1, 3.2 zur Oberfläche des Objekts 8 die Anordnung der parallelen Streifen 12.1 und 12.2 zueinander beeinflusst. Die Blendemittel 3.1, 3.2 sowie der übrige optische Aufbau der Aufnahmevorrichtung 1 müssen so angeordnet sein, dass bei einem für die Aufnahme festgelegten Abstand zwischen der Aufnahmevorrichtung und

der Oberfläche des Objekts 8 die Streifen 12.1, 12.2 sich nicht überlagern sondern die Oberfläche des Objekts 8 innerhalb des Messbereichs 19 wie dargestellt lückenlos abtasten. Bei den Ausführungsformen aus Fig. 1, Fig. 2A, Fig. 2B und Fig. 4 mit einer einzigen Projektionsrichtung 30 stellt sich diese technische Problem nicht, da die relative Lage der parallelen Streifen 12.1 zu den parallelen Streifen 12.2 sich in Abhängigkeit von Abstand zwischen der Aufnahmevorrichtung 1 und der Oberfläche des Objekts 8 nicht ändert.

Es werden ergänzend zu den beiden Triangulationsaufnahmen 53 und 54 fotografische Zusatzaufnahmen 57, 58 aufgenommen, aus denen wie in Fig. 4 ein photogrammetrischer 3D-Datensatz erzeugt und mit der ersten 3D-Datensatz 21 aus Fig.1 zur Verbesserung der Messgenauigkeit überlagert wird.

Die Fig. 6 zeigt eine Skizze der projizierten Muster 11.1 und 11.2 auf einer unebenen Oberfläche des Objekts 8 innerhalb des Messbereichs 19. Zur Verdeutlichung sind nur die parallelen Streifen 12.1 des ersten Musters dargestellt. Die Streifen 12.1 des ersten Musters 11.1 werden, wie in der Ausführungsform aus Fig. 4 und Fig. 5, aus einer ersten Beobachtungsrichtung 50 mittels des erstens CCD-Sensors 6.1 und aus einer zweiten Beobachtungsrichtung 51 mittels des zweiten CCD-Sensors 6.2 aufgenommen. Aus den Bilddaten des Sensors 6.1 wird die erste Triangulationsaufnahme 53 und aus den Bilddaten des zweiten CCD-Sensors 6.2 eine zweite Triangulationsaufnahme 54 erzeugt. Mittels der Auswerteeinheit 15 aus Fig. 1 werden die beiden Triangulationsaufnahmen 53 und 54 überlagert und zu einer gemeinsamen 3D-Abbildung 23 aus Fig.1 zusammengefügt. Die Lagebeziehung der ersten Triangulationsaufnahme 53 zur zweiten Triangulationsaufnahme 54 kann anhand der relativen Lage der Aufnah-

memittel 6.1, 6.2 zueinander und ihrer Beobachtungsrichtungen 50, 51 berechnet werden.

Alternativ dazu können die Triangulationsaufnahmen 53 und 54 auch anhand übereinstimmender Bereiche der projizierten Muster 11.1 und 11.2 überlagert werden. In der ersten Beobachtungsrichtung 50 sind die Bereiche der parallelen Streifen 12.1 zwischen den Positionen 60 und 61 aufgrund der Geometrieoberfläche des Objekts 8 nicht sichtbar. In der zweiten Beobachtungsrichtung 51 sind die Bereiche der parallelen Streifen 12.1 zwischen den Positionen 62 und 63 nicht sichtbar. Die beiden Triangulationsaufnahmen 53 und 54 müssen also überlagert und zusammengeführt werden, um ein vollständiges Bild der Oberfläche des Objekts 8 zu erhalten. Die erste Triangulationsaufnahme 53 und die zweite Triangulationsaufnahme 54 weisen übereinstimmende Bereiche 64 auf, die gestrichelt dargestellt sind. Diese übereinstimmende Bereiche 54 können in den Triangulationsaufnahmen 53 und 54 mit computergestützten Analyseverfahren ermittelt werden und anhand dieser übereinstimmender Bereiche 64 die Triangulationsaufnahmen 53 und 54 überlagert werden. Als computergestützte Analyseverfahren kommen das sogenannte ICP-Verfahren oder das Topology-Matching-Verfahren Verfahren in Frage.

Die Fig. 7 zeigt eine schematische Darstellung zur Verdeutlichung einer Überflugmessung (On-the-fly-Messung). Im dargestellten Fall ist das zu vermessende Objekt 8 eine Zahnreihe bestehend aus drei Zähnen, wobei eine erste Triangulationsaufnahme 20 aus einer ersten Projektionsrichtung 30 aufgenommen wird, die Aufnahmevorrichtung 1 in die Richtung 22 zu einer zweiten Position 1.1, wie in Fig. 1, geschwenkt wird, wobei die Richtung 22 einen bogenförmigen Verlauf aufweist, nach einem festgelegten Zeitintervall aus der

zweiten Position 1.1 der Aufnahmevorrichtung eine zweite Triangulationsaufnahme 20.1 in einer zweien Projektionsrichtung 30.1 aufgenommen wird, die Aufnahmevorrichtung zu einer dritten Position 1.2 geschwenkt wird, eine dritte Triangulationsaufnahme 20.2 in einer dritten Projektionsrichtung 30.2 aufgenommen wird die Aufnahmevorrichtung zu einer vierten Position 1.3 in einer Richtung 22.2 geschenkt wird, eine vierte Triangulationsaufnahme 20.3 in einer vierten Projektionsrichtung 30.3 vom Objekt 8 aufgenommen wird, und schließlich die Aufnahmevorrichtung in eine fünfte Position 1.4 geschwenkt wird und eine fünfte Triangulationsaufnahme 20.4 in einer fünften Projektionsrichtung 30.4 vom Objekt 8 aufgenommen wird. Die aus den Triangulationsaufnahmen 20, 20.1, 20.2, 20.3, 20.4, wie oben zu Fig. 1 beschrieben, erzeugten 3D-Datensätze werden zu einer gemeinsamen 3D-Abbildung 23 zusammengefügt, die die 3D-Daten des gesamten aufzunehmenden Objekts 8 lückenlos enthält. Die Überflugmessung kann solange fortgeführt werden, bis das gesamte aufzunehmende Objekt 8 lückenlos erfasst ist. Die Triangulationsaufnahmen 20, 20.1, 20.2, 20.3, 20.4 werden anhand der übereinstimmenden Bereiche mittels eines computergestützten Analyseverfahrens zusammengeführt. Als ein Analyseverfahren können die oben genannten ICP-Verfahren und das Topology-Matching-Verfahren verwendet werden.

Bezugszeichenliste

1	Aufnahmevorrichtung
1.1-1.3	Position
2.1-2.4	Lichtquellen
3.1-3.4	Blendenmittel
4.1-4.4	Umlenkmittel
5	Spiegel
6	CCD-Sensor
6.1	CCD-Sensor
6.2	CCD-Sensor
7.1-7.4	Projektionsstrahlen
8	Objekt
9	Triangulationsebene
10.1-10.4	Schlitze
11.1-11.4	Muster
12.1-12.4	Streifen
13.1-13.4	Beobachtungsstrahlen
14	Triangulationswinkel
15	Auswerteeinheit
16	Anzeigevorrichtung
17	Bedienungeseinheit
19	Messbereich
20	Triangulationsaufnahme
20.1-20.4	Triangulationsaufnahme
21	3D-Modell, 3D-Datensatz

21.1 3D-Modell, 3D-Datensatz

22 Richtung

22.2 Richtung

23 gemeinsamen 3D-Abbildung

30 Projektionsrichtung

30.1-30.4 Projektionsrichtung

31 Beobachtungsrichtung

40 Projektionsrichtung

41 Projektionsrichtung

42 Winkel zwischen den Projektionsrichtungen

50 Beobachtungsrichtung

51 Beobachtungsrichtung

52 Winkel zwischen den Beobachtungsrichtungen

53 Triangulationsaufnahme

54 Triangulationsaufnahme

60 Position am Streifen

61 Position am Streifen

62 Position am Streifen

63 Position am Streifen

Ansprüche

1. Verfahren zur optischen Vermessung der dreidimensionalen Geometrie eines Objekts unter Verwendung eines Triangulationsverfahrens mittels einer optischen Aufnahmevorrichtung (1) umfassend mindestens eine Lichtquelle (2.1-2.4), mindestens ein Blendenmittel (3.1-3.4) zur Erzeugung von strukturierten Mustern (11.1-11.4) und mindestens ein Aufnahmemittel (6, 6.1, 6.2), wobei mittels eines ersten Blendenmittels (3.1) ein erstes Muster (11.1) erzeugt wird und auf das aufzunehmende Objekt (8) als ein erster Projektionsstrahl (7.1) projiziert wird, wobei mittels mindestens eines weiteren Blendenmittels (3.1-3.4) ein weiteres Muster (11.2-11.4) erzeugt wird und auf das aufzunehmende Objekt (8) als ein weiterer Projektionsstrahl (7.2-7.4) projiziert wird, wobei das erste Muster (11.1) und das weitere Muster (11.2-11.4) vom Objekt (8) als Beobachtungsstrahlen (13.1-13.4) zurückgestrahlt werden und von dem mindestens einen Aufnahmemittel (6, 6.1, 6.2) aufgenommen werden, um einen 3D-Datensatz (21) des Objekts zu gewinnen, **dadurch gekennzeichnet, dass** das projizierte erste Muster (11.1) und das weitere Muster (11.2-11.4) in mindestens einer Triangulationsaufnahme (20, 53, 54) unter Verwendung des mindestens einen Aufnahmemittels (6, 6.1, 6.2) gleichzeitig aufgenommen werden.

2. Verfahren nach Anspruch 1, dadurch gekennzeichnet, dass das erste Muster (11.1) und das weitere Muster (11.2-11.4) als Projektionsstrahlen (7.1-7.4) in einer gemeinsamen Projektionsrichtung (30) auf das Objekt (8) projiziert werden.

3. Verfahren nach Anspruch 1 oder 2, dadurch gekennzeichnet, dass die Beobachtungsstrahlen (13.1-13.4) der Mus-

ter (11.1-11.4) aus mindestens zwei Beobachtungsrichtungen (50, 51) aufgenommen werden, wobei die erste Beobachtungsrichtung (50) zu der weiteren Beobachtungsrichtung (51) um einen Winkel (52) versetzt angeordnet ist.

4. Verfahren nach Anspruch 3, dadurch gekennzeichnet, dass die Beobachtungsstrahlen (50, 51) der Muster (11.1-11.4) mittels mehrerer Aufnahmemittel (6.1, 6.2) aus den unterschiedlichen Beobachtungsrichtungen (50, 51) in mehreren einzelnen Triangulationsaufnahmen (53, 54) aufgenommen werden.

5. Verfahren nach einem der Ansprüche 1 bis 4, dadurch gekennzeichnet, dass die Projektionsstrahlen (7.1-7.4) der Muster (11.1-11.4) aus mindestens zwei verschiedenen Projektionsrichtungen (41, 42) auf das Objekt (8) projiziert werden und dass die Beobachtungsstrahlen (13.1-13.4) der Muster (11.1-11.4) aus einer einzigen Beobachtungsrichtung (31) aufgenommen werden, wobei die erste Projektionsrichtung (41) zu der weiteren Projektionsrichtung (42) um einen Winkel (42) versetzt angeordnet ist.

6. Verfahren nach einem der Ansprüche 1 bis 5, dadurch gekennzeichnet, dass die einzelnen Muster (11.1-11.4) zur Unterscheidung untereinander und zur Identifizierung in der mindestens einen Triangulationsaufnahme (20, 53, 54) codiert sind.

7. Verfahren nach Anspruch 6, dadurch gekennzeichnet, dass die einzelnen Muster (11.1-11.4) farblich codiert sind, indem das erste Muster (11.1) eine erste Wellenlänge aufweist und das weitere Muster (11.2-11.4) eine davon abweichende Wellenlänge aufweist, wobei mindestens ein Farbsensor (6, 6.1, 6.2) als Aufnahmemittel vorhanden

ist, dessen Messbereich die Wellenlängen der Muster (11.1-11.4) abdeckt und der eine getrennte Analyse der farblich unterschiedlichen Muster (11.1-11.4) ermöglicht.

8. Verfahren nach Anspruch 6, dadurch gekennzeichnet, dass die einzelnen Muster (11.1-11.4) mit einem binären Grauwert-Code versehen sind und anhand dieses Grauwert-Codes die einzelnen Muster (11.1-11.4) in der mindestens einen Triangulationsaufnahme (20, 53, 54) identifiziert werden.

9. Verfahren nach einem der Ansprüche 1 bis 8, dadurch gekennzeichnet, dass die Projektionsstrahlen (7.1-7.4) der Muster (11.1-11.4) aus mindestens zwei verschiedenen Projektionsrichtungen (40, 41) auf das Objekt (8) projiziert werden und dass die Beobachtungsstrahlen (13.1-13.4) der Muster (11.1-11.4) aus mindestens zwei verschiedenen Beobachtungsrichtungen (50, 51) aufgenommen werden.

10. Verfahren nach einem der Ansprüche 1 bis 9,dadurch gekennzeichnet, dass die erste Projektionsrichtung (40) des ersten Musters (11.1) gegenüber der weiteren Projektionsrichtung (41) des weiteren Musters (11.2-11.4) einen Winkel größer als 10° aufweist.

11. Verfahren nach einem der Ansprüche 1 bis 10,dadurch gekennzeichnet, dass die erste Beobachtungsrichtung (50) gegenüber der weiteren Beobachtungsrichtung (51) einen Winkel größer als 10° aufweist.

12. Verfahren nach einem der Ansprüche 1 bis 11, dadurch gekennzeichnet, dass die Auswertung der mindestens einen Triangulationsaufnahme (20, 53, 54) nach einem

Streifenprojektionsverfahren erfolgt, welches auf dem Triangulationsverfahren beruht.

13. Verfahren nach einem der Ansprüche 3 bis 12, dadurch gekennzeichnet, dass zusätzlich zu den Triangulationsaufnahmen (20, 53, 54) weitere Zusatzaufnahmen (57, 58) basierend auf dem Prinzip der Photogrammetrie vom Objekt (8) aus unterschiedlichen Beobachtungsrichtungen (56, 57) aufgenommen werden und bei der Auswertung der Triangulationsaufnahmen (53, 54) berücksichtigt werden.

14. Verfahren nach Anspruch 13, dadurch gekennzeichnet, dass sowohl eine Auswertung der Triangulationsaufnahmen (53, 54) nach dem Prinzip der Streifenprojektion als auch eine Auswertung der Zusatzaufnahmen (57, 58) nach dem Prinzip der Photogrammetrie mittels einer Auswerteeinheit (15) erfolgt.

15. Verfahren nach einem der Ansprüche 1 bis 14, dadurch gekennzeichnet, dass die Aufnahmemittel (6, 6.1, 6.2) CCD-Sensoren sind.

16. Vorrichtung nach einem der Ansprüche 1 bis 15, dadurch gekennzeichnet, dass die Auswerteeinheit (15) aus den einzelnen Triangulationsaufnahmen (53, 54) 3D-Daten der jeweils erfassten Bereiche des Objekts (8) erzeugt und diese 3D-Daten zu dem 3D-Datensatz (21) des Objekts (8) zusammensetzt.

17. Vorrichtung nach Anspruchziffer 16, dadurch gekennzeichnet, dass eine Anzeigeeinheit (16) vorhanden ist, die den 3D-Datensatz (21) des Objekts als eine grafische 3D-Modell (21) grafisch anzeigt.

18. Vorrichtung nach einem der Ansprüche 12 bis 17, dadurch gekennzeichnet, dass bei der Verwendung des Streifenprojektionsverfahrens die einzelnen Muster (11.1-11.4)

aus mehreren parallelen Streifen (12.1-12.4) gebildet sind.

19. Vorrichtung nach einem der Ansprüche 3 bis 18, dadurch gekennzeichnet, dass die mindestens zwei Triangulationsaufnahmen (53, 54) aus unterschiedlichen Beobachtungsrichtungen (50, 51) analysiert werden, wobei die Triangulationsaufnahmen (53, 54) anhand von übereinstimmenden Bereichen (64) überlagert werden, wobei als Analyseverfahren zum Auffinden der übereinstimmenden Bereiche (64) das ICP-Verfahren oder das Topology-Matching-Verfahren verwendet wird.

20. Vorrichtung nach einem der Ansprüche 12 bis 19, dadurch gekennzeichnet, dass die 3D-Daten ausschließlich durch die Analyse der Muster (11.1-11.4) der jeweiligen Triangulationsaufnahme (20, 53, 54) erzeugt werden, wobei die einzelnen Streifen (12.1-12.4) durch das Abzählen der Streifen (12.1-12.4) oder durch ein Binär-Kode-Verfahren identifiziert werden.

21. Vorrichtung nach einem der Ansprüche 12 bis 20, dadurch gekennzeichnet, dass die 3D-Daten einer einzelnen Triangulationsaufnahme (20, 53, 54) durch die Analyse von mindestens vier in ihrer Phase unterschiedlichen Mustern (12.1-12.4) in der mindestens einen Triangulationsaufnahme (20, 53, 54) erzeugt werden, wobei ein Phasenschiebeverfahren verwendet wird, um die Koordinate eines Messpunktes zu ermitteln.

22. Vorrichtung nach einem der Ansprüche 1 bis 21, dadurch gekennzeichnet, dass Projektionsmittel (4.1-4.4, 5) für eine zeitgleiche Projektion von mindestens zwei auf das Objekt (8) projizierten Mustern (11.1-11.4) vorhanden sind.

23. Vorrichtung nach einem der Ansprüche 1 bis 22, dadurch gekennzeichnet, dass in einem ersten Schritt eine erste Gruppe von Mustern (11.1-11.4) in mindestens einer ersten Triangulationsaufnahme (20, 53, 54) unter Verwendung des mindestens einen Aufnahmemittels (6, 6.1, 6.2) gleichzeitig aufgenommen wird und in einem weiteren Schritt nach einem festgelegten Zeitintervall eine weitere Gruppe von Mustern (11.1-11.4) in mindestens einer weiteren Triangulationsaufnahme (20.1-20.4) gleichzeitig aufgenommen wird, wobei die Lage der Aufnahmevorrichtung (1) während des Zeitintervalls relativ zum aufzunehmenden Objekt (8) geändert wird.

24. Vorrichtung nach Anspruche 23, dadurch gekennzeichnet, dass aus der ersten Gruppe von Mustern (11.1-11.4) in der ersten Triangulationsaufnahme (20, 53, 54) ein erster 3D-Datensatz (21) des Objekts gewonnen wird und aus der weiteren Gruppe von Mustern (11.1-11.4) in der weiteren Triangulationsaufnahme (20.1-20.4) ein weiterer 3D-Datensatz (21.1) des Objekts gewonnen wird, wobei anschließend der erste 3D-Datensatz (21) und der weitere 3D-Datensatz (21.1) zu einer gemeinsamen 3D-Abbildung (23) des Objekts zusammengefügt werden.

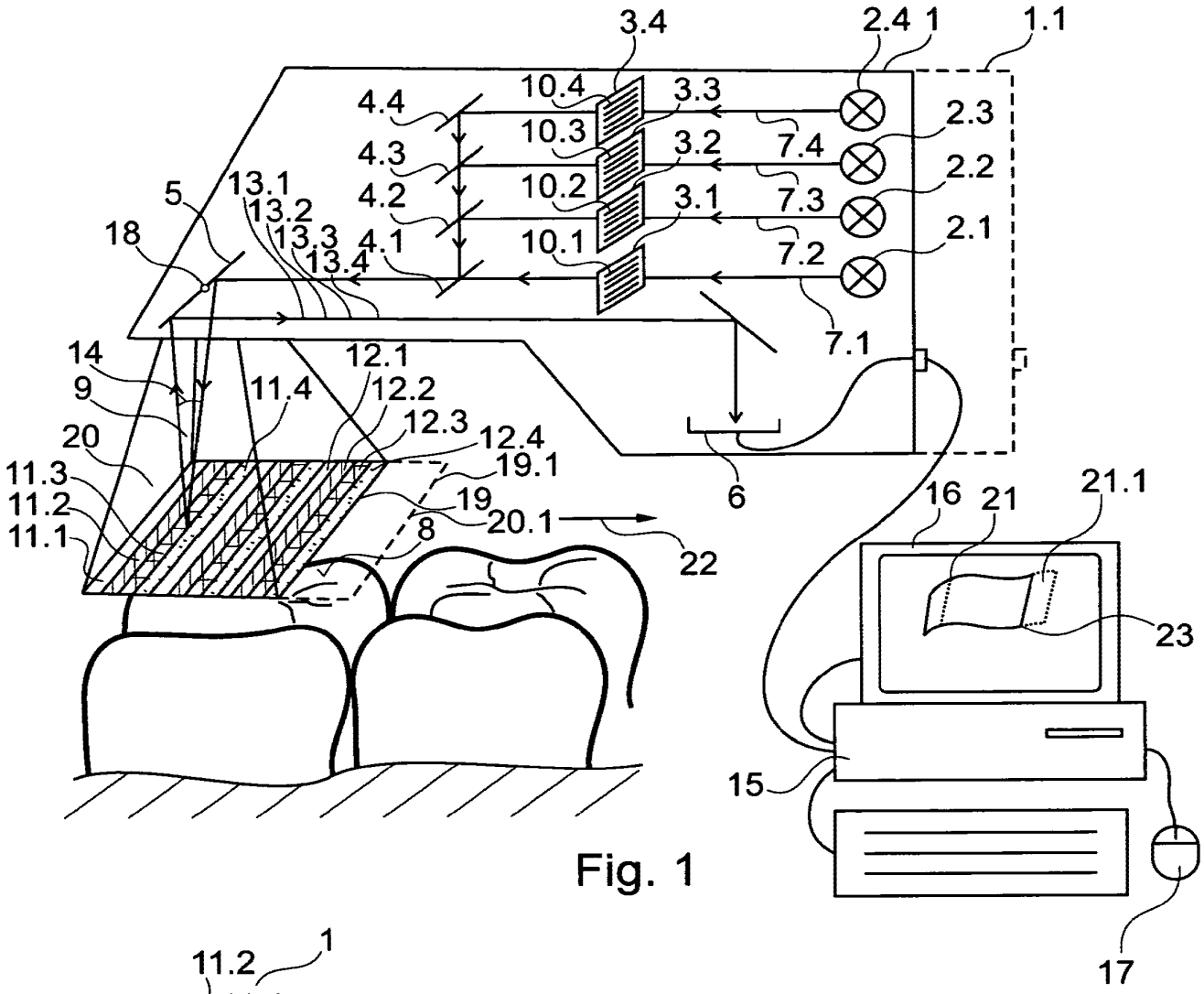


Fig. 1

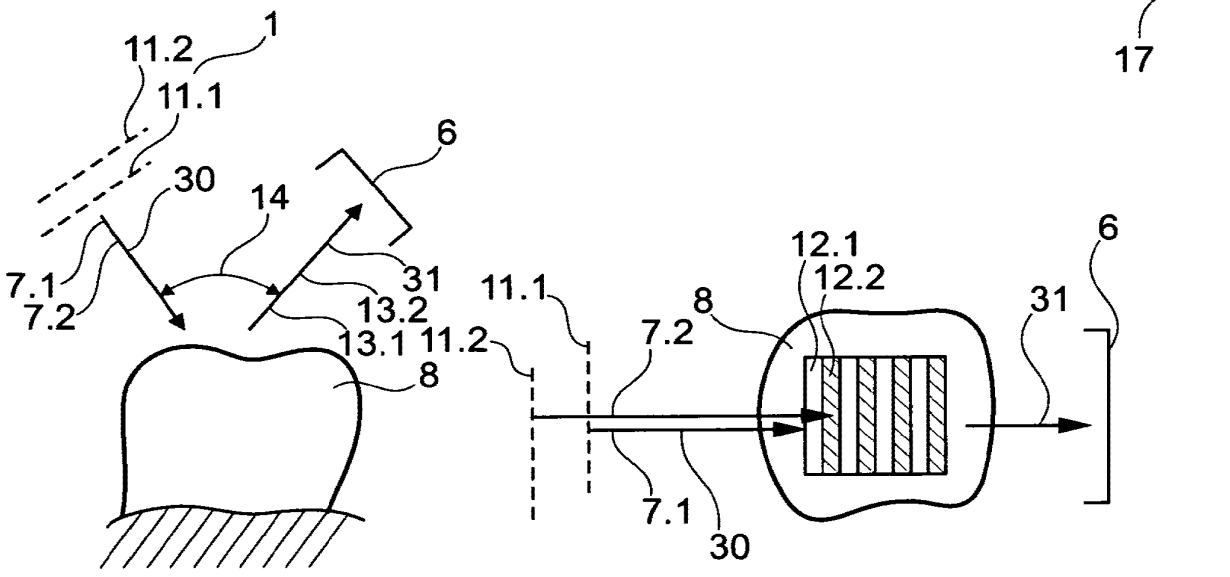


Fig. 2A

Fig. 2B

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DENTAL IMAGING

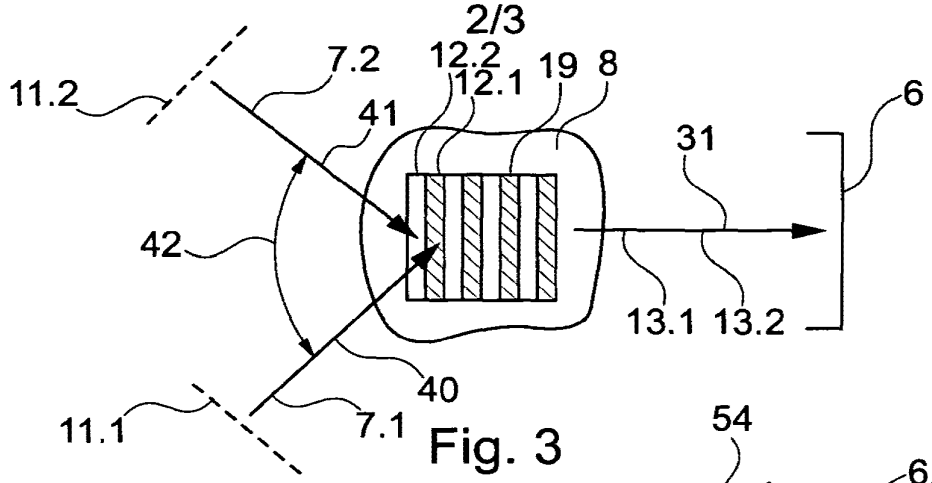


Fig. 3

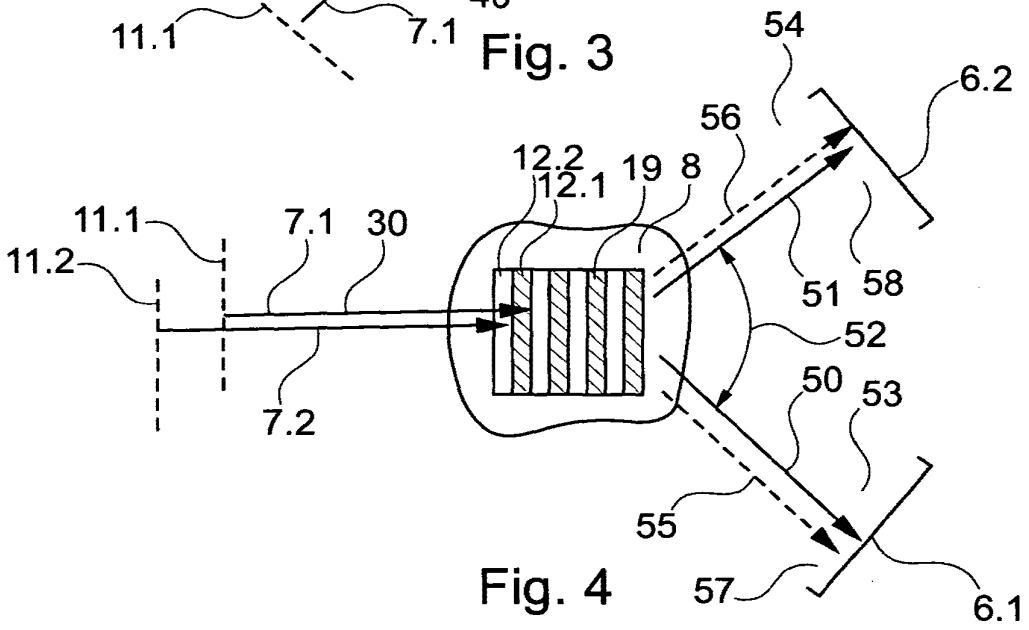


Fig. 4

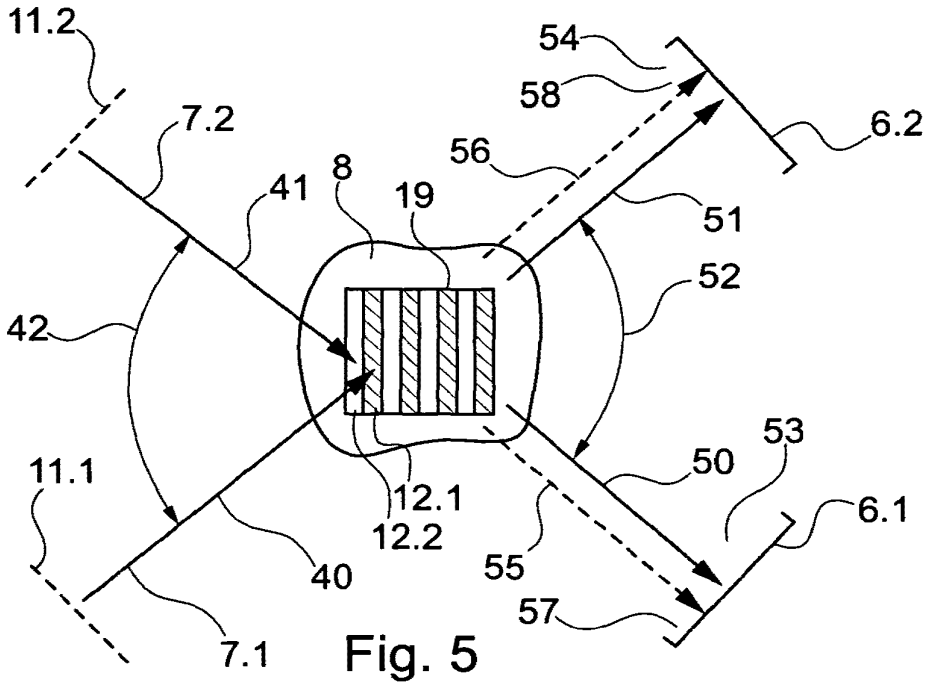


Fig. 5

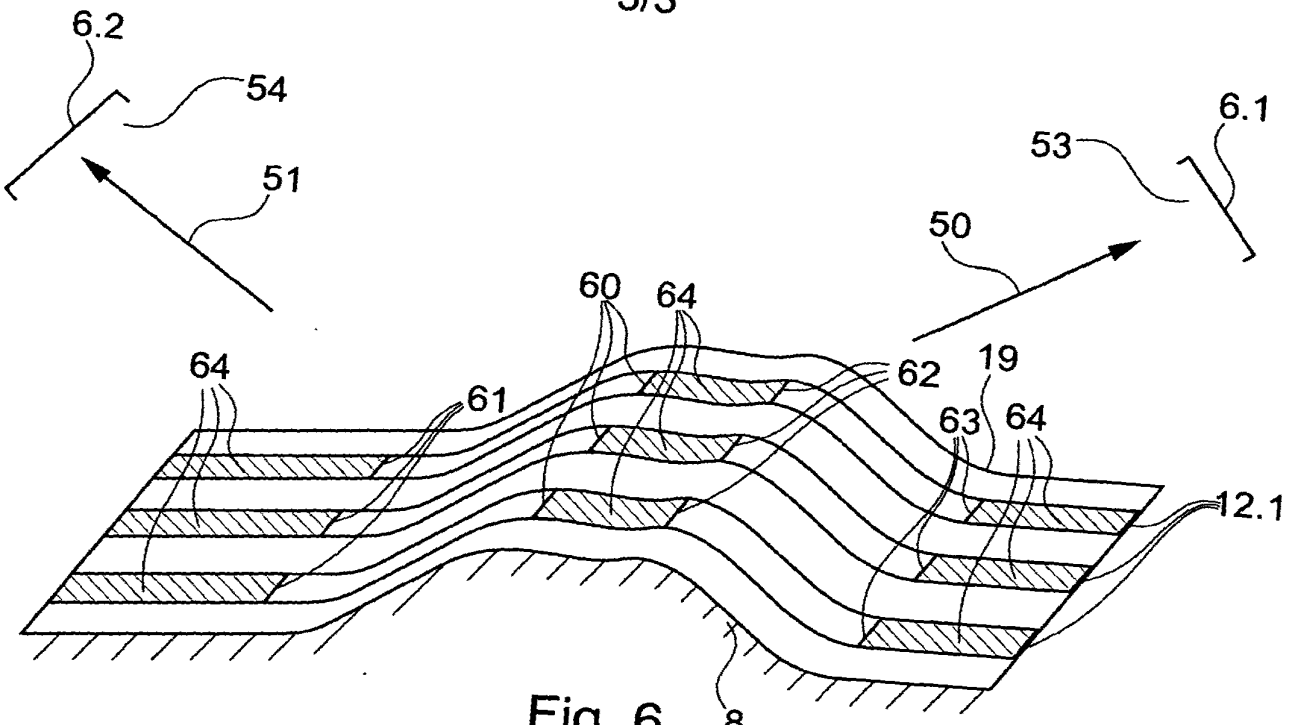

6.2
54
51
6.1
53
50
60
64
64
61
62
19
63
64
12.1
8

Fig. 6

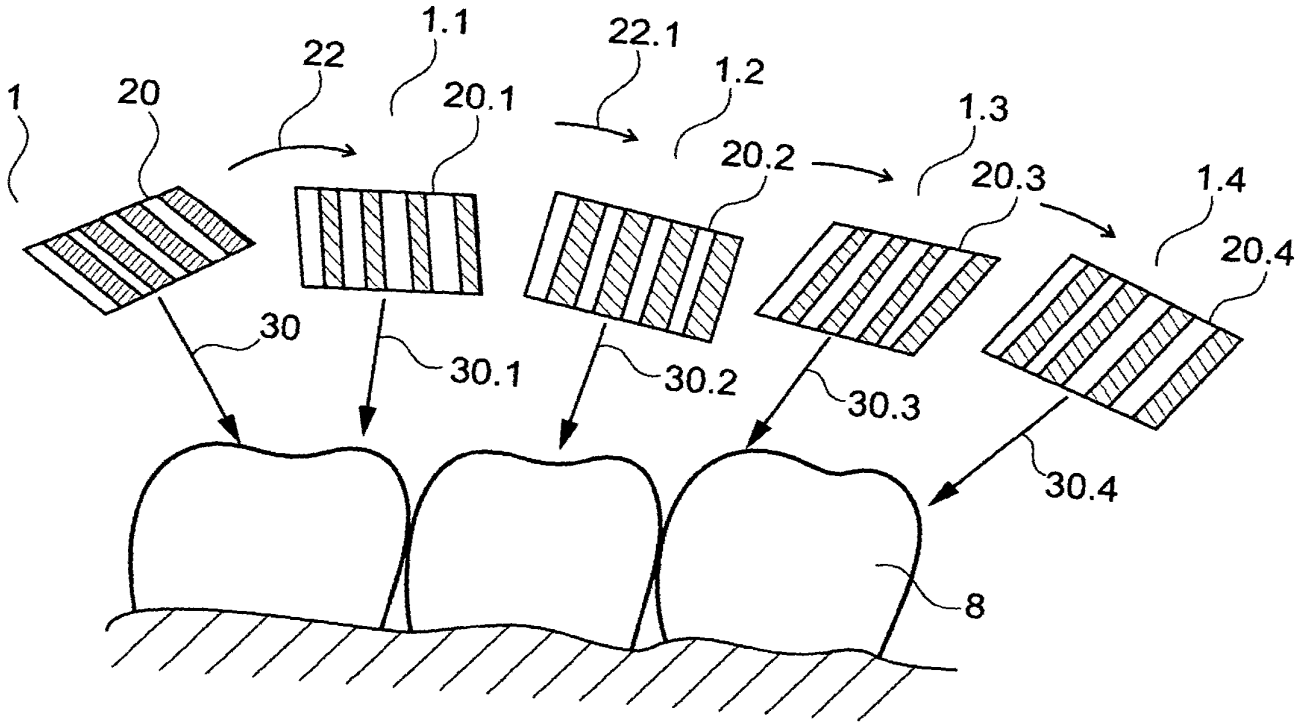

1
20
22
1.1
20.1
22.1
1.2
20.2
1.3
20.3
1.4
20.4
30
30.1
30.2
30.3
30.4
8

Fig. 7

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(54) **Title:** THREE-DIMENSIONAL MODEL REFINEMENT

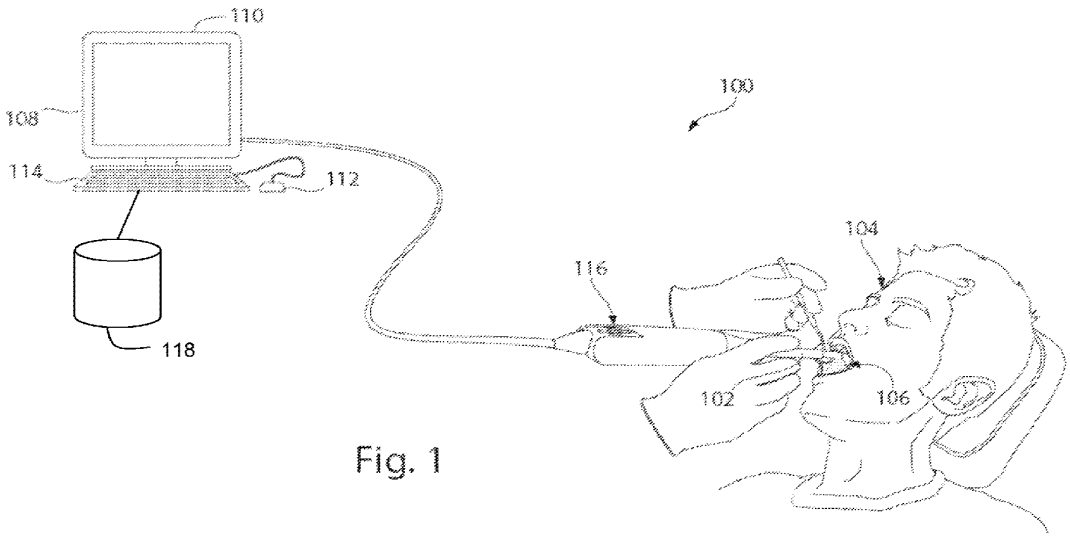


Fig. 1

(57) **Abstract:** A three-dimensional measurement is refined by warping two-dimensional images of an object from offset camera positions according to a three-dimensional model of the object, and applying any resulting discrepancies to refine the three-dimensional model, or to refine one of a number of three-dimensional measurements used to create the three-dimensional model.

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THREE-DIMENSIONAL MODEL REFINEMENT

[0001] The present application claims priority from the U.S. Provisional Patent Application No. 61/019,159, filed January 4, 2008, which is hereby incorporated by reference in its entirety.

FIELD OF INVENTION

[0002] This invention relates generally to three-dimensional imaging and more specifically to refinement of three dimensional models reconstructed from a sequence of three-dimensional measurements captured along a camera path.

BACKGROUND

[0003] In one technique for three-dimensional image reconstruction, a number of images or image sets of an object are captured with a camera that travels in a path over the surface of the object. Information from this image catalogue can then be used to reconstruct a three-dimensional model of the object based upon each camera position and three-dimensional measurement captured along the path. While individual measurements from the camera can contain noise from a variety of sources, the resulting three-dimensional model tends to smooth out this noise to recover three-dimensional data points more accurate than the individual measurements.

[0004] There remains a need for post-processing techniques to refine individual three-dimensional measurements based upon the full data set available for a completed three-dimensional scan.

SUMMARY

[0005] A three-dimensional measurement is refined by warping two-dimensional images of an object from offset camera positions according to a three-dimensional model of the object, and applying any resulting discrepancies to refine the three-dimensional model, or to refine one of a number of three-dimensional measurements used to create the three-dimensional model.

[0006] In one aspect, a method of refining a three-dimensional model described herein includes providing a three-dimensional model of an object; obtaining a first two-dimensional image of the object from a first camera pose; obtaining a second two-dimensional image of the object from a second camera pose, wherein the second two-dimensional image includes a common portion of a surface of the object with the first two-dimensional image; deforming the first two-dimensional image based upon a spatial relationship of the first camera pose, the second camera pose, and the three-dimensional model to obtain an expected image from the second camera pose based upon the first camera pose; comparing the second two-dimensional image to the expected image to identify one or more discrepancies; and correcting the three-dimensional model based upon the one or more discrepancies.

[0007] The first camera pose and the second camera pose may be a position and an orientation of a single camera in two dependent positions. The first camera pose and the second camera pose may be a position and an orientation of two offset channels of a multi-aperture camera. The first camera pose and the second camera pose may be a position and an orientation of a single camera in two independent positions. A relationship between the first camera pose and the second camera pose may be calculated based upon a three-dimensional measurement of the surface of the object from each of the first camera pose and the second camera pose. The method may include deriving the three-dimensional model from a plurality of three-dimensional measurements of the surface of the object from a plurality of camera poses including the first camera pose and the second camera pose. The method may include applying the one or more discrepancies to directly refine the three-dimensional model. The method may include applying the one or more discrepancies to refine a three-dimensional measurement from one or more of the first camera pose and the second camera pose to provide a refined measurement. The method may include refining a camera path calculation for a camera path used to create the three-dimensional model using the refined measurement to provide a refined camera path. The method may include using the refined camera path and the refined measurement to refine the three-dimensional model. The three-dimensional model may be a point cloud or a polygonal mesh. The object may be human dentition. The second camera pose may correspond to a center channel of a multi-

aperture camera system, the center channel providing a conventional two-dimensional image of the object. The method may include obtaining a third two-dimensional image of the object from a third camera pose corresponding to a second side channel of the multi-aperture system and deforming the third two-dimensional image to an expected image for the center channel for use in further refining the three-dimensional measurement from the multi-aperture camera system.

[0008] In another aspect, computer program product for refining a three-dimensional model of an object described herein includes computer executable code embodied on a computer readable medium that, when executing on one or more computing devices, performs the steps of providing a three-dimensional model of an object; obtaining a first two-dimensional image of the object from a first camera pose; obtaining a second two-dimensional image of the object from a second camera pose, wherein the second two-dimensional image includes a common portion of a surface of the object with the first two-dimensional image; deforming the first two-dimensional image based upon a spatial relationship of the first camera pose, the second camera pose, and the three-dimensional model to obtain an expected image from the second camera pose based upon the first camera pose; comparing the second two-dimensional image to the expected image to identify one or more discrepancies; and correcting the three-dimensional model based upon the one or more discrepancies.

[0009] The first camera pose and the second camera pose may be a position and an orientation of a single camera in two dependent positions. The first camera pose and the second camera pose may be a position and an orientation of two offset channels of a multi-aperture camera. The first camera pose and the second camera pose may be a position and an orientation of a single camera in two independent positions. A relationship between the first camera pose and the second camera pose may be calculated based upon a three-dimensional measurement of the surface of the object from each of the first camera pose and the second camera pose. The computer program produce may include code for performing the step of deriving the three-dimensional model from a plurality of three-dimensional measurements of the surface of the object from a plurality of camera poses including the first camera pose and the second camera pose. The computer program produce may include code for performing the step of applying the one

or more discrepancies to directly refine the three-dimensional model. The computer program produce may include code for performing the step of applying the one or more discrepancies to refine a three-dimensional measurement from one or more of the first camera pose and the second camera pose to provide a refined measurement. The computer program produce may include code for performing the step of refining a camera path calculation for a camera path used to create the three-dimensional model using the refined measurement to provide a refined camera path. The computer program produce may include code for performing the step of using the refined camera path and the refined measurement to refine the three-dimensional model. The three-dimensional model may be a point cloud or a polygonal mesh. The object may be human dentition. The second camera pose may correspond to a center channel of a multi-aperture camera system, the center channel providing a conventional two-dimensional image of the object. The computer program product may include code for performing the steps of obtaining a third two-dimensional image of the object from a third camera pose corresponding to a second side channel of the multi-aperture system and deforming the third two-dimensional image to an expected image for the center channel for use in further refining the three-dimensional measurement from the multi-aperture camera system.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] The invention and the following detailed description of certain embodiments thereof may be understood by reference to the following figures.

[0011] Fig. 1 shows a three-dimensional scanning system.

[0012] Fig. 2 shows a schematic diagram of an optical system for a three-dimensional camera.

[0013] Fig. 3 shows a processing pipeline for obtaining three-dimensional data from a video camera.

[0014] Fig. 4 illustrates a coordinate system for three-dimensional measurements.

[0015] Fig. 5 illustrates a sequence of images captured from a moving camera.

[0016] Fig. 6 is a conceptual representation of a three-dimensional data acquisition process.

[0017] Fig. 7 is a flow chart of a process for refining three-dimensional data.

[0018] Fig. 8 is a flow chart of a global path optimization.

DETAILED DESCRIPTION

[0019] In the following text, references to items in the singular should be understood to include items in the plural, and vice versa, unless explicitly stated otherwise or clear from the text. Grammatical conjunctions are intended to express any and all disjunctive and conjunctive combinations of conjoined clauses, sentences, words, and the like, unless otherwise stated or clear from the context.

[0020] The following description details specific scanning technologies and focuses on dental applications of three-dimensional imaging; however, it will be appreciated that variations, adaptations, and combinations of the methods and systems below will be apparent to one of ordinary skill in the art. For example, while an image-based system is described, non-image based scanning techniques such as infrared time-of-flight techniques or structured light techniques using patterned projections may similarly employ reconstruction based on camera path that may benefit from the improvements described herein. Similarly, while the following description emphasizes a refinement using concurrent images from two offset channels of a multi-aperture camera, it will be understood that the techniques may be similarly applied to refine frame-to-frame data for a camera path of a multi-aperture camera, or different frames of data for a conventional camera. As another example, while digital dentistry is one useful application of the improved accuracy that results from the techniques described herein, the teachings of this disclosure may also usefully be employed to refine three-dimensional animation models, three-dimensional scans for machine vision applications, and so forth. All such variations, adaptations, and combinations are intended to fall within the scope of this disclosure.

[0021] In the following description, the term "image" generally refers to a two-dimensional set of pixels forming a two-dimensional view of a subject within an image plane. The term "image set" generally refers to a set of related two-dimensional images that might be resolved into three-dimensional data. The term "point cloud" generally refers to a three-dimensional set of points forming a three-dimensional view of the

subject reconstructed from a number of two-dimensional images. In a three-dimensional image capture system, a number of such point clouds may also be registered and combined into an aggregate point cloud constructed from images captured by a moving camera. Thus it will be understood that pixels generally refer to two-dimensional data and points generally refer to three-dimensional data, unless another meaning is specifically indicated or clear from the context.

[0022] The terms "three-dimensional model", "three-dimensional surface representation", "digital surface representation", "three-dimensional surface map", and the like, as used herein, are intended to refer to any three-dimensional reconstruction of an object, such as a point cloud of surface data, a set of two-dimensional polygons, or any other data representing all or some of the surface of an object, as might be obtained through the capture and/or processing of three-dimensional scan data, unless a different meaning is explicitly provided or otherwise clear from the context. A "three-dimensional representation" may include any of the three-dimensional surface representations described above, as well as volumetric and other representations, unless a different meaning is explicitly provided or otherwise clear from the context.

[0023] In general, the terms "render" or "rendering" refer to a two-dimensional visualization of a three-dimensional object, such as for display on a monitor. However, it will be understood that a variety of three-dimensional rendering technologies exist, and may be usefully employed with the systems and methods disclosed herein. For example, the systems and methods described herein may usefully employ a holographic display, an autostereoscopic display, an anaglyph display, a head-mounted stereo display, or any other two-dimensional and/or three-dimensional display. As such, rendering as described herein should be interpreted broadly unless a narrower meaning is explicitly provided or otherwise clear from the context.

[0024] The term "dental object", as used herein, is intended to refer broadly to subject matter related to dentistry. This may include intraoral structures such as dentition, and more typically human dentition, such as individual teeth, quadrants, full arches, pairs of arches (which may be separate or in occlusion of various types), soft tissue, and the like, as well bones and any other supporting or surrounding structures. As used herein, the term "intraoral structures" refers to both natural structures within a

mouth as described above and artificial structures such as any of the dental objects described below that might be present in the mouth. Dental objects may include "restorations", which may be generally understood to include components that restore the structure or function of existing dentition, such as crowns, bridges, veneers, inlays, onlays, amalgams, composites, and various substructures such as copings and the like, as well as temporary restorations for use while a permanent restoration is being fabricated. Dental objects may also include a "prosthesis" that replaces dentition with removable or permanent structures, such as dentures, partial dentures, implants, retained dentures, and the like. Dental objects may also include "appliances" used to correct, align, or otherwise temporarily or permanently adjust dentition, such as removable orthodontic appliances, surgical stents, bruxism appliances, snore guards, indirect bracket placement appliances, and the like. Dental objects may also include "hardware" affixed to dentition for an extended period, such as implant fixtures, implant abutments, orthodontic brackets, and other orthodontic components. Dental objects may also include "interim components" of dental manufacture such as dental models (full and/or partial), wax-ups, investment molds, and the like, as well as trays, bases, dies, and other components employed in the fabrication of restorations, prostheses, and the like. Dental objects may also be categorized as natural dental objects such as the teeth, bone, and other intraoral structures described above or as artificial dental objects such as the restorations, prostheses, appliances, hardware, and interim components of dental manufacture as described above.

[0025] Terms such as "digital dental model", "digital dental impression" and the like, are intended to refer to three-dimensional representations of dental objects that may be used in various aspects of acquisition, analysis, prescription, and manufacture, unless a different meaning is otherwise provided or clear from the context. Terms such as "dental model" or "dental impression" are intended to refer to a physical model, such as a cast, printed, or otherwise fabricated physical instance of a dental object. Unless specified, the term "model", when used alone, may refer to either or both of a physical model and a digital model.

[0026] It will further be understood that terms such as "tool" or "control", when used to describe aspects of a user interface, are intended to refer generally to a variety of techniques that may be employed within a graphical user interface or other user interface

to receive user input that stimulates or controls processing including without limitation drop-down lists, radio buttons, cursor and/or mouse actions (selections by point, selections by area, drag-and-drop operations, and so forth), check boxes, command lines, text input fields, messages and alerts, progress bars, and so forth. A tool or control may also include any physical hardware relating to the user input, such as a mouse, a keyboard, a display, a keypad, a track ball, and/or any other device that receives physical input from a user and converts the physical input into an input for use in a computerized system. Thus in the following description the terms "tool", "control" and the like should be broadly construed unless a more specific meaning is otherwise provided or clear from the context.

[0027] Fig. 1 depicts a three-dimensional scanning system that may be used with the systems and methods described herein. In general, the system 100 may include a camera 102 that captures images from a surface 106 of an object 104, such as a dental patient, and forwards the images to a computer 108, which may include a display 110 and one or more user-input devices 112, 114 such as a mouse 112 or a keyboard 114. The camera 102 may also include an integrated input or output device 116 such as a control input (e.g., button, touchpad, thumbwheel, etc.) or a display (e.g., LCD or LED display) to provide status information.

[0028] The camera 102 may include any camera or camera system suitable for capturing images from which a three-dimensional point cloud or other three-dimensional data may be recovered. For example, the camera 102 may employ a multi-aperture system as disclosed in U.S. Pat. No. 7,372,642 to Rohály et al., the entire content of which is incorporated herein by reference. While Rohály discloses one multi-aperture system, it will be appreciated that any multi-aperture system suitable for reconstructing a three-dimensional point cloud from a number of two-dimensional images may similarly be employed. In one multi-aperture embodiment, the camera 102 may include a plurality of apertures including a center aperture positioned along a center optical axis of a lens that provides a center channel for the camera 102, along with any associated imaging hardware. In such embodiments, the center channel may provide a conventional video image of the scanned subject matter, while a number of axially offset channels yield image sets containing disparity information that can be employed in three-dimensional

reconstruction of a surface. In other embodiments, a separate video camera and/or channel may be provided to achieve the same result, i.e., a video of an object corresponding temporally to a three-dimensional scan of the object, preferably from the same perspective, or from a perspective having a fixed, known relationship to the perspective of the camera 102. The camera 102 may also, or instead, include a stereoscopic, triscopic or other multi-camera or other configuration in which a number of cameras or optical paths are maintained in fixed relation to one another to obtain two-dimensional images of an object from a number of different perspectives. The camera 102 may include suitable processing for deriving a three-dimensional point cloud from an image set or a number of image sets, or each two-dimensional image set may be transmitted to an external processor such as contained in the computer 108 described below. In other embodiments, the camera 102 may employ structured light, laser scanning, direct ranging, or any other technology suitable for acquiring three-dimensional data, or two-dimensional data that can be resolved into three-dimensional data. While the techniques described below can usefully employ video data acquired by a video-based three-dimensional scanning system, it will be understood that any other three-dimensional scanning system may be supplemented with a video acquisition system that captures suitable video data contemporaneously with, or otherwise synchronized with, the acquisition of three-dimensional data.

[0029] In one embodiment, the camera 102 is a handheld, freely-positionable probe having at least one user-input device 116, such as a button, a lever, a dial, a thumb wheel, a switch, or the like, for user control of the image capture system 100 such as starting and stopping scans. In an embodiment, the camera 102 may be shaped and sized for dental scanning. More particularly, the camera 102 may be shaped and sized for intraoral scanning and data capture, such as by insertion into a mouth of an imaging subject and passing over an intraoral surface 106 at a suitable distance to acquire surface data from teeth, gums, and so forth. The camera 102 may, through such a continuous data acquisition process, capture a point cloud of surface data having sufficient spatial resolution and accuracy to prepare dental objects such as prosthetics, hardware, appliances, and the like therefrom, either directly or through a variety of intermediate processing steps. In other embodiments, surface data may be acquired from a dental

model such as a dental prosthesis, to ensure proper fitting using a previous scan of corresponding dentition, such as a tooth surface prepared for the prosthesis.

[0030] Although not shown in Fig. 1, it will be appreciated that a number of supplemental lighting systems may be usefully employed during image capture. For example, environmental illumination may be enhanced with one or more spotlights illuminating the object 104 to speed image acquisition and improve depth of field (or spatial resolution depth). The camera 102 may also, or instead, include a strobe, a flash, or some other light source to supplement illumination of the object 104 during image acquisition.

[0031] The object 104 may be any object, collection of objects, portion of an object, or other subject matter. More particularly with respect to the dental techniques discussed herein, the object 104 may include human dentition captured intraorally from a dental patient's mouth. A scan may capture a three-dimensional representation of some or all of the dentition according to a particular purpose of the scan. Thus the scan may capture a digital model of a tooth, a quadrant of teeth, or a full collection of teeth including two opposing arches, as well as soft tissue or any other relevant intraoral structures. The scan may capture multiple representations, such as a tooth surface before and after preparation for a restoration. As will be noted below, this data may be employed for subsequent modeling such as designing a restoration or determining a margin line for same. During the scan, a center channel of the camera 102 or a separate video system may capture video of the dentition from the point of view of the camera 102. In other embodiments where, for example, a completed fabrication is being virtually test fitted to a surface preparation, the scan may include a dental prosthesis such as an inlay, a crown, or any other dental prosthesis, dental hardware, dental appliance, or the like. The object 104 may also, or instead, include a dental model, such as a plaster cast, a wax-up, an impression, or a negative impression of a tooth, teeth, soft tissue, or some combination of these.

[0032] The computer 108 may include, for example, a personal computer or other processing device. In one embodiment, the computer 108 includes a personal computer with a dual 2.8GHz Opteron central processing unit, 2 gigabytes of random access memory, a TYAN Thunder K8WE motherboard, and a 250 gigabyte, 10,000 rpm

hard drive. In one current embodiment, the system can be operated to capture more than five thousand points per image set in real time using the techniques described herein, and store an aggregated point cloud of several million points. Of course, this point cloud may be further processed to accommodate subsequent data handling, such as by decimating the point cloud data or generating a corresponding mesh of surface data. As used herein, the term "real time" means generally with no observable latency between processing and display. In a video-based scanning system, real time more specifically refers to processing within the time between frames of video data, which may vary according to specific video technologies between about fifteen frames per second and about thirty frames per second. More generally, processing capabilities of the computer 108 may vary according to the size of the object 104, the speed of image acquisition, and the desired spatial resolution of three-dimensional points. The computer 108 may also include peripheral devices such as a keyboard 114, display 110, and mouse 112 for user interaction with the camera system 100. The display 110 may be a touch screen display capable of receiving user input through direct, physical interaction with the display 110. In another aspect, the display may include an autostereoscopic display or the like capable of displaying stereo images.

[0033] Communications between the computer 108 and the camera 102 may use any suitable communications link including, for example, a wired connection or a wireless connection based upon, for example, IEEE 802.11 (also known as wireless Ethernet), BlueTooth, or any other suitable wireless standard using, e.g., a radio frequency, infrared, or other wireless communication medium. In medical imaging or other sensitive applications, wireless image transmission from the camera 102 to the computer 108 may be secured. The computer 108 may generate control signals to the camera 102 which, in addition to image acquisition commands, may include conventional camera controls such as focus or zoom.

[0034] In an example of general operation of a three-dimensional image capture system 100, the camera 102 may acquire two-dimensional image sets at a video rate while the camera 102 is passed over a surface of the subject. The two-dimensional image sets may be forwarded to the computer 108 for derivation of three-dimensional point clouds. The three-dimensional data for each newly acquired two-dimensional image set

may be derived and fitted or "stitched" to existing three-dimensional data using a number of different techniques. Such a system may employ camera motion estimation to avoid the need for independent tracking of the position of the camera 102. One useful example of such a technique is described in commonly-owned U.S. App. No. 11/270,135, filed on November 9, 2005, the entire content of which is incorporated herein by reference. However, it will be appreciated that this example is not limiting, and that the principles described herein may be applied to a wide range of three-dimensional image capture systems.

[0035] The display 110 may include any display suitable for video or other rate rendering at a level of detail corresponding to the acquired data. Suitable displays include cathode ray tube displays, liquid crystal displays, light emitting diode displays and the like. In general, the display 110 may be operatively coupled to, and capable of receiving display signals from, the computer 108. This display may include a CRT or flat panel monitor, a three-dimensional display (such as an anaglyph display), an autostereoscopic three-dimensional display or any other suitable two-dimensional or three-dimensional rendering hardware. In some embodiments, the display may include a touch screen interface using, for example capacitive, resistive, or surface acoustic wave (also referred to as dispersive signal) touch screen technologies, or any other suitable technology for sensing physical interaction with the display 110.

[0036] The system 100 may include a computer-usable or computer-readable medium. The computer-usable medium 118 may include one or more memory chips (or other chips, such as a processor, that include memory), optical disks, magnetic disks or other magnetic media, and so forth. The computer-usable medium 118 may in various embodiments include removable memory (such as a USB device, tape drive, external hard drive, and so forth), remote storage (such as network attached storage), volatile or non-volatile computer memory, and so forth. The computer-usable medium 118 may contain computer-readable instructions for execution by the computer 108 to perform the various processes described herein. The computer-usable medium 118 may also, or instead, store data received from the camera 102, store a three-dimensional model of the object 104, store computer code for rendering and display, and so forth.

[0037] Fig. 2 depicts an optical system 200 for a three-dimensional camera that may be used with the systems and methods described herein, such as for the camera 102 described above with reference to Fig. 1.

[0038] The optical system 200 may include a primary optical facility 202, which may be employed in any kind of image processing system. In general, a primary optical facility refers herein to an optical system having one optical channel. Typically, this optical channel shares at least one lens, and has a shared image plane within the optical system, although in the following description, variations to this may be explicitly described or otherwise clear from the context. The optical system 200 may include a single primary lens, a group of lenses, an object lens, mirror systems (including traditional mirrors, digital mirror systems, digital light processors, or the like), confocal mirrors, and any other optical facilities suitable for use with the systems described herein. The optical system 200 may be used, for example in a stereoscopic or other multiple image camera system. Other optical facilities may include holographic optical elements or the like. In various configurations, the primary optical facility 202 may include one or more lenses, such as an object lens (or group of lenses) 202b, a field lens 202d, a relay lens 202f, and so forth. The object lens 202b may be located at or near an entrance pupil 202a of the optical system 200. The field lens 202d may be located at or near a first image plane 202c of the optical system 200. The relay lens 202f may relay bundles of light rays within the optical system 200. The optical system 200 may further include components such as aperture elements 208 with one or more apertures 212, a refocusing facility 210 with one or more refocusing elements 204, one or more sampling facilities 218, and/or a number of sensors 214a, 214b, 214c.

[0039] The optical system 200 may be designed for active wavefront sampling, which should be understood to encompass any technique used to sample a series or collection of optical data from an object 220 or objects, including optical data used to help detect two-dimensional or three-dimensional characteristics of the object 220, using optical data to detect motion, using optical data for velocimetry or object tracking, or the like. Further details of an optical system that may be employed as the optical system 200 of Fig. 2 are provided in U.S. Pat. No. 7,372,642, the entire content of which is incorporated herein by reference. More generally, it will be understood that, while Fig. 2

depicts one embodiment of an optical system 200, numerous variations are possible. One salient feature of the optical system related to the discussion below is the use of a center optical channel that captures conventional video or still images at one of the sensors 214b concurrent with various offset data (at, e.g., 214a and 214c) used to capture three-dimensional measurements. This center channel image may be presented in a user interface to permit inspection, marking, and other manipulation by a user during a user session as describe below.

[0040] Fig. 3 shows a three-dimensional reconstruction system 300 employing a high-speed pipeline and a high-accuracy pipeline. In general, the high-speed processing pipeline 330 aims to provide three-dimensional data in real time, such as at a video frame rate used by an associated display, while the high-accuracy processing pipeline 350 aims to provide the highest accuracy possible from camera measurements, subject to any external computation or time constraints imposed by system hardware or an intended use of the results. A data source 310 such as the camera 102 described above provides image data or the like to the system 300. The data source 310 may for example include hardware such as LED ring lights, wand sensors, a frame grabber, a computer, an operating system and any other suitable hardware and/or software for obtaining data used in a three-dimensional reconstruction. Images from the data source 310, such as center channel images containing conventional video images and side channels containing disparity data used to recover depth information may be passed to the real-time processing controller 316. The real-time processing controller 316 may also provide camera control information or other feedback to the data source 310 to be used in subsequent data acquisition or for specifying data already obtained in the data source 310 that is needed by the real-time processing controller 316. Full resolution images and related image data may be retained in a full resolution image store 322. The stored images may, for example, be provided to the high-accuracy processing controller 324 during processing, or be retained for image review by a human user during subsequent processing steps.

[0041] The real-time processing controller 316 may provide images or frames to the high-speed (video rate) processing pipeline 330 for reconstruction of three-dimensional surfaces from the two-dimensional source data in real time. In an exemplary

embodiment, two-dimensional images from an image set such as side channel images, may be registered by a two-dimensional image registration module 332. Based on the results of the two-dimensional image registration, a three-dimensional point cloud generation module 334 may create a three-dimensional point cloud or other three-dimensional representation. The three-dimensional point clouds from individual image sets may be combined by a three-dimensional stitching module 336. Finally, the stitched measurements may be combined into an integrated three-dimensional model by a three-dimensional model creation module 338. The resulting model may be stored as a high-speed three-dimensional model 340.

[0042] The high-accuracy processing controller 324 may provide images or frames to the high-accuracy processing pipeline 350. Separate image sets may have two-dimensional image registration performed by a two-dimensional image registration module 352. Based on the results of the two-dimensional image registration a three-dimensional point cloud or other three-dimensional representation may be generated by a three-dimensional point cloud generation module 354. The three-dimensional point clouds from individual image sets may be connected using a three-dimensional stitching module 356. Global motion optimization, also referred to herein as global path optimization or global camera path optimization, may be performed by a global motion optimization module 357 in order to reduce errors in the resulting three-dimensional model 358. In general, the path of the camera as it obtains the image frames may be calculated as a part of the three-dimensional reconstruction process. In a post-processing refinement procedure, the calculation of camera path may be optimized – that is, the accumulation of errors along the length of the camera path may be minimized by supplemental frame-to-frame motion estimation with some or all of the global path information. Based on global information such as individual frames of data in the image store 322, the high-speed three-dimensional model 340, and intermediate results in the high-accuracy processing pipeline 350, the high-accuracy model 370 may be processed to reduce errors in the camera path and resulting artifacts in the reconstructed model. As a further refinement, a mesh may be projected onto the high-speed model by a mesh projection module 360. The resulting images may be warped or deformed by a warping module 362. Warped images may be utilized to ease alignment and stitching between

images, such as by reducing the initial error in a motion estimation. The warped images may be provided to the two-dimensional image registration module 352. The feedback of the high-accuracy three-dimensional model 370 into the pipeline may be repeated until some metric is obtained, such as a stitching accuracy or a minimum error threshold.

[0043] Various aspects of the system 300 of Fig. 3 are described in greater detail below. In particular, a model refinement process is described that may be used by the high-accuracy processing controller 324 to refine the high accuracy three-dimensional model 370 using measured data in the image store 322. It should be understood that various processing modules, or the steps implied by the modules, shown in this figure are exemplary in nature and that the order of processing, or the steps of the processing sequence, may be modified, omitted, repeated, re-ordered, or supplemented, without departing from the scope of this disclosure.

[0044] Fig. 4 illustrates a coordinate system for three-dimensional measurements using a system such as the optical system 200 described above. The following description is intended to provide useful context, and should not be interpreted as limiting in any sense. In general an object 408 within an image plane 402 of a camera has world coordinates $\{X_w, Y_w, Z_w\}$ in a world coordinate system 410, camera coordinates $\{X_c, Y_c, Z_c\}$ in a camera coordinate system 406, and image set coordinates $\{x_i, y_i, \underline{d}_i(x_i, y_i)\}$ for i = 1 to N points or pixels within a processing mesh of the field of view 402, where $\underline{d}_i$ is a disparity vector 412 containing one or more disparity values that characterize z-axis displacement (Z_c) or depth 404 of a point in the image plane 402 based upon x-axis and/or y-axis displacement in the image plane 402 between a number of physically offset apertures or other imaging channels. The processing mesh may be understood as any overlay or grid for an image or other two-dimensional data that identifies locations where processing will occur. While a processing mesh may be a regular grid of locations in a square, rectangular, triangular, or other pattern, the processing mesh may also, or instead, include irregular patterns selected randomly or according to the specific subject matter being processed. The disparity vector 412 may be expressed, for example, in terms of displacement relative to a center channel, if any, for the camera. In general, the disparity vector 412 encodes depth, and in various other

three-dimensional imaging systems, this disparity vector 412 may be replaced by one or more other measured quantities that encode depth. Thus terms such as disparity vector, disparity value, and disparity data and the like should be understood broadly to include any one or more scalar and/or vector quantities measured by a system to capture depth information. Also more generally, a three-dimensional measurement as used herein may refer to any form of data encoding three-dimensional data including without limitation, groups of two dimensional images from which disparity vectors might be obtained, the disparity field (of disparity vectors) itself, or a three-dimensional surface reconstruction derived from the disparity field. In image-based three-dimensional reconstruction, a camera model may be employed to relate disparity vectors to depth within a field of view of a camera. The camera model may be determined theoretically based upon optical modeling or other physics, empirically through observation, or some combination of these, and may be calibrated to compensate for optical aberrations, lens defects, and any other physical variations or features of a particular physical system.

[0045] While a single image plane 402 is illustrated for purposes of explanation, it will be appreciated that a multi-aperture camera (or other multi-channel system) may have a number of physically offset optical channels that provide a different image plane for each channel, and the differences in feature locations (the x-y displacement) between the images for each optical channel may be represented as the disparity field. In various certain processing steps, the disparity data may be referenced to a single image plane such as a center channel image plane of the camera.

[0046] Fig. 5 illustrates a sequence of images captured from a moving camera. In the sequence 500, a camera 502, which may include, for example, any of the cameras 102 described above, may capture an image of an object 504 from a number of different positions 506a-506e along a camera path 507. While the camera path 507 is depicted as a continuous curvilinear path which represents the physical path of a camera, it will be understood that analytically the camera path 507 may be represented by discrete, straight line transformations along with associated rotations in three-dimensional space. While five camera positions are shown in the camera path 507 of Fig. 5, it will be appreciated that more or fewer camera positions may be used consistent with the principles described

herein. In an embodiment, the camera 502 may at each position 506 capture an image set:

$$\mathrm{ISn} = \left\{ \mathbf{x}_i = (x_i, y_i)^T \mid i = 1, \cdots, N_n \right\} \qquad \text{[Eq. 1]}$$

of two-dimensional images from which a point cloud:

$$PC_n = \left\{ \mathbf{X}_i = (X_i, Y_i, Z_i)^T \mid i = 1, \cdots, N_n \right\} \qquad \text{[Eq. 2]}$$

may be reconstructed (or any other suitable three-dimensional measurement for the camera position). In general, these three-dimensional point clouds (or other three-dimensional data) captured from the sequence 500 may be combined into a three-dimensional model such as an aggregate point cloud or other three-dimensional model of the object, such as by minimization of errors in a three-dimensional registration of individual three-dimensional measurements, or any of a variety of other techniques. It should also be understood that, in certain embodiments, the camera may remain fixed while the subject moves. In such cases, motion of the object 504 is determined, rather than motion of the camera 502, although the use of camera motion versus object motion may be a relatively arbitrary matter of convenience, or of the computational efficiency of a camera coordinate system versus an object coordinate system.

[0047] Fig. 6 is a conceptual representation of a three-dimensional data acquisition process 600 that may be used in the systems described above. In general, the camera (which may be any of the cameras described above) obtains two-dimensional measurements of a surface of an object 601 such as a first measurement 602 from a side channel (e.g., a left channel image), a second measurement from another side channel 604 (e.g., a right channel image), and a third measurement from a center channel 603 (e.g., a center channel image). It will be understood that while three channels are depicted, a system may recover three-dimensional data from more or less channels using various techniques that will be apparent to one of ordinary skill, and any such techniques that might be improved with the refinement techniques described herein are intended to fall within the scope of this disclosure. These measurements 602, 603, 604 may be processed, for example, to obtain a disparity field 606 that identifies relative movement of features within the images of each measurement. A camera model 610 for the camera may be used to relate the disparity field 606 to the three-dimensional reconstruction 612

of the surface of the object 610 as measured from a camera pose. While a center channel image may conveniently be used as the reference for the camera pose of the resulting three-dimensional reconstruction 612, this is not required and may not, in certain systems be available as a reference in any event. The three-dimensional reconstruction 612 can be stitched to other such three-dimensional measurements using camera path information or the like to obtain a three-dimensional model 620 of the object 601.

[0048] In a model refinement process as described below, one of the two-dimensional measurements, such as the first measurement 602, may be projected onto the three-dimensional model using available spatial information (e.g., the camera position and orientation). The resulting projection may then be backprojected to the second camera pose using warping or other deformation techniques to obtain an expected measurement at the second camera position. In the case of a side channel two-dimensional image or the like, the expected measurement may be a corresponding image expected in the center channel or another side channel. By adapting the three-dimensional measurement from this image pair to reduce or minimize an error between the actual and expected measurements in an overlapping area of the object, the three-dimensional measurement may be refined for that camera position to more accurately represent a surface of the object 601. In one aspect, the three-dimensional model may be directly refined with the new spatial information. In another aspect, the improved three-dimensional measurement for the camera may be used in a new motion estimation to recover camera path and three-dimensional model data for an entire scan or any portion thereof. By refining the individual three-dimensional measurements and the camera path in this manner, a more accurate three-dimensional model for the object may be obtained. It will be appreciated that, in general, error minimization may be performed on a number of different data sets that encode three-dimensional information, such as the two-dimensional image sets, or upon processed representations of these measurement such as the disparity field.

[0049] Fig. 7 is a flow chart of a process for refining three-dimensional data. In general, the process 700 refines a three-dimensional model by refining individual three-dimensional-measurements taken at different camera positions, which information may be employed to refine the resulting model. This process 700 may be usefully employed,

for example, to warp two-dimensional images in a module 362 of a high accuracy processing pipeline 350, such as to improve two-dimensional registration and/or three-dimensional stitching results. While a particular embodiment is described below in detail, it will be appreciated that any similar technique for generating an expected two-dimensional measurement at one camera position using an actual two-dimensional measurement from a different camera position, along with a three-dimensional model of the imaged subject matter (and a camera model as appropriate), may similarly be employed. Thus the techniques described herein may be readily adapted to other systems that obtain a three-dimensional model from a series of individual three-dimensional measurements, such as systems using structured light or systems using a series of two-dimensional images.

[0050] As shown in step 710, the process 700 may begin by acquiring frames of image data along a camera path. This image data may include image pairs that capture an image from two or more offset optical channels of a multi-aperture camera or other multi-channel imaging device. In one embodiment, each image in an image pair contains a two-dimensional image from two coupled poses having a known, fixed relationship to one another. In such an embodiment, a center channel may also be provided that captures a third image as a part of the frame of image data to provide a conventional, undistorted two-dimensional view of the scanned subject matter (where distortions in the side channels encode distance to a surface). The center channel may also serve as a reference pose for a three-dimensional measurement derived from the pair of two-dimensional images. It will be understood, however, that this arrangement is somewhat arbitrary, and other cameras may be employed such as a camera with a center channel and a single side channel, or only two side channels, or any of a number of other arrangements. More generally, any camera that captures two-dimensional images for use in a three-dimensional reconstruction may be used with techniques described herein.

[0051] As shown in step 712, three-dimensional measurements may be obtained from the image data. In general, this may include processing image sets or the like to obtain disparity data across a processing mesh of the camera, and further processing the disparity data to obtain a three-dimensional surface reconstruction. In one embodiment, the disparity data encodes depth information, and may be employed to recover a three-

dimensional measurement using a camera model or the like to relate disparity data to depth information for each pixel of the processing mesh. This step 712 may be repeated for each individual measurement (e.g., image set) obtained by the camera. As a result, a three-dimensional measurement or reconstruction may be obtained for each camera pose along a camera path. It will be understood that the disparity data is itself a three-dimensional measurement, and may be employed in place of a three-dimensional reconstruction for many of the processing steps described herein, with suitable adaptations being readily understood by one of ordinary skill in the art. It will further be understood that other three-dimensional imaging techniques are known and may be adapted to obtain three-dimensional measurements from an object surface.

[0052] As shown in step 714, a three-dimensional model may be constructed from the individual three-dimensional measurements obtained in step 712. Where the three-dimensional measurements of the surface of the object overlap, these three-dimensional measurements may be registered to one another using any of a variety of known techniques. As a result, the camera path from pose to pose may be recovered, and the three-dimensional measurements from each pose may be combined into a full three-dimensional model of scanned regions of the surface of the object.

[0053] As shown in step 716, a two-dimensional image or other measurement from one channel of a camera may be spatially projected onto the full three-dimensional model obtained in step 714. In general, the raw camera measurement includes a two-dimensional image of pixel values, which may be projected onto the three-dimensional model using texture mapping or any other suitable techniques to place the two-dimensional data from the image sets into the coordinate system of the three-dimensional model. As a significant advantage, this approach employs a three-dimensional model of the object that may, for example, contain global information that was not available when the data was initially collected. The model may, for example, average errors and/or reduce noise in individual camera measurements, as well as minimizing errors in a global camera path where possible. Using this initial model as a starting spatial reference point, the process 700 may revisit the individual three-dimensional measurements as further described below.

[0054] As shown in step 718, the projected measurement may be backprojected from the three-dimensional model to another channel of the camera, which may be the center channel or another side channel of the camera described above. The projected result from step 716 may be backprojected using any suitable techniques to obtain a synthetic view of the measurement from one camera channel as it should appear from the other camera channel, based upon the spatial relationship between the projected result, the three-dimensional model, and the position and rotation of the other channel. It will be appreciated that if there were no errors in the initial measurement, this synthetic view would exactly correspond to the actual two-dimensional image obtained from the other channel. However, in a high-speed processing pipeline such as that described above, an initial three-dimensional model may fail to accurately capture surface details for any number of reasons (lower resolution processing, absence of global surface data such as the completed three-dimensional model, etc.). Thus it is expected that in a practical system there may be variations between a synthesized view (based on observations from a different position) and an actual view. Backprojection may be accomplished, for example, by warping or otherwise deforming the projected result based upon the three-dimensional model and camera pose information for respective measurements. By processing these synthesized image sets to obtain disparity data, and further backprojecting the synthesized disparity data through the camera model, a backprojected result may be obtained that represents a synthesized or expected version of the three-dimensional measurement from the second camera position.

[0055] As shown in step 720, a three-dimensional measurement by a camera (e.g., the measurement derived from an image set in a frame of data) may be refined by adjusting the three-dimensional reconstruction to minimize an error between the backprojected result obtained in step 718 and an actual corresponding two-dimensional measurement captured in step 710. More generally, where two images contain measurements from an overlapping portion of the surface of the object, the backprojected (e.g., synthesized) measurement and the actual measurement may be directly compared. In one embodiment, camera calibration data and other information descriptive of the camera or the channels of the camera may be incorporated into the projection and/or

backprojection in order to improve three-dimensional accuracy of the resulting three-dimensional measurement.

[0056] As shown in step 722, the three-dimensional model may be refined based upon the refined three-dimensional measurements for each frame of image data. A number of techniques may be employed to refine the model. In one aspect, the three-dimensional data for a refined three-dimensional measurement may be used to directly modify the three-dimensional model, e.g., by estimating the contribution of the changes in the refined three-dimensional measurement on the reconstruction process for the three-dimensional model. In another aspect, a new motion-based reconstruction for some or all of the scan data may be performed using the refined three-dimensional measurements in place of the initial three-dimensional measurements to recover a camera path used to relate the individual measurements to a global coordinate system. In another aspect, this process may be repeated to obtain iterative refinements in the three-dimensional model, e.g., for a predetermined number of iterations, or until a predetermined error threshold is reached, or until no further refinement is obtained from a previous iteration, and so forth, as well as various combinations of these. Iterations may be performed locally (e.g., on specific regions where errors are large) or globally (e.g., for every overlapping region between camera positions), or some combinations of these.

[0057] It will also be appreciated that this approach may be usefully employed with other three-dimensional reconstruction techniques, as well as in other ways within the image-pair based processing described above. For example, while the model-based refinement of a specific three-dimensional measurement may improve accuracy, the same approach may be employed to backproject a two-dimensional image from one image set onto a two-dimensional image from another image set in order to achieve frame-to-frame improvements in accuracy. Further, these image sets may be offset by any number of intervening image sets, and complementary, bi-directional refinements may be performed for any and all of the foregoing wherever the two measurements contain some overlap on the surface of the object. More generally, while a technique for testing a specific set of overlapping measurements is described above, this technique may be repeated any number of times, in any order, for some or all of the overlapping regions in

measurements used to obtain a three-dimensional model, and all such variations are intended to fall within the scope of this disclosure.

[0058] Fig. 8 is a flow chart of a global path optimization. In one aspect, the refinement of individual three-dimensional measurements may be used in combination with numerical techniques for global path optimization for an entire camera path to yield further iterative improvement to a resulting three-dimensional model. A suitable global path optimization technique is now described in greater detail.

[0059] The process 800 may begin with preprocessing as shown in step 810. It will be understood that preprocessing as described herein presupposes the availability of a number of frames of image data from which a camera path and three-dimensional model can be reconstructed. The information for the three-dimensional reconstruction may be generated in numerous ways including coming from structured light projection, shading based three-dimensional reconstruction, or disparity data. Disparity data may be generated by a conventional image plus one or more other channels or side channels. The preprocessing may include determining the number of available frames, the amount of overlap between neighboring frames, identification and elimination of frames with blurred or badly distorted images, and any other suitable preprocessing steps. An estimate of the number of desired key frames may be initially determined during the preprocessing step.

[0060] As shown in step 812, key frames may be selected from among all of the frames of data acquired from a scanner along a camera path. In general, computational costs can be reduced by storing certain data and performing certain calculations and processing steps exclusively with reference to key frames. These key frames may be related to one another in a manner that permits characterization of a complete camera path, typically through the registration of overlapping three-dimensional data in respective key frames. Various methods are known in the art for selecting a subset of frames of data as key frames, including techniques based on image overlap, camera path distance, the number of intervening non-key frames and so forth. Key frames may also or instead be selected based upon an amount of image overlap from the preceding key frame and/or a candidate for a following key frame (if available). Too little overlap may impair frame-to-frame registration. Too much overlap may produce excess key frames

requiring additional processing. Key frames may be selected based on spatial displacement. Key frames may also be selected based on sequential displacement. This type of sequential displacement could mean for example that every tenth frame is selected as a key frame. In one aspect, key frames may be selected as data is acquired based on any number of suitable criteria. In another aspect, key frame pairs may be determined post hoc by examining all possible candidate key frames. All possible key frame pairs may be examined and candidates may be removed, for example, where there is insufficient overlap to form a stitch. Still more generally, any technique suitable for selecting a subset of frames in a data set may be usefully employed to select key frames for processing in order to reduce computational complexity.

[0061] Once key frames have been selected, additional processing may be performed. For example, full image data (e.g., full resolution center and side channel images) may be stored for each key frame, along with image signature data, point cloud centroid calculations, and any other measured or calculated data to support use of the key frames in a three-dimensional reconstruction process as described herein.

[0062] As shown in step 814, candidate stitches may be identified. In general, a stitch is a relationship between two separate three-dimensional measurements from two different camera poses. Once a stitch is established, a rotation and a translation may be determined for the path of a camera between the two poses. In a complementary fashion, the three-dimensional measurements from the poses may be combined into a portion of a three-dimensional model. Candidate stitches may be analyzed around each key frame, such as from the key frame to some or all of the frames of data between the key frame and neighboring key frames. In another aspect, a candidate stitch may be made to every other key frame, or in order to reduce computational complexity, every key frame within a spatial or sequential neighborhood around a key frame. Stitches may be based on the originally imaged frames. It may also be useful to deform or warp two-dimensional images during registration and other steps in a stitching process in order to improve accuracy and/or speed. Stitches may also or instead be based on other observed epipolar relationships in source data.

[0063] As shown in step 816, stitches may be selected for the complete camera path from the universe of candidate stitches. The selection of stitches may be made based

upon, e.g., the lowest calculated error in resulting portions of the three-dimensional model. In general, each key frame may be stitched to one or more other key frames and each non-key frame may be stitched to at least one sequentially neighboring key frame.

[0064] As shown in step 818, a graph analysis may be performed using the key frames and the associated stitching to calculate a global path for the camera used to obtain a three-dimensional model. The graph analysis may consider each key frame as a node or vertex and each stitch as an edge between a pair of nodes. A key frame is selected as a starting point. A breadth- or depth-first search may be performed through the graph to identify stitches which may connect the current key frame to another key frame. Each key frame may be marked as the graph is processed. A check may be performed to see if all key frames have been reached within the graph. If all key frames have not been reached through traversing stitches in the graph analysis, the largest sub-graph is identified. This sub-graph may be examined to see if the entire three-dimensional image may be modeled.

[0065] It may be that certain sub-graphs are not required to complete the three-dimensional imaging. If the camera lingered over a particular region of a surface of an object, or if the camera looped on a region multiple times, the associated sub-graph(s) may not be needed. If a separate sub-graph is identified, which is needed to complete the three-dimensional imaging, an optional branch back to step 812 may be performed. For example, a set of key frames may have been selected which did not have sufficient stitching from one key frame to the next key frame. By choosing a different set of key frames, sufficient stitching may be obtained in order to obtain a complete graph of all needed aspects of the three-dimensional imaging. A key frame which is too sparse, meaning it has insufficient stitches to aid in building a graph, may indicate that a different set of key frames should be selected. Based on the graph analysis, a global path may be selected, and the graph may then be analyzed to optimize the path calculation.

[0066] As shown in step 820, a numerical optimization may be performed to reduce errors in the calculated camera path based upon available data for the complete camera path such as, for example, cross links that interrelate temporally distant measurements. In general, the objective of numerical optimization is to minimize a calculated error based upon an error function for the camera path and/or reconstructed

three-dimensional model. A useful formulation of the error minimization problem for a global camera path is presented below.

[0067] There may be a set of candidate camera poses, each including a rotation and a translation (or position) referenced to a world coordinate system. There may also be a set of measured frame-to-frame camera motions, each including a rotation and a translation between poses. A measured camera motion may be referenced in the coordinate system of one camera pose. An example set of three key frames may be considered with an origin "O" and three other points "A", "B", and "C", each of the points having a position in a three-dimensional space. In addition to the position of these points, a camera at each of these points may have a different orientation. Therefore, between each of these points is a translation, meaning a change in position, and a rotation, meaning a change in orientation. The translation and rotation values comprise the motion parameters. The relationship between a point, X, expressed in the world coordinate system as X_O and the same point expressed in the A coordinate system, X_A may be expressed as:

$$X_A = R_{OA} X_O + T_{OA} \qquad \text{[Eq. 3]}$$

R_{OA} is the rotation taking points from the world to the A coordinate system. T_{OA} is the translation of the world coordinate system to the A coordinate system. It should be understood that symbols X and T may represent a vector, rather than a scalar, e.g. where X includes x, y, and z coordinate values. Further, it should be understood that symbol R may represent a matrix. The following equations may similarly represent the transformation between the world and the B and C coordinate systems respectively:

$$X_B = R_{OB} X_O + T_{OB} \qquad \text{[Eq. 4]}$$

$$X_C = R_{OC} X_O + T_{OC} \qquad \text{[Eq. 5]}$$

[0068] By rearranging, equations 4 and 5 may be represented as follows:

$$X_O = R_{OA}^{-1}\left(X_A - T_{OA}\right) = R_{OB}^{-1}\left(X_B - T_{OB}\right) \qquad \text{[Eq. 6]}$$

[0069] The representation of a point in one camera's coordinate system may be related to the same point in another coordinate system. For example, as in equations 3-5, coordinates of a point, X, may be transformed from the A coordinate system to the B coordinate system as follows:

$$X_B = R_{AB} X_A + T_{AB} \qquad \text{[Eq. 7]}$$

[0070] The rotation R_{AB} rotates points from the A to the B coordinate system and T_{AB} translates the origin of the A coordinate system to the B coordinate system.

[0071] In optimization, the pose of every camera may be optimized based on measured transformations between poses. That is, a number of camera-to-world rotations and camera-to-world translations, R_{On} and T_{On} may be performed. In general, one of these may be defined as the identity rotation and zero translation, with the remaining values may be optimized as described below.

[0072] The rotations and translations may be measured for many pairs of cameras. For the ith such measured frame-to-frame motion, let one of the cameras of the pair be camera A and the other be camera B. This may also be considered the ith stitch. Let R^i_{AB} be the measured rotation taking points in the A system to the B system and T^i_{AB} be the coordinates of the A position expressed in the B system, as in equation 7.

[0073] The rotations and translations for all cameras, R_{On} and T_{On} may be optimized. $R^i_{C,OA}$ and $R^i_{C,OB}$ may be defined to be the candidate rotations; $T^i_{C,OA}$ and $T^i_{C,OB}$ may be defined to be the candidate translations corresponding to the A and B camera of the ith stitch. Further, $R^i_{C,AB} = R^i_{C,OB}(R^i_{C,OA})^{-1}$ may be defined as the candidate rotation from A to B, and $T^i_{C,AB} = T^i_{C,OB} - R^i_{C,AB} T^i_{C,OA}$, the candidate translation for the transformation from A to B.

[0074] Note that with sufficient stitches, the motion constraints may form an overdetermined system of motion constraint equations. Using these equations as a starting point, numerical optimization may be performed on the rotational and translational components of each camera based on the measured stitches.

[0075] In a decoupled optimization, the rotational and translational components may be independently optimized. Given a candidate set of camera rotations, R^i_C the corresponding candidate camera-to-camera rotations, $R^i_{C,AB}$, may be computed that correspond to each of the measured camera-to-camera rotations, R^i_{AB}. Thus the corresponding residual rotations are given by $R^i_{residual,AB} = R^i_{C,AB}(R^i_{AB})^{-1}$. A scalar-valued

rotational cost function, e_r, may be computed that depends on the candidate camera rotations

$$e_r(R_{C,On}) = \sum_{i=1}^{\#stitches} r_r^{iT} r_r^i, \quad where\ r_r^i = \log_{SO(3)} R^i_{residual,AB}, \qquad [Eq.\ 8]$$

[0076] In equation 8, $\log_{SO(3)}(R)$ returns the axis-angle vector, v, that corresponds to the rotation R. In other words, $\log_{SO(3)}(R)$ returns the vector, v, that has a cross-product matrix, $[v]_x$, that is the matrix logarithm of R.

[0077] Next, a similar scalar-valued cost function may be computed for translation that depends on the candidate rotations and translations.

$$e_t(R_{C,On}, T_{C,On}) = \sum_{i=1}^{\#stitches} r_t^{iT} r_t^i, \quad where\ r_t^i = T^i_{C,AB} - T^i_{AB} \qquad [Eq.\ 9]$$

[0078] Equation 8 may be minimized as a nonlinear optimization; equation 9 may be minimized as a linear optimization.

[0079] In one conventional, decoupled approach to solving these simultaneous systems of equations, the rotational error function may be converted into a quaternion expression in order to translate the numerical problem into a linear system of equations for solution. While this approach may increase computational efficiency, it offers an incomplete optimization solution.

[0080] The decoupled approach described above does not provide a truly optimal one, in a maximum-likelihood sense, as it cannot use information from the translation portion of the stitches in determining rotation. In order to achieve a coupled optimization a weighting may be used to balance the contributions of rotational and translational components to a combined cost function:

$$e_c(R_{C,On}, T_{C,On}) = \sum_{i=1}^{\#stitches} \left(\begin{bmatrix} r_t^i \\ r_r^i \end{bmatrix}^T W_c^i \begin{bmatrix} r_t^i \\ r_r^i \end{bmatrix} \right) \qquad [Eq.\ 10]$$

Multiple approaches may be used to optimize this cost function, but in one embodiment the weights may be expressed as matrices. Different stitches may receive different weightings based upon a number of factors including the number of points in the stitch (e.g., the shared content), the quality of a particular three-dimensional measurement, and/or any other factors impacting the known reliability of a stitch. In one approach, the

weight matrices may also account for anisotropic error in the individual points collected, such as due to acquisition of depth information from disparity measurements, which results in measurement precision that varies with distance from the camera.

[0081] In some cases, equation 10 may be reformulated so that the rotation and translation weights are decoupled for each stitch (i.e., W_c^i is a block diagonal). In particular, this may occur in the case where the motion stitches are recovered from three-dimensional point correspondences with isotropic point error. In that case, for a given stitch i, between camera A and camera B, the optimal solution may bring the point cloud as seen from camera A into correspondence with that seen from camera B. If $\overline{X}_A^i$ and $\overline{X}_B^i$ are the positions of the center of the point cloud in the A and B systems respectively, then r_t^i may be replaced in equation 10 with the residual displacement between the point-cloud centers based on the candidate camera pose as follows:

$$r_{t,ctr}^i = \overline{X}_B^i - (R_{C,AB}^i \overline{X}_A^i + T_{C,AB}^i) \qquad \text{[Eq. 11]}$$

Equation 10 may then be reformulated as:

$$e_c(R_{C,On}, T_{C,On}) = \sum_{i=1}^{\#stitches} \left(r_{t,ctr}^{i\,T} W_r^i r_{t,ctr}^i + r_r^{iT} W_r^i r_r^i \right) \qquad \text{[Eq. 12]}$$

This coupled optimization problem may still be considered as being non-linear. It should be understood that other optimizations are also possible that would fall within the scope of this disclosure.

[0082] In general, by minimizing equation 10, both rotational errors and translational errors may be minimized simultaneously. The weight matrices can be chosen, for example, according to "First Order Error Propagation of the Procrustes Method for 3D Attitude Estimation" by Leo Dorst, IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol. 27, No. 2, Feb. 2005, pp. 221-9 which is incorporated in its entirety by reference. Once a more consistent set of motion parameters has been generated the three-dimensional model may be updated.

[0083] In one aspect, the residual error may be employed as a calibration metric. When total error or some portion of error has been minimized, the residual error may be evaluated. If a minimized error falls beyond a certain threshold then calibration for the scanner and associated hardware may be recommended, based upon an inference that the

inability to produce better quality results is due to a miscalibration or other malfunction of the camera system. The threshold value may be empirically determined based on the specific scanner hardware equipment or it may be learned experientially over time for a given system. When a system is new or has been freshly aligned, expected minimized error values may be obtained. When minimized error values deviate from these expected values, a calibration state evaluation flag may be set, or other alert or message generated, indicating that the tool should be calibrated.

[0084] As shown in step 822, upsampling may be performed to augment a three-dimensional model with data from non-key frames. For example, non-key frames may be registered to nearby key frames to create small, local reconstruction patches including the full image detail available from non-key frames. In this manner, path optimization may be performed on a key-frame-based data set, thus reducing the data requiring processing, while retaining additional data points from non-key frames for use in the final three-dimensional model.

[0085] It will be appreciated that any of the above system and/or methods may be realized in hardware, software, or any combination of these suitable for the data acquisition and modeling technologies described herein. This includes realization in one or more microprocessors, microcontrollers, embedded microcontrollers, programmable digital signal processors or other programmable devices, along with internal and/or external memory. The may also, or instead, include one or more application specific integrated circuits, programmable gate arrays, programmable array logic components, or any other device or devices that may be configured to process electronic signals. It will further be appreciated that a realization may include computer executable code created using a structured programming language such as C, an object oriented programming language such as C++, or any other high-level or low-level programming language (including assembly languages, hardware description languages, and database programming languages and technologies) that may be stored, compiled or interpreted to run on one of the above devices, as well as heterogeneous combinations of processors, processor architectures, or combinations of different hardware and software. Thus in one aspect there is disclosed herein a computer program product comprising computer executable code that, when executing on one or more computing devices, performs any

and/or all of the steps described above. At the same time, processing may be distributed across devices such as a camera and/or computer and/or fabrication facility and/or dental laboratory and/or server in a number of ways or all of the functionality may be integrated into a dedicated, standalone device. All such permutations and combinations are intended to fall within the scope of the present disclosure.

[0086] While the invention has been disclosed in connection with the preferred embodiments shown and described in detail, various modifications and improvements thereon will become readily apparent to those skilled in the art. Accordingly, the spirit and scope of the present invention is not to be limited by the foregoing examples, but is to be understood in the broadest sense allowable by law.

CLAIMS

What is claimed is:

1. A method of refining a three-dimensional model comprising the steps of:

providing a three-dimensional model of an object;

obtaining a first two-dimensional image of the object from a first camera pose;

obtaining a second two-dimensional image of the object from a second camera pose, wherein the second two-dimensional image includes a common portion of a surface of the object with the first two-dimensional image;

deforming the first two-dimensional image based upon a spatial relationship of the first camera pose, the second camera pose, and the three-dimensional model to obtain an expected image from the second camera pose based upon the first camera pose;

comparing the second two-dimensional image to the expected image to identify one or more discrepancies; and

correcting the three-dimensional model based upon the one or more discrepancies.

2. The method of claim 1 wherein the first camera pose and the second camera pose include a position and an orientation of a single camera in two dependent positions.

3. The method of claim 2 wherein the first camera pose and the second camera pose include a position and an orientation of two offset channels of a multi-aperture camera.

4. The method of claim 1 wherein the first camera pose and the second camera pose include a position and an orientation of a single camera in two independent positions.

5. The method of claim 4 wherein a relationship between the first camera pose and the second camera pose is calculated based upon a three-dimensional measurement of the surface of the object from each of the first camera pose and the second camera pose.

6. The method of claim 1 further comprising deriving the three-dimensional model from a plurality of three-dimensional measurements of the surface of the object from a plurality of camera poses including the first camera pose and the second camera pose.

7. The method of claim 1 further comprising applying the one or more discrepancies to directly refine the three-dimensional model.

8. The method of claim 1 further comprising applying the one or more discrepancies to refine a three-dimensional measurement from one or more of the first camera pose and the second camera pose to provide a refined measurement.

9. The method of claim 8 further comprising refining a camera path calculation for a camera path used to create the three-dimensional model using the refined measurement to provide a refined camera path.

10. The method of claim 9 further comprising using the refined camera path and the refined measurement to refine the three-dimensional model.

11. The method of claim 1 wherein the three-dimensional model includes a point cloud or a polygonal mesh.

12. The method of claim 1 wherein the object includes human dentition.

13. The method of claim 1 wherein the second camera pose corresponds to a center channel of a multi-aperture camera system, the center channel providing a conventional two-dimensional image of the object.

14. The method of claim 14 further comprising obtaining a third two-dimensional image of the object from a third camera pose corresponding to a second side channel of the multi-aperture system and deforming the third two-dimensional image to an expected

image for the center channel for use in further refining the three-dimensional measurement from the multi-aperture camera system.

15. A computer program product for refining a three-dimensional model of an object comprising computer executable code embodied on a computer readable medium that, when executing on one or more computing devices, performs the steps of:

providing a three-dimensional model of an object;

obtaining a first two-dimensional image of the object from a first camera pose;

obtaining a second two-dimensional image of the object from a second camera pose, wherein the second two-dimensional image includes a common portion of a surface of the object with the first two-dimensional image;

deforming the first two-dimensional image based upon a spatial relationship of the first camera pose, the second camera pose, and the three-dimensional model to obtain an expected image from the second camera pose based upon the first camera pose;

comparing the second two-dimensional image to the expected image to identify one or more discrepancies; and

correcting the three-dimensional model based upon the one or more discrepancies.

16. The computer program product of claim 15 wherein the first camera pose and the second camera pose include a position and an orientation of a single camera in two dependent positions.

17. The computer program product of claim 16 wherein the first camera pose and the second camera pose include a position and an orientation of two offset channels of a multi-aperture camera.

18. The computer program product of claim 15 wherein the first camera pose and the second camera pose include a position and an orientation of a single camera in two independent positions.

19. The computer program product of claim 18 wherein a relationship between the first camera pose and the second camera pose is calculated based upon a three-dimensional measurement of the surface of the object from each of the first camera pose and the second camera pose.

20. The computer program product of claim 15 further comprising code for performing the step of deriving the three-dimensional model from a plurality of three-dimensional measurements of the surface of the object from a plurality of camera poses including the first camera pose and the second camera pose.

21. The computer program product of claim 15 further comprising code for performing the step of applying the one or more discrepancies to directly refine the three-dimensional model.

22. The computer program product of claim 15 further comprising code for performing the step of applying the one or more discrepancies to refine a three-dimensional measurement from one or more of the first camera pose and the second camera pose to provide a refined measurement.

23. The computer program product of claim 22 further comprising code for performing the step of refining a camera path calculation for a camera path used to create the three-dimensional model using the refined measurement to provide a refined camera path.

24. The computer program product of claim 23 further comprising code for performing the step of using the refined camera path and the refined measurement to refine the three-dimensional model.

25. The computer program product of claim 15 wherein the three-dimensional model includes a point cloud or a polygonal mesh.

26. The computer program product of claim 15 wherein the object includes human dentition.

27. The computer program product of claim 15 wherein the second camera pose corresponds to a center channel of a multi-aperture camera system, the center channel providing a conventional two-dimensional image of the object.

28. The computer program product of claim 15 further comprising code for performing the steps of obtaining a third two-dimensional image of the object from a third camera pose corresponding to a second side channel of the multi-aperture system and deforming the third two-dimensional image to an expected image for the center channel for use in further refining the three-dimensional measurement from the multi-aperture camera system.

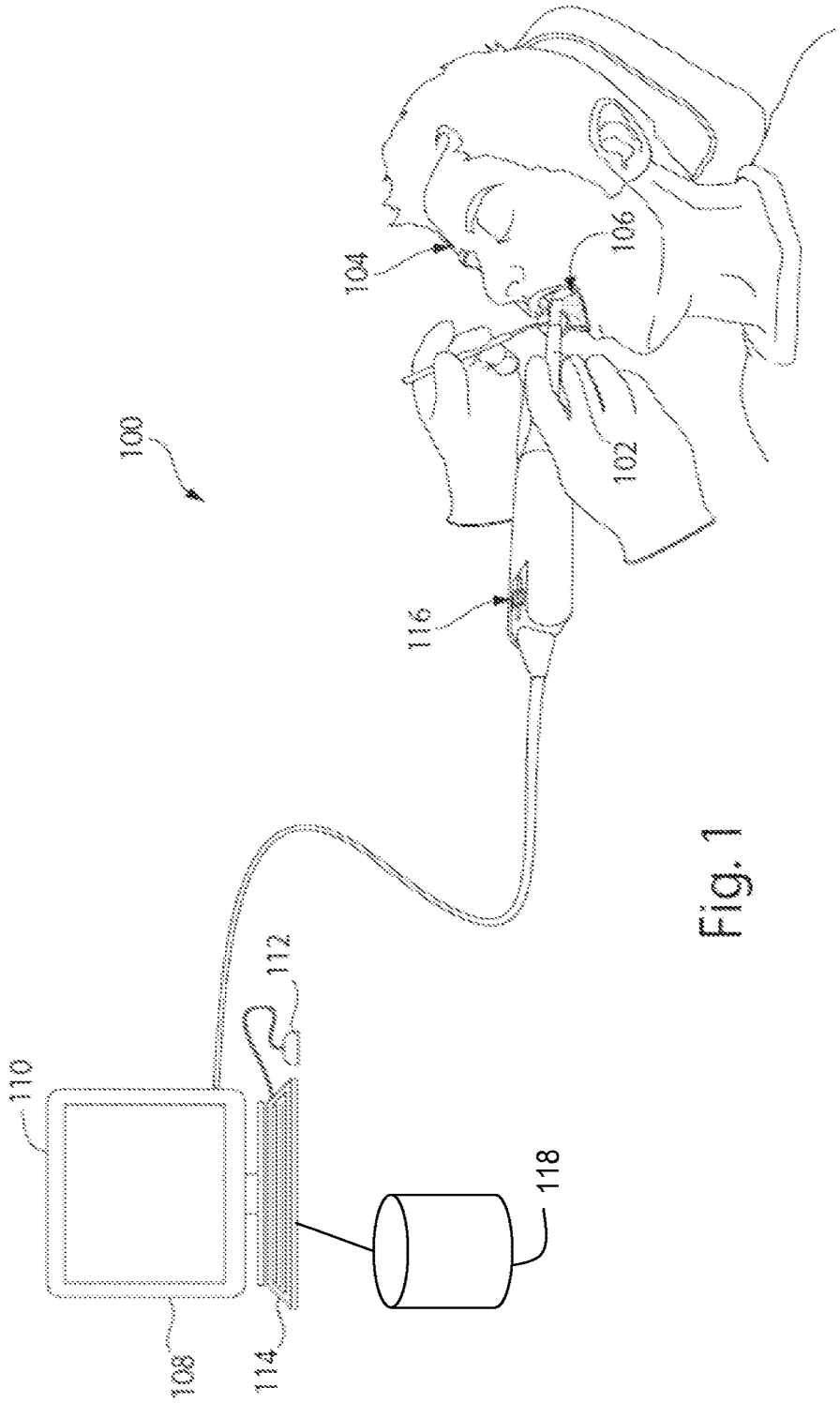


Fig. 1

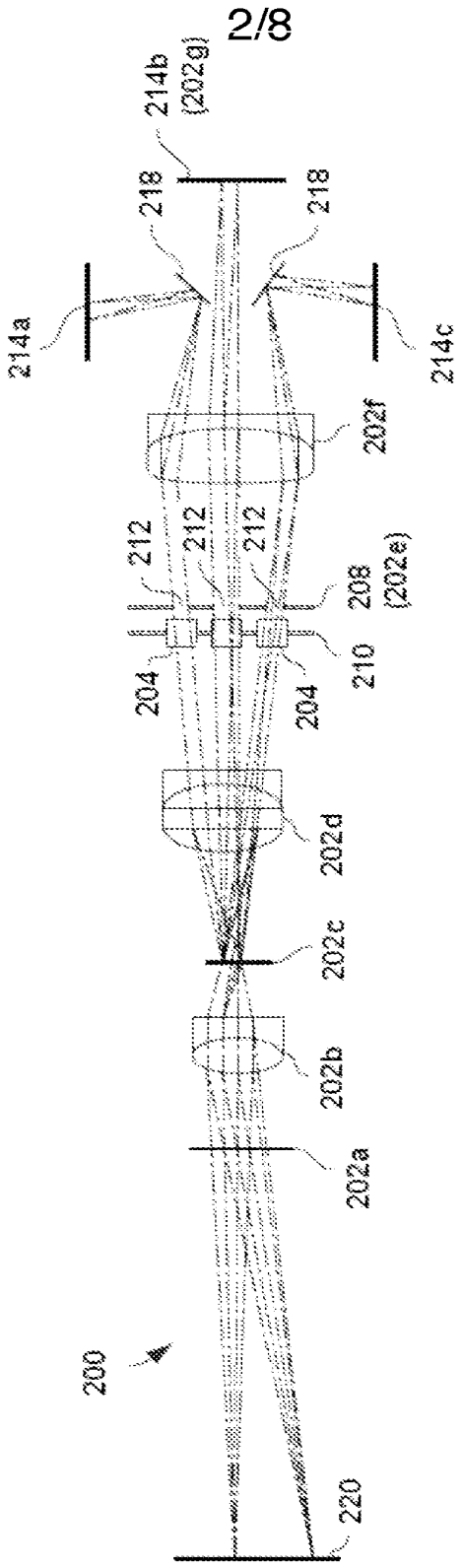
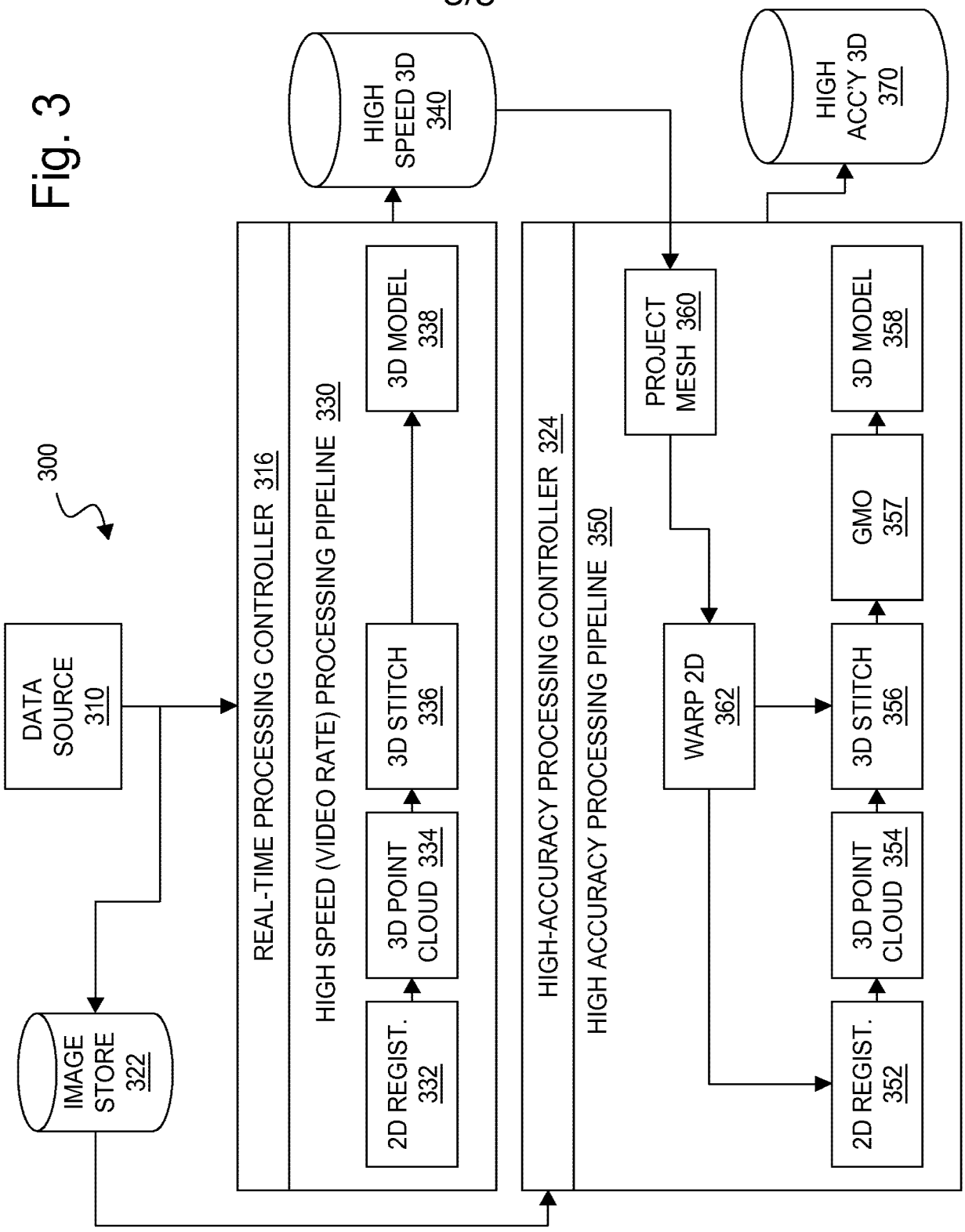

214b
(202g)
218
218
214a
214c
202f
212
212
212
208
(202e)
210
204
204
202d
202c
202b
202a
200
220

Fig. 2

Fig. 3


300
DATA SOURCE 310
IMAGE STORE 322
REAL-TIME PROCESSING CONTROLLER 316
HIGH SPEED (VIDEO RATE) PROCESSING PIPELINE 330
2D REGIST. 332
3D POINT CLOUD 334
3D STITCH 336
3D MODEL 338
HIGH SPEED 3D 340
HIGH-ACCURACY PROCESSING CONTROLLER 324
HIGH ACCURACY PROCESSING PIPELINE 350
2D REGIST. 352
3D POINT CLOUD 354
3D STITCH 356
GMO 357
3D MODEL 358
WARP 2D 362
PROJECT MESH 360
HIGH ACC'Y 3D 370

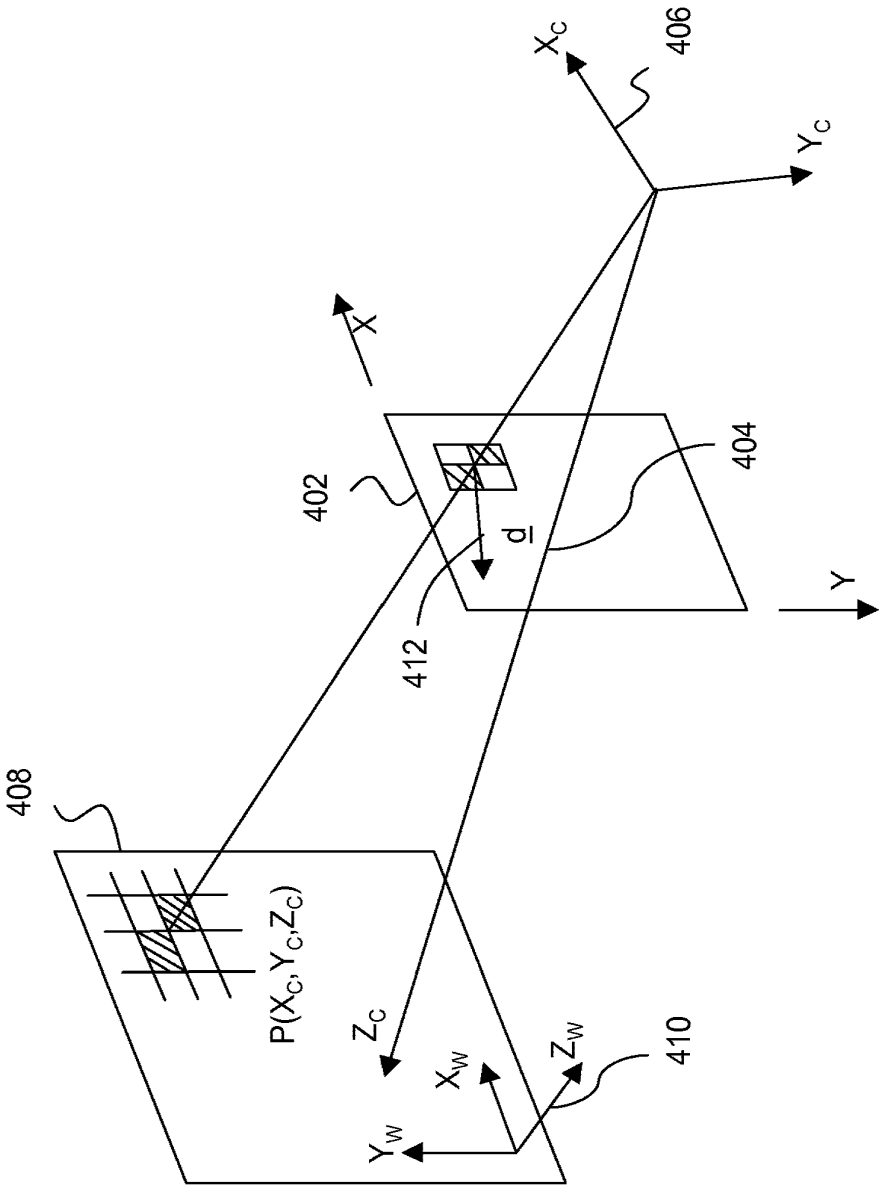


Fig. 4

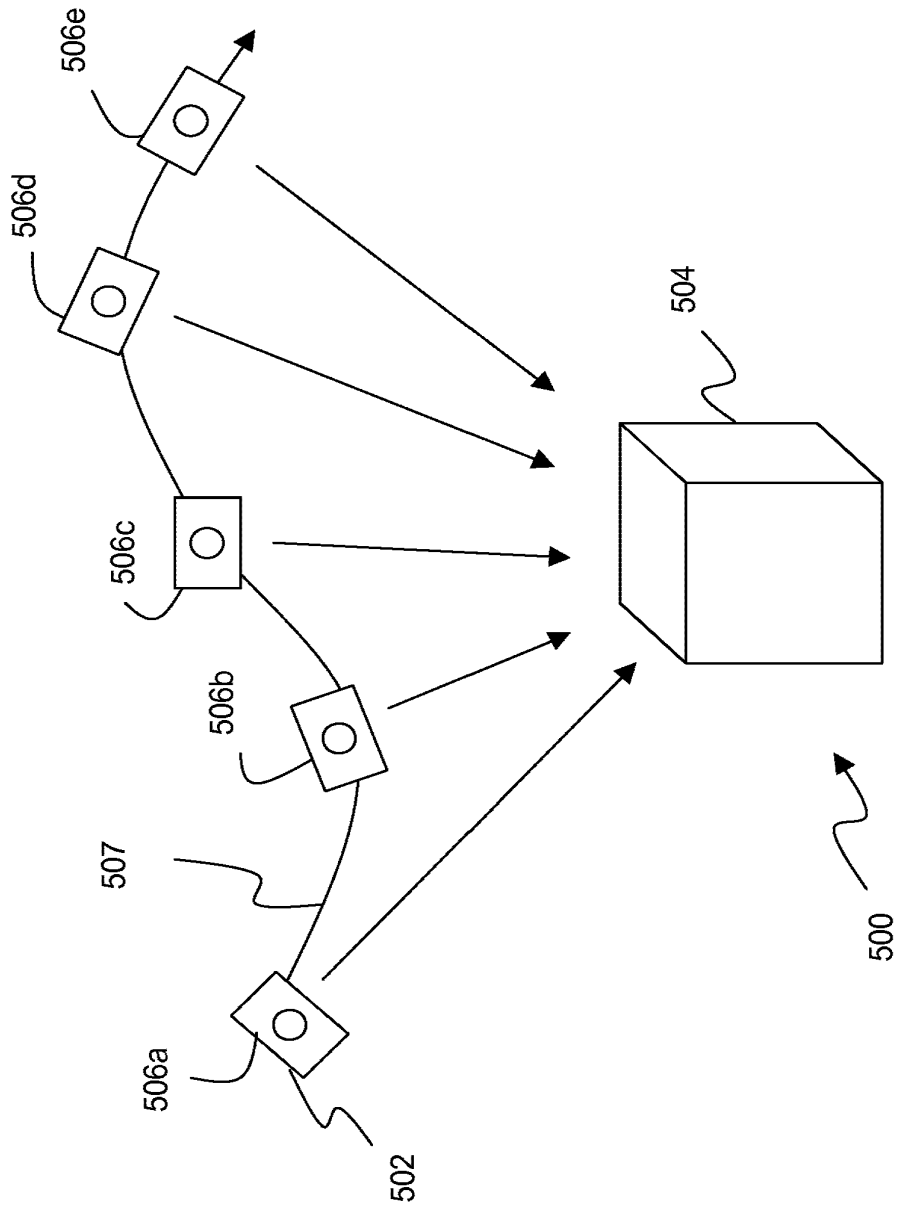


Fig. 5

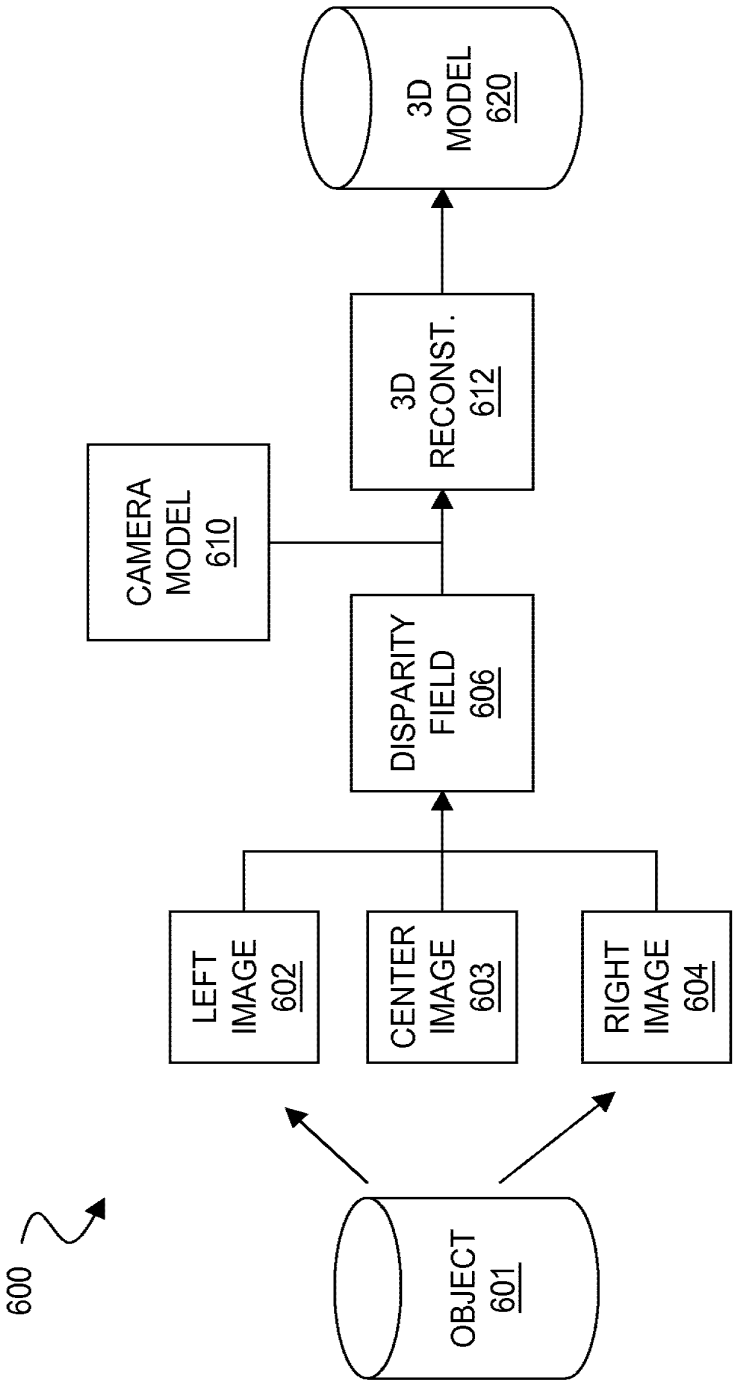

600
OBJECT 601
LEFT IMAGE 602
CENTER IMAGE 603
RIGHT IMAGE 604
DISPARITY FIELD 606
CAMERA MODEL 610
3D RECONST. 612
3D MODEL 620

Fig. 6

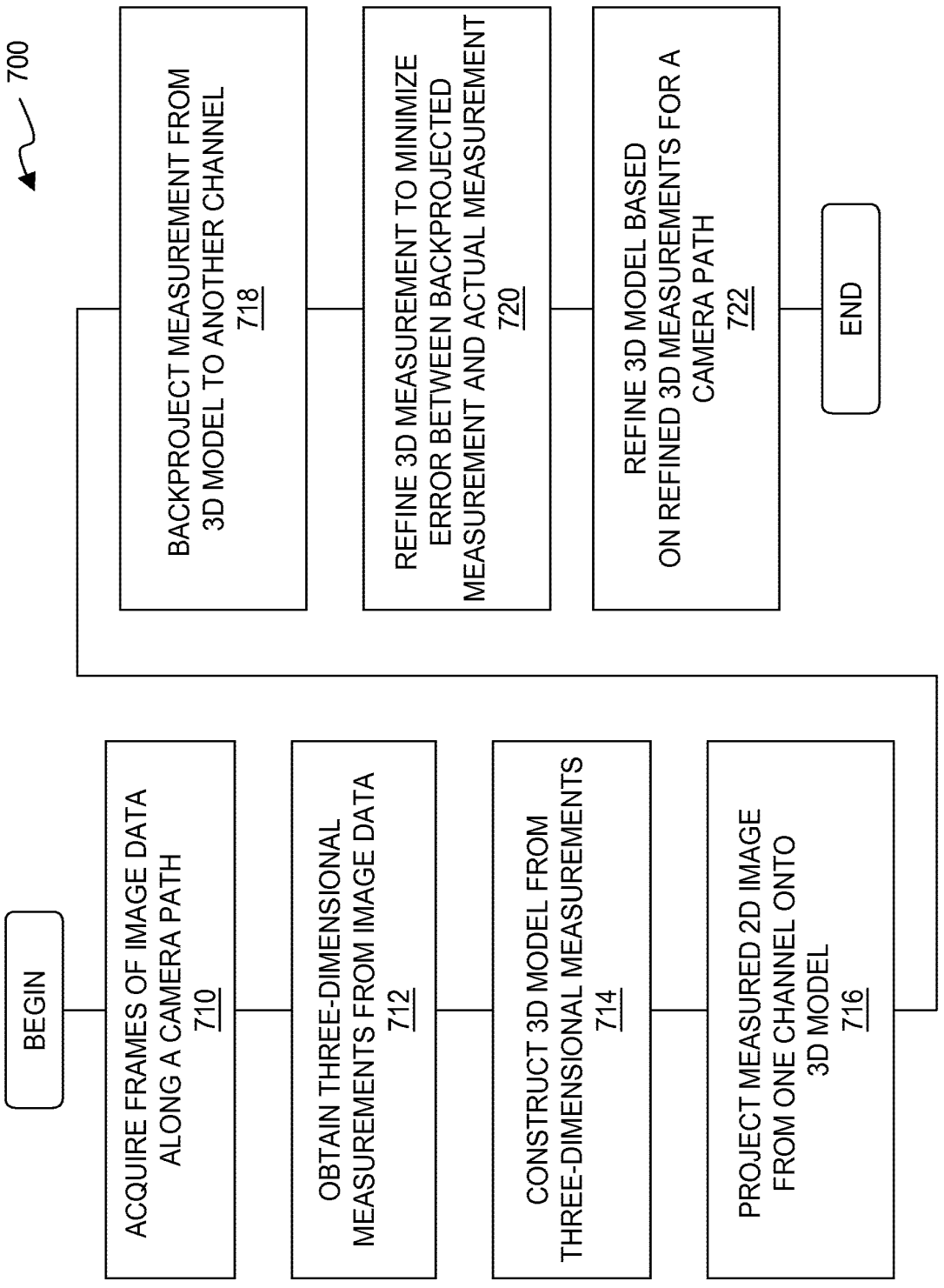

700
BEGIN
ACQUIRE FRAMES OF IMAGE DATA ALONG A CAMERA PATH
710
OBTAIN THREE-DIMENSIONAL MEASUREMENTS FROM IMAGE DATA
712
CONSTRUCT 3D MODEL FROM THREE-DIMENSIONAL MEASUREMENTS
714
PROJECT MEASURED 2D IMAGE FROM ONE CHANNEL ONTO 3D MODEL
716
BACKPROJECT MEASUREMENT FROM 3D MODEL TO ANOTHER CHANNEL
718
REFINE 3D MEASUREMENT TO MINIMIZE ERROR BETWEEN BACKPROJECTED MEASUREMENT AND ACTUAL MEASUREMENT
720
REFINE 3D MODEL BASED ON REFINED 3D MEASUREMENTS FOR A CAMERA PATH
722
END

Fig. 7

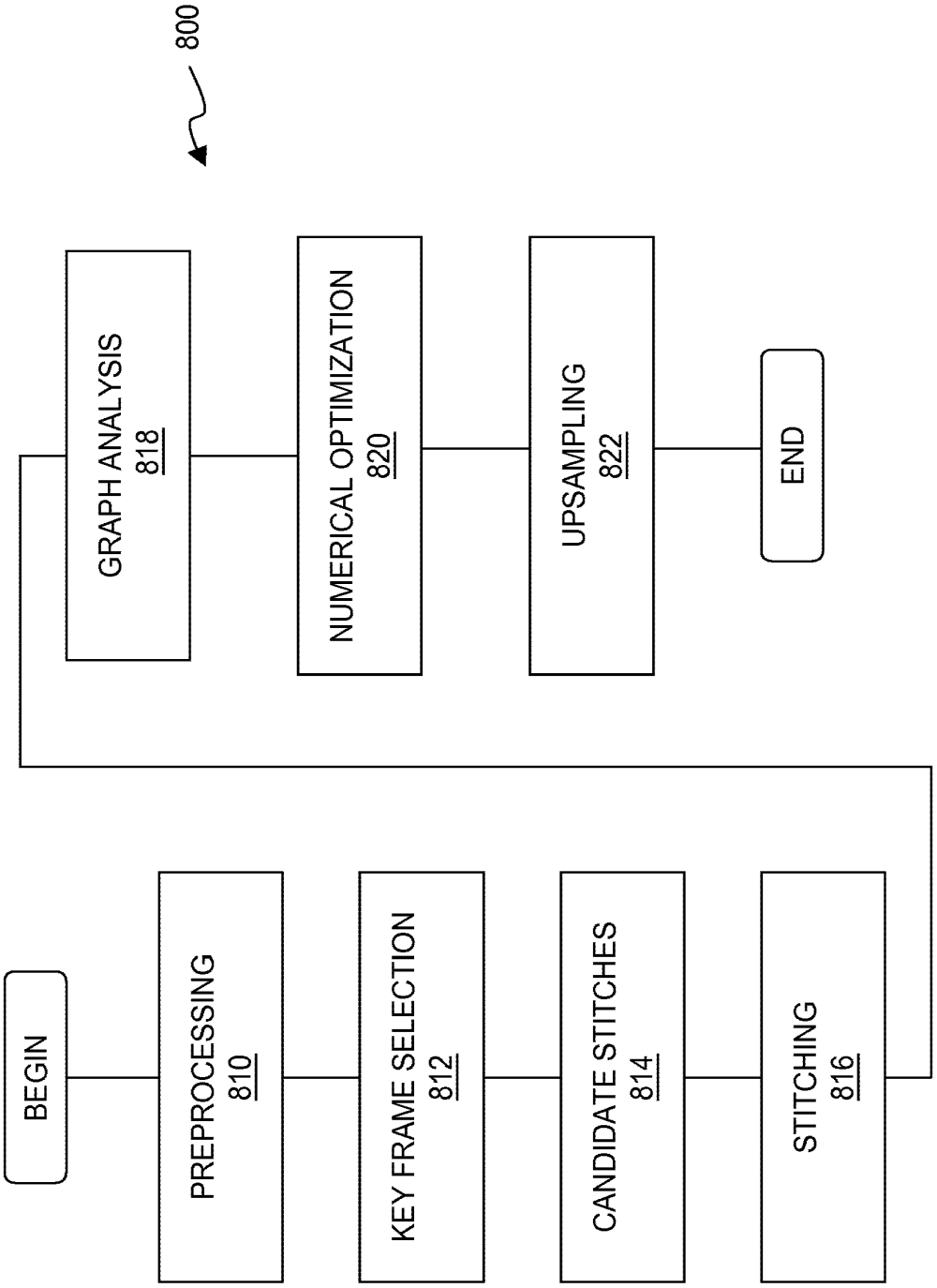

800
BEGIN
PREPROCESSING
810
KEY FRAME SELECTION
812
CANDIDATE STITCHES
814
STITCHING
816
GRAPH ANALYSIS
818
NUMERICAL OPTIMIZATION
820
UPSAMPLING
822
END

Fig. 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2009/030065

A. CLASSIFICATION OF SUBJECT MATTER

H04N 13/00(2006.01)i, H04N 13/02(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC H04N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean Utility models and applications for Utility Models : IPC as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKIPASS(KIPO Internal) : "3D", "MODEL", "CAMERA", "DISCREPANCY"

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y A	US 2006-0204076 A1 (GOPAL B. AVINASH et al.) 14 September 2006 See abstract; claims 1-25; figures 1-9.	1, 4,11-12,15,18,25-26 2-3,5-10,13-14, 16-17, 19-24, 27-28
Y A	US 2007-0103460 A1 (TONG ZHANG et al.) 10 May 2007 See abstract; claims 1-53; figures 1-5.	1, 4,11-12,15,18,25-26 2-3,5-10,13-14, 16-17, 19-24, 27-28
A	KR 10-2007-0039641 A (PANTECH CO., LTD.) 13 April 2007 See abstract; claims 1-13; figures 1-7.	1-28

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
27 MAY 2009 (27.05.2009)	**28 MAY 2009 (28.05.2009)**

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2009/030065

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2006-0204076 A1	14.09.2006	DE 102006009570 A1	07.09.2006
		JP 2006-239420 A	14.09.2006
US 2007-0103460 A1	10.05.2007	EP 1952354 A2	06.08.2008
		WO 2007-056768 A2	18.05.2007
KR 10-2007-0039641 A	13.04.2007	None	

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23 September 2010 (23.09.2010)

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(30) Priority Data:
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(74) Agent: **HEPWORTH, John**; Hepworth Browne, Bourton Hall, Rugby Warwickshire CV23 9SD (GB).

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(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

(54) **Title**: ULTRASOUND PROBE WITH ACCELEROMETER

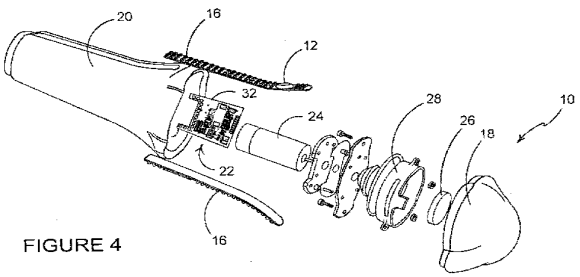


FIGURE 4

(57) **Abstract**: An ultrasonic probe (10) that scans a subject with beams of high frequency sound. The probe (10) includes a transducer (26) to produce high frequency sound waves, a means to steer the sound waves in the proper direction, a printed circuit board (22) with a non-volatile memory (38), a micro electrico- mechanical accelerometer integrated circuit (32) and an outlet connector (19). The accelerometer (32) is configured to detect the movement of the probe (10) in from two to three axes when the probe (10) is rotated or moved in a linear direction to allow the probe (10) to detect images from more than one plane.

WO 2010/106379 A1

ULTRASOUND PROBE WITH ACCELEROMETER

FIELD OF THE INVENTION

This application is a European application that claims priority to co-pending U.S. Provisional Patent Application entitled, "Ultrasound Probe with Accelerometer", having Serial Number 61/161,910, filed March 20, 2009, which are entirely incorporated herein by reference.

This present invention discloses an ultrasound probe with accelerometer for scanning the outside or inside of the human body for producing visual images of various organs in the body.

SUMMARY OF THE INVENTION

Handheld ultrasonic probes attached by a cable to a processing unit and a display unit are known in the field. This invention incorporates an accelerometer in the probe to detect movement of the probe in three axes as the probe is rotated or moved in a linear direction. The accelerometer detects the rotation of the probe along the longitudinal axes of the probe. This allows the projection of images of the reflected ultrasound waves from different angles. Images can be produced from the transverse plane and the sagittal plane. 3D images can be produced.

The probe may have an electric motor to mechanically move the sound beam or it can have a number of transducer elements, such as piezoelectric crystals , which may arranged in an array to steer the sound beam. Either of these means can be used to steer the sound beam in the proper direction.

Exhibit 1004 page 708 of 1621
DENTAL IMAGING

The conventional ultrasonic probe has a fluid bulb at its forward end. By producing a probe that is cylindrical and of a uniform diameter, the probe can be used for transrectal, pelvic floor and urethra scanning.

This invention uses a three-axis digital accelerometer suitable with use with probe of this invention.

The accelerometers used with the probe of this invention can be a low cost analog devices. The LIS3LV02DL accelerometer made by STMicroelectronics is preferred type of accelerometer because it has a programmable interrupt output when it detects movement. With this feature the processor does not have to waste time if there is nothing to see. A three-axes digital accelerometer is preferred over a two-axes accelerometer.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is the front longitudinal view of the ultrasound probe with accelerometer of this invention.

Fig. 2 is the back longitudinal view of the ultrasound probe of Fig. 1.

Fig. 3. is the bottom end view of the ultrasound probe of Fig. 1.

Fig. 4 a longitudinal cross-section of the internal components of the ultrasound probe of Fig. 1.

Fig.5. is a schematic view of the Micro electro-mechanical systems accelerometer integrated circuit(MEMS)

Fig. 6 is side-by-side view taken at right angles to each other of a human bladder (Transverse and Sagittal planes)

Exhibit 1004 page 709 of 1621
DENTAL IMAGING

Fig. 7A is a graph showing a measurement of the accelerometer graphically displaying velocity and distance traveled which shows that velocity is the integral of accelerometer.

Fig. 7B is a graph showing that distance traveled in the integral of velocity (double integral of accelerometer).

Fig. 8A is a longitudinal view of an end cavity ultrasound probe with accelerometer.

Fig.8B is longitudinal view of a sidefire ultrasound probe with accelerometer.

PARTS LIST:

10. Ultrasound Probe
12. Probe Switch
14. Orientation spot
16. Soft grips
17. Longitudinal axis
18. Fluid chamber
19. Outlet connector
20. Probe casing
22. Interface Printed circuit board
24. Motor
26. Transducer
28. Transducer cradle
30. Scanner connector
32. Micro electro-mechanical systems accelerometer integrated circuit (MEMS)
34. Logic buffers
36. Probe switch connector
Non-volatile memory
Transverse plane of bladder
42 Sagittal plane of bladder

Exhibit 1004 page 710 of 1621
DENTAL IMAGING

DETAILED DESRIPTION OF THE PREFERED EMBODIMENT

Ultrasound probes normally consist of a piezoelectric element which is driven by a high voltage pulse to produce a high frequency sound wave between l-20MHz. The piezoelectric element may consist of a number of elements as used in a phased array or electronic probe or a single or annular element mechanically driven.

Fig. 1 illustrates a front longitudinal view of the ultrasound probe with accelerometer 10 of this invention. This ultrasound probe with accelerometer 10 as shown in the longitudinal cross-section of Fig.4 consists of the piezoelectric element in a transducer 26, electric drive motor 24, interface printed circuit board (PCB 22, probe switch 12 and outlet connector (19).

The transducer 26 is a piezoelectric transducer which converts mechanical waves to electrical signals and vice versa. These transducers frequently incorporate a polycrystalline piezoelectric and may be based upon the composition $Pb(Zr_{1-x},Ti_x)O_3$, generally known as PZT. Other crystals which convert mechanical waves to electrical signals may also be used.

The printed circuit board 22 shown in Fig. 5 acts as the interface between the incoming cable from the ultrasound scanner electronic and the probe element.

Exhibit 1004 page 711 of 1621
DENTAL IMAGING

The printed circuit board 22 contains the interface electronics containing the non-volatile memory 38, the micro electro-mechanical systems accelerometer integrated circuit (MEMS) 32, and clock buffers. An accelerometer is a device that measures non-gravitational accelerometers. The accelerometer is detected by mechanically accelerating the accelerometer via its casing.

MEMS PHYSICAL PRINCIPLES

Under the influence of external accelerometers that are transmitted via the casing the MEMS sensor deflects from its neutral position. This deflection is measured in an analog or digital manner. Most commonly the capacitance between a set of fixed beams and a set of beams attached to the proof mass is measured. This method is simple, reliable and does not require additional process steps making it inexpensive.

An accelerometer measures the non gravitational acceleration it experiences. It is simplest to consider that the gravitational forces accelerate the whole accelerometer equally, and therefore give no reading. Non-gravitational acceleration is produced by forces other than gravity or inertial forces. Such forces include all simple mechanical forces. These are transmitted to the accelerometer device through mechanical stress on its mounting.

The non-volatile memory 38 can be used to contain the serial number, probe characteristics, time gain characteristics, last used settings for when probe is interchanged with other types of probe, i.e. abdominal, endocavity, linear etc.

Exhibit 1004 page 712 of 1621
DENTAL IMAGING

The accelerometer detects movement of the probe in three axes and allows detection of the probe 10 when rotated or moved in a linear direction. The probe 10 could be used to detect movement of the probe in two axes, but the results would be less accurate.

90 DEGREE SCANNING

When scanning an organ (such as a bladder) as shown in Fig.6 and the probe 10 is aligned in the normal direction for scanning that organ and the probe switch 12 is then pressed, it will save the image from that position and mark that position as 0 degrees. The probe 10 is then rotated through 90 degrees as shown in the sketch below. When the 90 degree position is detected by the sensor, the information can be automatically saved or used to open a second window to display the sagittal view, which is the vertical plane passing through the standing body from front to back. The two views can also be used to calculate the organ volume (such as bladder volume) to a greater accuracy.

180 DEGREE SCANNING

If the probe is rotated through 180 degrees, a complete 3D image of the organ will be obtained to allow greater accuracy in determining dimensions and volume.

Linear Scanning

If the probe is moved linearly across the organ a 3D image of the organ could be obtained. The velocity is the integral of the acceleration measured by the MEMS

Exhibit 1004 page 713 of 1621
DENTAL IMAGING

accelerometer 32 and the distance traveled is the integral of the velocity. The linear displacement is interpolated from the accelerometer and deceleration and time of displacement of the probe 10.

BLADDER SCANNING

The image shown in Fig. 6 are two scans taken at right angles to each other of the bladder of a person (Transverse and Sagittal planes).By using both images a more accurate valuation of the bladder volume can be made. By using the MEMS accelerometer 32 sensor the 90° turn in the probe 10 can be detected and the image automatically switched to the other window. This allows the two images to be shown side by side.

Single plane scanning

The scan can be started by either pressing the probe switch 12 on the probe 10 or on the START button on the monitor screen as shown in Fig. 6, the maximum bladder size can be manually or automatically detected.

Manual Detection

Manual detection is achieved by the operator moving the probe 10 to visually maximize the image of the bladder. The operator places the probe 10 approximately over where the bladder should be and then moves the probe in the horizontal or vertical direction to centre the bladder, then moves the probe angularly with the front end of the probe as represented by the fluid chamber

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18 remaining in the same position until the maximum bladder area is observed. When the operator finds the maximum bladder area, the operator presses the probe switch 12 or the STOP/Freeze button on the monitor screen to stop the scan and save the image and instigate the calculation for the bladder volume.

Automatic Detection

Automatic detection is achieved by the operator moving the probe 10 as described in the manual detection. During the scan each frame is compared to see if the image of the bladder area is larger than that in the preceding frame. The frame with the image of the largest bladder area is then stored.

Pressing the probe switch 12 or the Stop/freeze button on the monitor screen to stop the scan would instigate the calculation for the bladder volume using the frame image stored with the image of the bladder with the maximum area obtained during the investigation.

ORIENTATION SPOT

The probe 10 of this invention has an orientation spot 14 as shown Fig. 1 which provides the operator with a starting point analogous to a GPS starting point or on a map direction website on the internet.

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Transverse and sagittal plane scanning

Pressing the probe switch 12 or the START button on the monitor screen starts the transverse scan, so that the maximum bladder size can be detected either manually as described previously or automatically. Automatic detection is achieved by moving the probe 10 to maximize the image of the bladder; each frame is compared to see if the image of the bladder area is larger than that in the preceding frame. The frame with the image of the largest bladder area is then stored.

After having obtained the transverse scan, the sagittal scan can then be obtained manually when the operator rotates the probe 90° to the previous scan and repeats the process of scanning as just denote the sagittal scan position and another orientation spot or dot 14 or the start/stop button on the monitor denoting the transverse position. The operator moves the probe 10 to visually maximize the image of the bladder. Pressing the probe switch or the Stop/Freeze button on the screen will stop the scan and save the image and instigate the calculation for the bladder volume. However, it could also instigate the calculation for the bladder volume using the transverse and sagittal frame images stored showing the bladder with the maximum area.

The sagittal scan can also be obtained automatically such that when the operator rotates the probe 10 by 90°. The MEMS 32 accelerometer sensor automatically senses when the probe 10 is rotated 90° to automatically display the sagittal plane on the display either individually or side by side with the transverse scan.

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As the operator moves the probe 10 to visually maximize the image of the bladder the frame with the image of the largest bladder area is then stored. Pressing the probe switch 12 or the STOP/Freeze button on the screen to stop the scan will start the calculation for the bladder volume using the images stored with the bladder with the maximum area for transverse and sagittal frames. This method can also apply to other organs such as the prostate.

The non-contact method to measure accelerometer, velocity, and distance traveled is illustrated in Fig. 7A. Velocity is the integral of Accelerometer observed. When the operator finds the maximum bladder area, the operator presses the probe button or the STOP/Freeze button on the screen to stop the scan and save the image and instigate the calculation for the bladder volume.

Automatic Detection

Automatic detection is achieved by the operator moving the probe as described in the manual detection. During the scan each frame is compared to see if the image of the bladder area is larger than that in the preceding frame. The frame with the image of the largest bladder area is then stored.

Pressing the probe button or the Stop/freeze button on the screen to stop the scan would instigate the calculation for the bladder volume using the frame image stored with the image of the bladder with the maximum area obtained during the investigation.

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ORIENTATION

The orientation of the probe 10 can be determined by placing an orientation spot or dot 14 as illustrated in Fig. 1 and in the sketch below. It is analogous to the start position of GPS or map directions on some internet websites such as Mapquest^{tm}.

Transverse and sagittal plane scanning

Pressing the probe switch 12 or the START button on the monitor screen starts the transverse scan so that the maximum bladder size can be detected either manually as described previously or automatically. Automatic detection is achieved by moving the probe 10 to maximize the image of the bladder, each frame is compared to see if the image of the bladder area is larger than that in the preceding frame. The frame with the image of the largest bladder area is then stored. After having obtained the transverse scan, the sagittal scan can then be obtained manually when the operator rotates the probe 90° to the previous scan and repeats the process of scanning as just described for the transverse scan. The probe 10 is usually marked with a spot or dot on the probe to denote the sagittal scan position and another orientation spot or dot 14 or the start/stop button on the monitor denoting the transverse position. The operator moves the probe 10 to visually maximize the image of the bladder. Pressing the probe switch or the Stop/Freeze button on the screen will stop the scan and save the image and instigate the calculation for the bladder volume. However, it could also instigate

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the calculation for the bladder volume using the transverse and sagittal frame images stored showing the bladder with the maximum area.

The sagittal scan can also be obtained automatically such that when the operator rotates the probe 10 by 90°. The MEMS 32 accelerometer sensor automatically senses when the probe 10 is rotated 90° to automatically display the sagittal plane on the display either individually or side by side with the transverse scan. As the operator moves the probe 10 to visually maximize the image of the bladder the frame with the image of the largest bladder area is then stored. Pressing the probe switch 12 or the STOP/Freeze button on the screen to stop the scan will start the calculation for the bladder volume using the images stored with the bladder with the maximum area for transverse and sagittal frames. This method can also apply to other organs such as the prostate. The non-contact method to measure accelerometer, velocity, and distance traveled is illustrated in Fig. 7A.

Velocity is the integral of Accelerometer as shown in Fig.7B. The distance is the integral of velocity (double integral of accelerometer.

Different approaches to accelerometer sensing

Piezo-film (Vibration, shock), AC Response only, Senses many things besides motion (sound, temperature, pressure)

Electromechanical Servo (Tilt, Inertial) DC accurate, low frequency only.

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Piezoelectric (Vibration, Shock) Wide-dynamic range, AC Response only.

Liquid tilt sensors (Tilt) DC response,

Bulk Micromachined Piezo Resistive (Tilt, Vibration, Inertial) DC Response,

Bulk Micromachined Capacitive (Tilt, Vibration, and Inertial) DC Response, Good DC accuracy, low noise,

Surface Micro machined Capacitive (Tilt, Vibration, and Inertial) DC Response, Standard IC form factors

Endocavity probes

Endocavity probes as illustrated in Figs 8A and 8B are used for transrectal, pelvic floor and urethra scanning.

In a similar mode to the abdominal probe scan of the bladder the prostate is usually scanned in the anteroposterior and sagittal planes and as described before for the abdominal probe, the 90° turn can be automatically detected using the MEMS 32 accelerometer sensor and the image automatically saved.

Using an endfire endocavity probe as illustrated in Fig. 8A an arc of sound is emitted in line with the shaft of the probe (A) (in the directions indicated by the arrows), for example to scan a prostate situated in front of the probe . If the probe is rotated through 180° (B) whilst scanning in this mode, then by using a MEMS 32 accelerometer sensor in the probe to sense the angular rotation, a 3D image can be built up.

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Using a sidefire endocavity probe as the sound is emitted at right angles to the shaft of the probe (C) to image the tissue surrounding the probe. To image the rectum for example, extracting the probe in a linear mode (D) whilst scanning, a 3D image can be built up. The MEMS 32 accelerometer sensor is used to sense the linear motion. Although the sensor only detects the accelerometer, the linear displacement is interpolated from the accelerometer and deceleration and time of displacement of the probe.

The above applies to both mechanical and electronic Endocavity probes.
Other systems, methods, features, and advantages of the present invention will be or become apparent to one with skill in the art upon examination of the following drawings and detailed description. It is intended that all such additional systems, methods, features, and advantages be included within this description, be within the scope of the present invention, and be protected by the accompanying claims.

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CLAIMS

1. An ultrasonic probe which scans a subject with beams of high frequency sound comprising:

a transducer to produce high frequency sound waves;

a means to steer the sound waves in the proper direction;

a printed circuit board with a non-volatile memory;

a micro electrico-mechanical accelecerometer integrated circuit;

an outlet connector;

said accelecelerometer detects the movement of the probe in from two to three axes when the probe is rotated or moved in a linear direction to allow the probe to detect images from more than one plane.

2. The probe of claim 1 in which the probe can produce a 3d image of an organ of a subject when the probe is rotated 180 degrees.

3. The probe of claim 1 in which the probe can produce a 3d transverse plane scanning of an organ of a subject and sagittal plane scanning by linearly moving the probe across the body.

4. An ultrasonic endocavity probe which scans a cavity of a subject having an end for inserting into the cavity comprising:

a transducer to produce high frequency sound waves;

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a means to steer the sound waves in the proper direction;

a printed circuit board with a non-volatile memory;

a micro electrico-mechanical accelecerometer integrated circuit;

an outlet connector;

said accelecelerometer detects the movement of the probe in two or three axes when the probe is rotated or moved in a linear direction to allow the probe to detect images from more than one plane, said probe being of a size and shape to enter the cavity of the subject.

5. The probe of claim 4 in which probe emits an arc of sound forward (endfire) of the probe.

6. The probe of claim 4 in which the probe emits an arc of sound at right angles(sidefire) to the longitudinal axes of the probe.

7. The probe of any of claims 1-6 which also has clock buffers.

8. The probe of claims 1 to 7 which has piezoelectric crystals in the t ransducer.

9. An ultrasound imaging system comprising a hand held ultrasonic probe which scans a subject with beams of high frequency sound comprising:

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a transducer with a piezoelectric crystals to produce high frequency sound waves;

a means to steer the sound waves in the proper direction;

a printed circuit board with a non-volatile memory;

a micro electrico-mechanical accelecerometer integrated circuit;

an outlet connector;

said accelecelerometer detects the movement of the probe in two or three axes when the probe is rotated or moved in a linear direction to allow the probe to detect images from more than one plane and a console processing and display unit coupled by a cable to the hand-held display, in which the piezoelectric crystalsconvert the ultrasonic reflected energy from the subject into electrical signals transferred from the probe over the cable to the processing unit.

10. An ultrasonic probe which scans a subject with beams of high frequency sound comprising:

a transducer to produce high frequency sound waves; means to steer the sound waves in the proper direction;

a printed circuit board with a non-volatile memory,

a micro electric-mechanical accelecerometer integrated circuit, an outlet connector; and

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said accelecelerometer detects the movement of the probe in all three axes when the probe is rotated or moved in a linear direction to allow the probe to detect images from more than one plane.

11. The probe of any of claims 1-10 in which the accelerometer is a digital 3 axis device.

12. The probe of any of claims 1 to 11 in which the accelerometer has an interrupt output sensor when it detects movement to prevent the processor to which the probe is attached from wasting time looking at images when the images produced are not clear views of an organ of a subject.

13. The probe of any of claims 1 to 12 in which the means to steer the sound waves is an electric motor to mechanically move the sound direction.

14. The probe of any of claims 1 to 12 in which the sound waves are produced by a plurality of transducer elements, including a piezoelectric crystal array, with the means to steer the sound waves arranged in the array.

15. The probe of any of claims 1 to 12 in which the sound waves are steered by an electric motor.

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16. The probe of any of the claims from 1 to 15 which is connected to a video monitor with controls.

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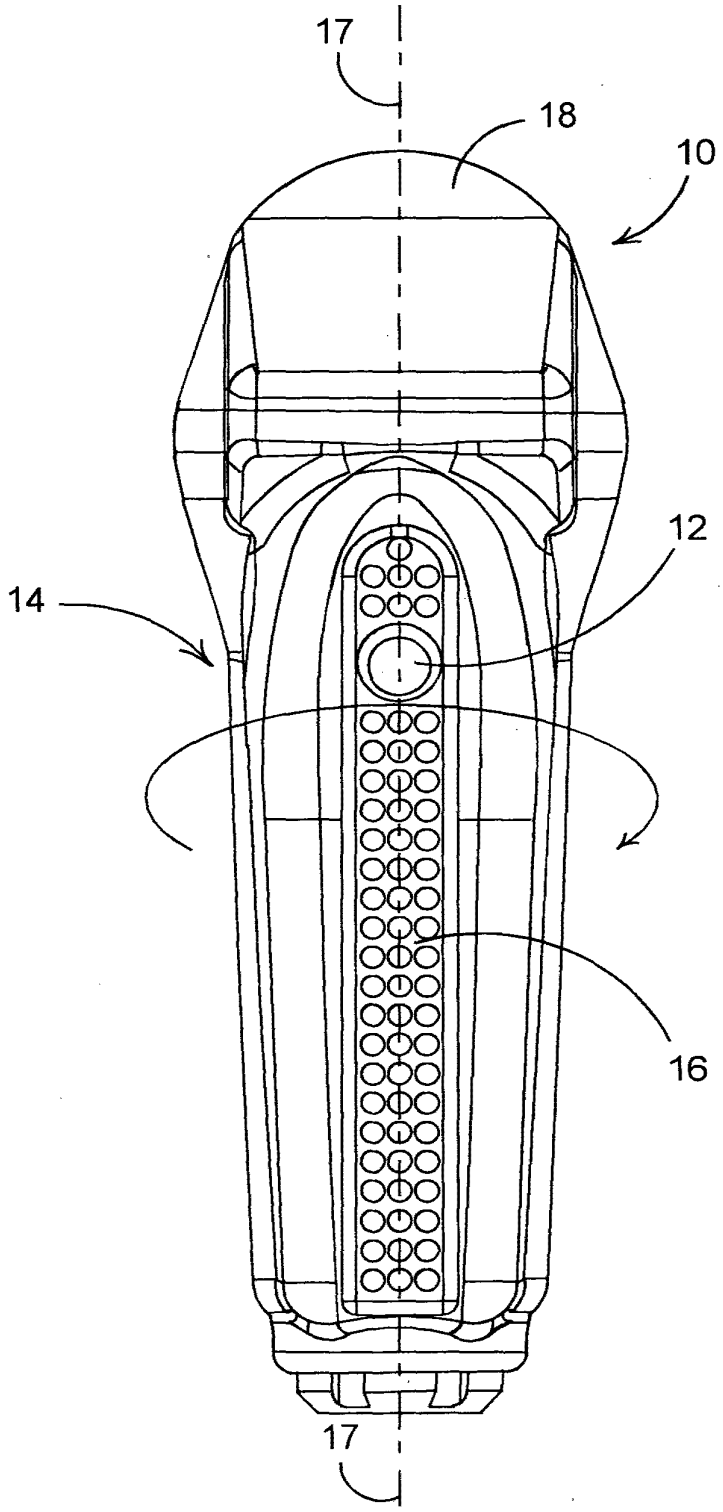


FIGURE 1

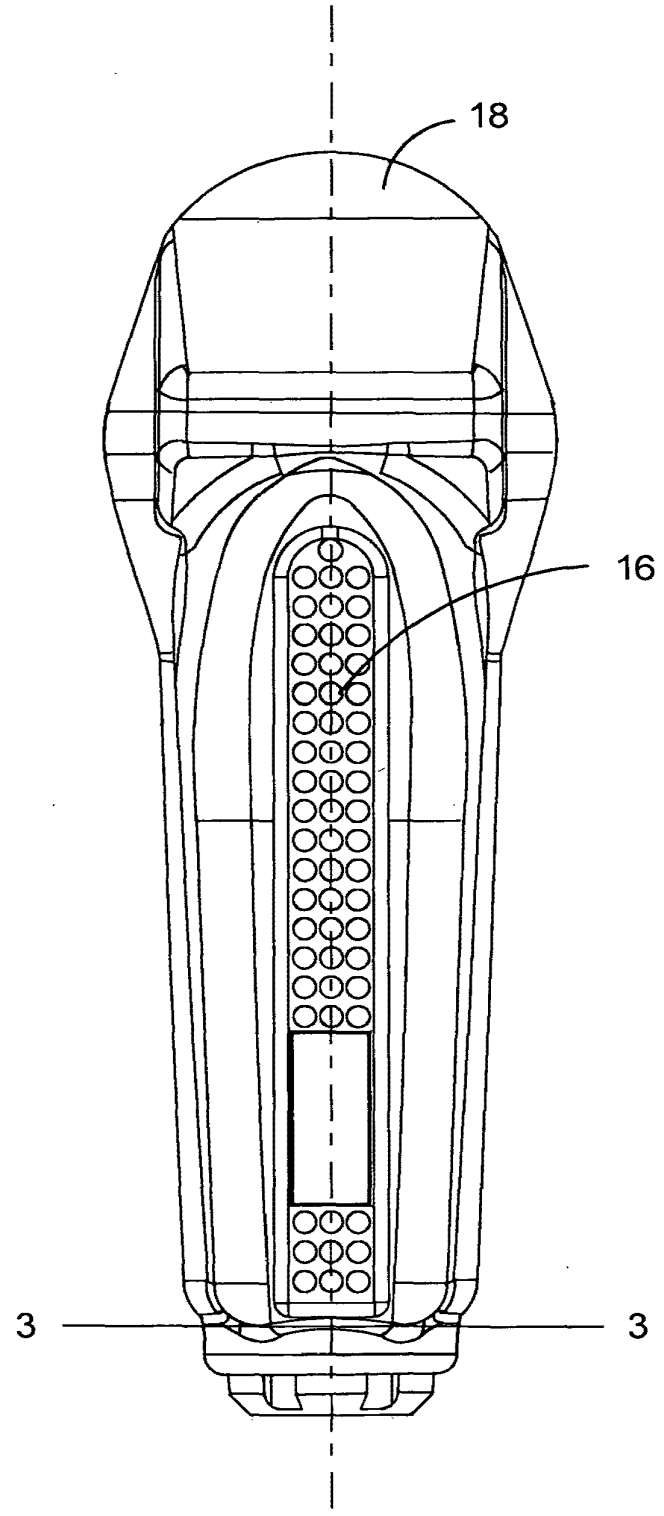


FIGURE 2

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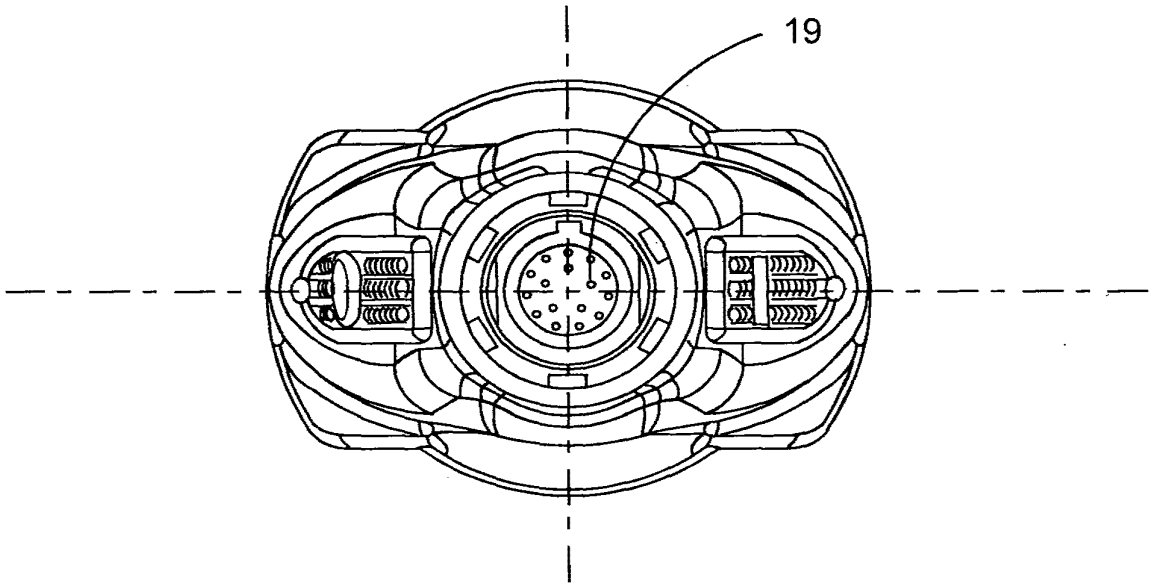


FIGURE 3

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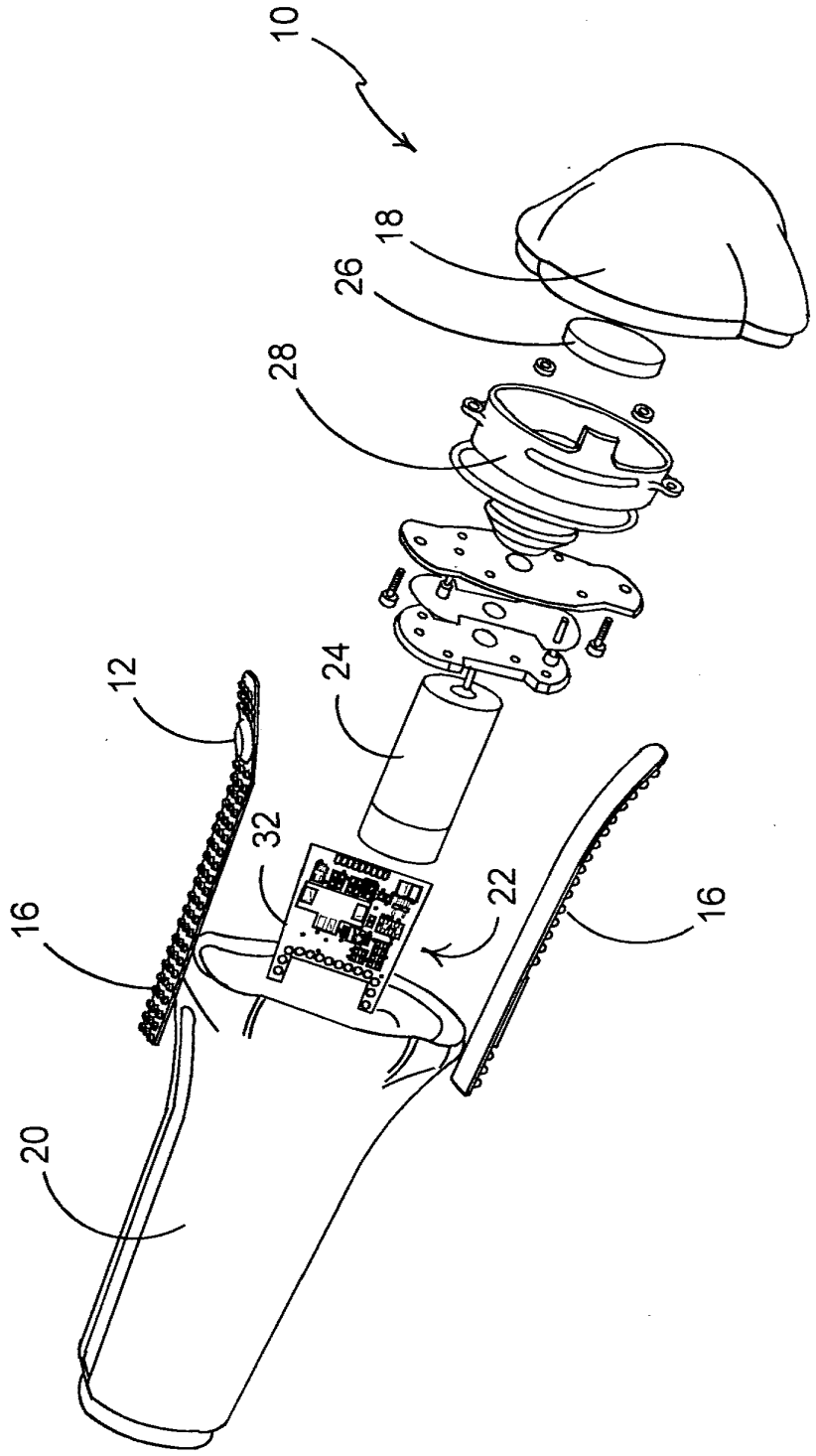


FIGURE 4

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DENTAL IMAGING

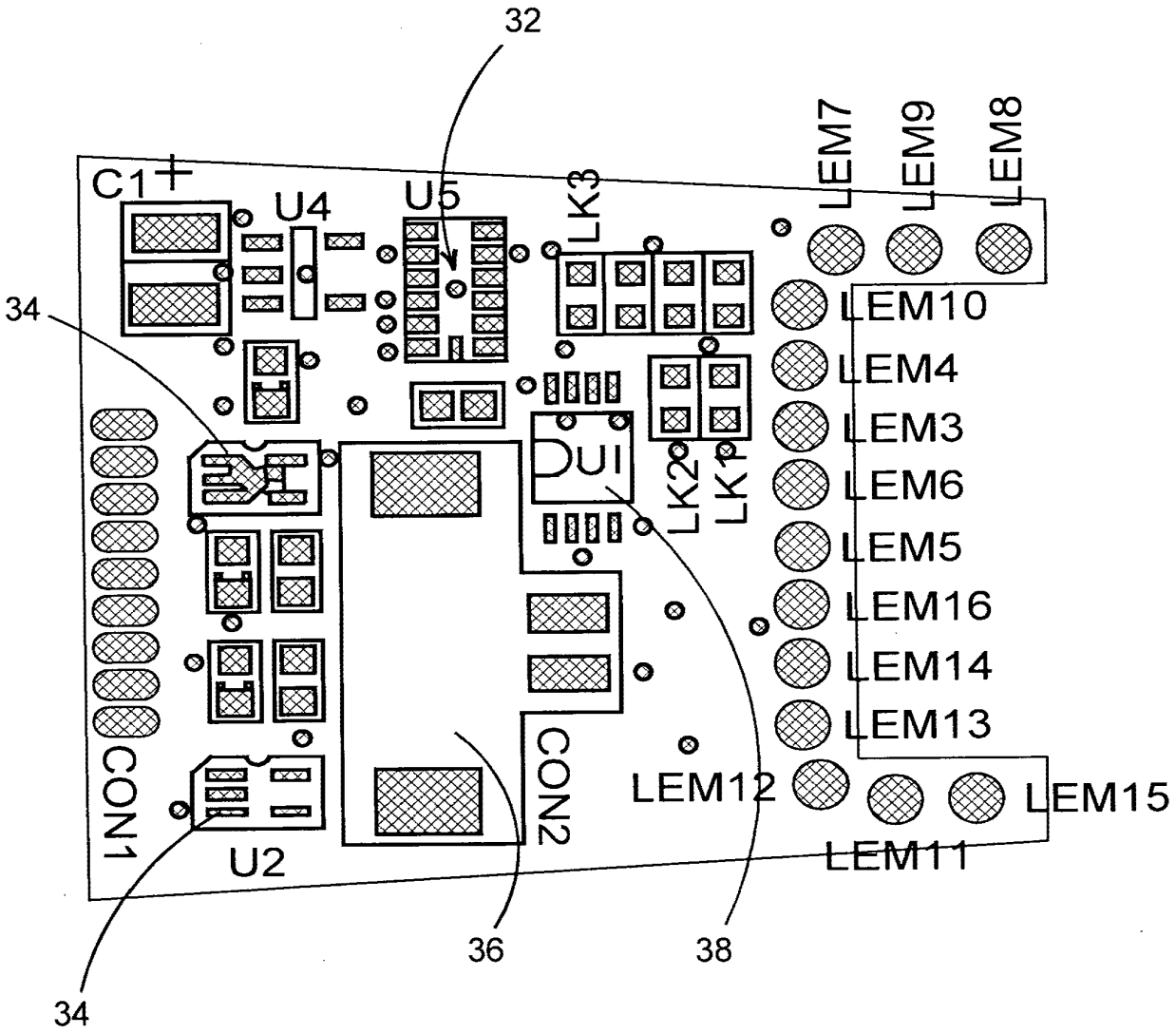


FIGURE 5

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DENTAL IMAGING

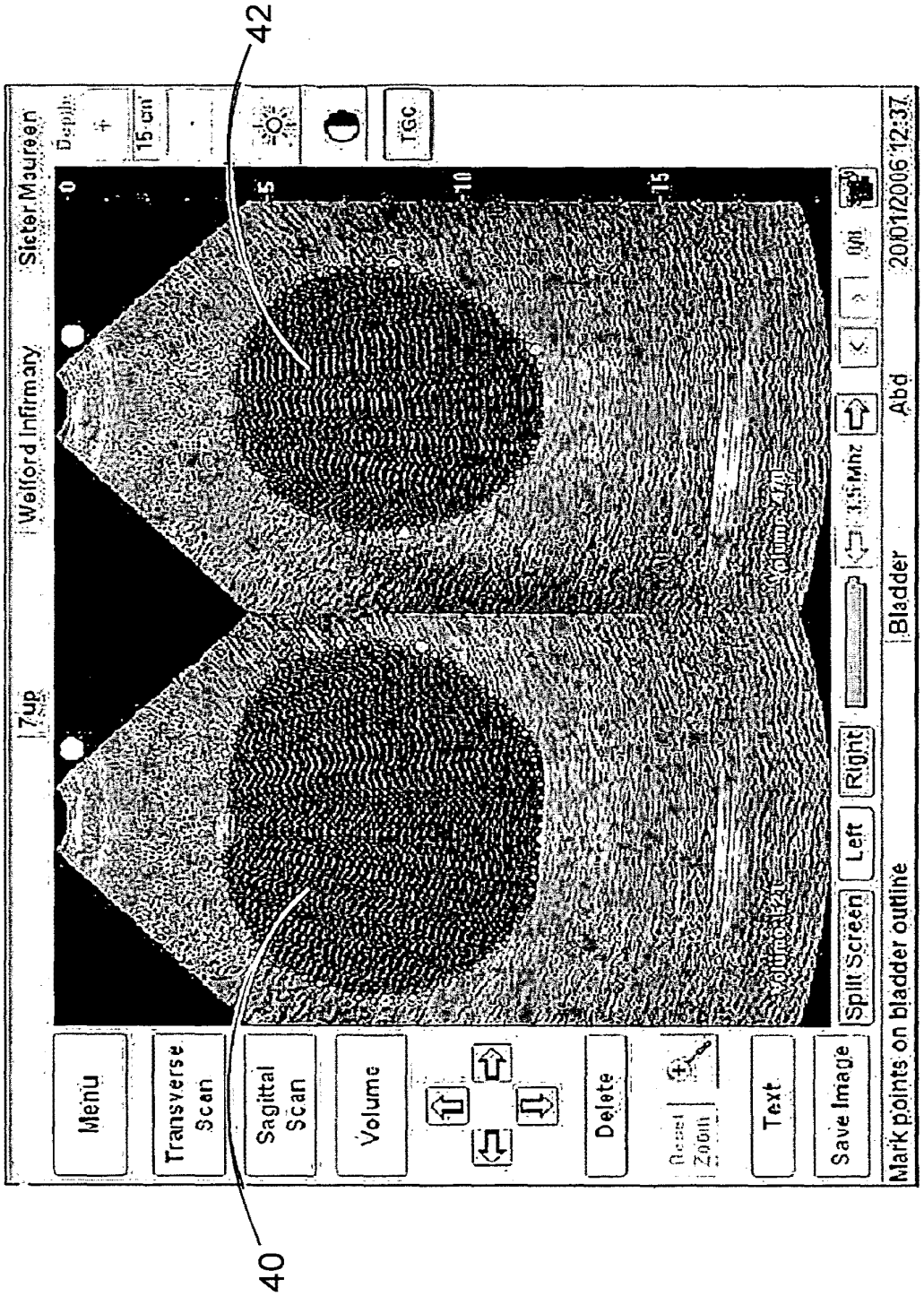

42
40
Menu
Transverse Scan
Sagittal Scan
Volume
Delete
Reset Zoom
Text
Save Image
Split Screen
Left
Right
Mark points on bladder outline
Bladder
Abd
20/01/2006 12:37
Welford Infirmary
Sister Maureen
TGC

FIGURE 6

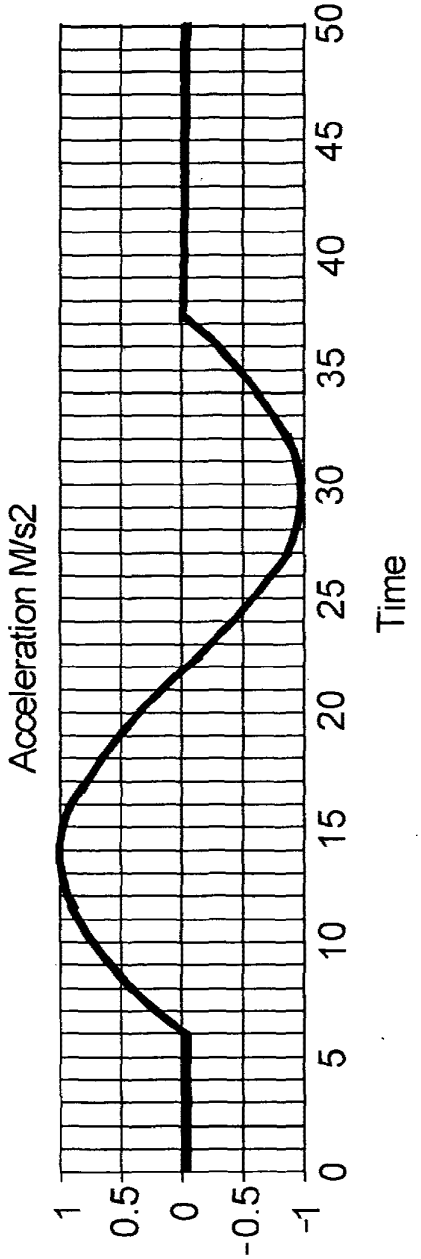


FIGURE 7A

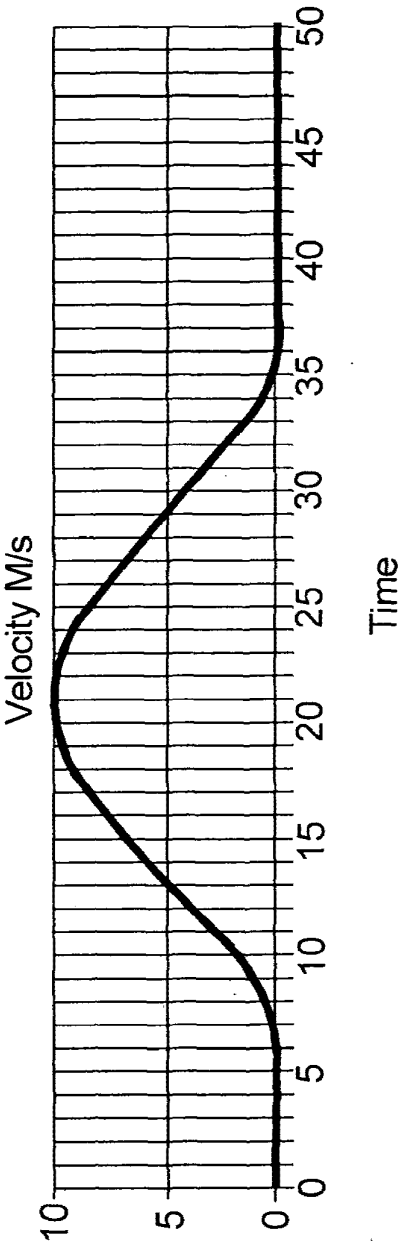


FIGURE 7B

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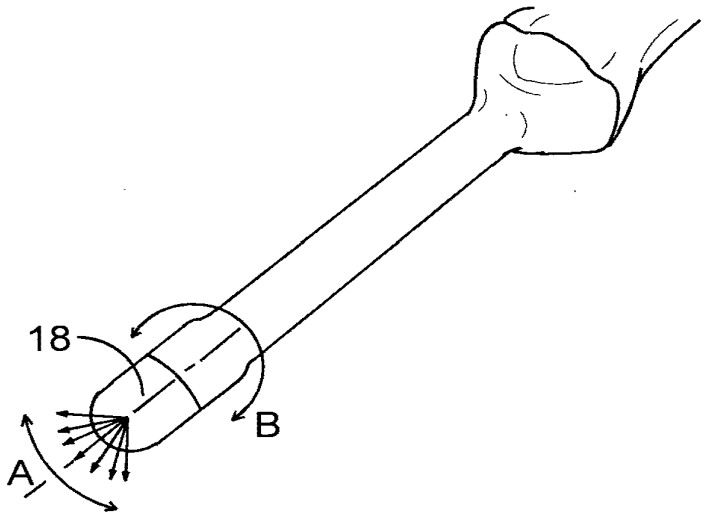


FIGURE 8A

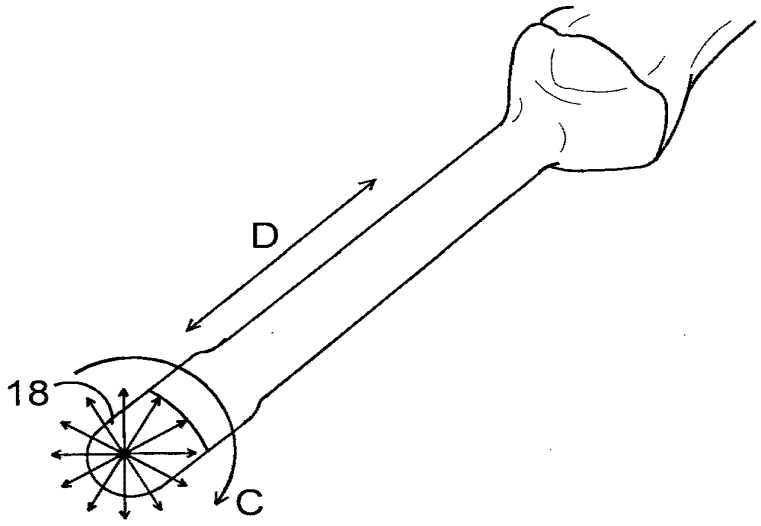


FIGURE 8B

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DENTAL IMAGING

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2010/050480

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61B8/12 G10K11/35 G01P13/00 G01S15/89
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
A61B G10K G01P G01S

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2008/146941 A1 (DALA-KRISHNA PRAVEEN [US]) 19 June 2008 (2008-06-19) paragraphs [0005] - [0010] paragraphs [0028] - [0037] paragraphs [0042] - [0053] paragraphs [0061] - [0065] figures	1-4, 6-12,14, 16
X	US 2008/146932 A1 (CHALANA VIKRAM [US] ET AL) 19 June 2008 (2008-06-19) paragraphs [0127] - [0141] paragraphs [0298] - [0308] figure 1A	1-3,9-16

-/--

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
16 June 2010	23/06/2010

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Bataille, Frédéric

Form PCT/ISA/210 (second sheet) (April 2005)

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DENTAL IMAGING

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2010/050480

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 122 538 A (SLIWA JR JOHN WILLIAM [US] ET AL) 19 September 2000 (2000-09-19) column 8, lines 5-21 column 14, lines 7-67 column 19, lines 39-51 figures	1-7,10, 11,16
A	US 6 338 716 B1 (HOSSACK JOHN A [US] ET AL) 15 January 2002 (2002-01-15) column 2, line 35 - column 4, line 20 column 7, line 40 - column 8, line 44 figures	1-16
A	EP 1 348 385 A1 (INSIGHTEC TXSONICS LTD [IL]) 1 October 2003 (2003-10-01) the whole document	1-16

Form PCT/ISA/210 (continuation of second sheet) (April 2005)

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/GB2010/050480

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2008146941 A1	19-06-2008	NONE	
US 2008146932 A1	19-06-2008	US 2008242985 A1	02-10-2008
US 6122538 A	19-09-2000	NONE	
US 6338716 B1	15-01-2002	NONE	
EP 1348385 A1	01-10-2003	US 2003181806 A1	25-09-2003

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(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: **WALLACE, Nathan E.** [US/US]; 17 Steinbeck Street, Tyngsborough, Massachusetts 01879 (US). **FILLION, Timothy I.** [US/US]; 44 Gould Road, Bedford, Massachusetts 01730 (US).

(74) Agent: **GUERIN, William G.**; Guerin & Rodriguez, LLP, 5 Mount Royal Avenue, Mount Royal Office Park, Marlborough, MA 01752 (US).

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(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

(54) **Title**: INTEGRATED DISPLAY IN A HAND-HELD THREE-DIMENSIONAL METROLOGY SYSTEM

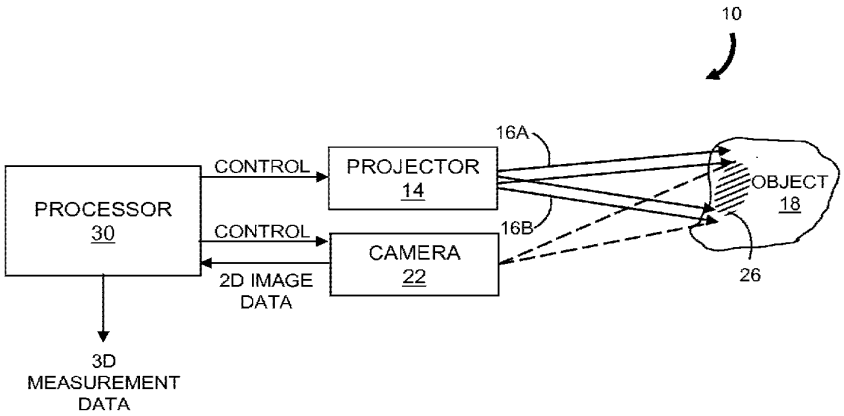


FIG. 1

(57) **Abstract**: Described is a user-manipulated imaging device for measuring a three-dimensional surface of an object. The device includes an imager configured for acquiring two-dimensional images of the surface and a device housing coupled to the imager and configured for manual positioning of the imager. The device also includes a processor in communication with the imager and configured to generate three-dimensional surface data based on the two-dimensional images. The device further includes a display coupled to the device housing and in communication with at least one of the imager and the processor. The display shows images of the surface and is observable within a field of view of the user while the device housing is manually positioned within the field of view and relative to the surface. In various embodiments, the display shows the two-dimensional images and representations of the three-dimensional surface data.

WO 2011/011193 A1

DPI-019PC

INTEGRATED DISPLAY IN A HAND-HELD THREE-DIMENSIONAL METROLOGY SYSTEM

RELATED APPLICATION

This application claims the benefit of the earlier filing date of U.S. Provisional Patent Application Serial No. 61/227,255, filed July 21, 2009, titled "Integrated Display in a Hand-Held Three-Dimensional Metrology System," the entirety of which is incorporated herein by reference.

FIELD OF THE INVENTION

The invention relates to the field of three-dimensional imaging and more specifically to the field of displaying non-contact surface measurement data for dental and medical applications.

BACKGROUND OF THE INVENTION

A variety of precision non-contact three-dimensional (3D) metrology systems have been developed for dental and medical applications. Conventional systems typically include a handheld camera or scanner connected to a processing unit that communicates with a display monitor. The display monitor presents a variety of information to the user. The information can include control options, acquired images, and operator assistance information such as an indication of an optimal focus condition. This configuration requires the user to look in two directions, that is, to look at the position of the handheld device with respect to the patient and to look at the display monitor to determine that proper images are being acquired. Thus the time and effort to obtain the desired measurement data is adversely affected by the requirement for the user to alternately view the position of the device and view the acquired images.

SUMMARY

In one aspect, the invention features a method of displaying information for a user-manipulated 3D imaging device. The method includes acquiring a plurality of two-dimensional (2D) images of a surface of an object with an imaging device manipulated by a user in position relative to the surface of the object and within a field of view of the user. The 2D images are processed to generate three-dimensional surface data for the surface of the object. Measurement data are displayed to the user within the field of view of the user during continued manipulation of the imaging device. In one embodiment, the displayed measurement information includes the two-dimensional images acquired by the imaging device and, in another embodiment, the displayed information includes a representation of the 3D surface data.

In another aspect, the invention features a user-manipulated imaging device for measuring a 3D surface of an object. The imaging device includes an imager, a device housing, a processor and a display. The imager is configured for acquiring 2D images of a surface of the object. The device housing is coupled to the imager and configured for manipulation by a user to position the imager relative to the surface of the object. The processor communicates with the imager and is configured to generate 3D surface data for the surface based on the 2D images. The display is coupled to the device housing and communicates with at least one of the imager and the processor. The display shows images of the surface observable within a field of view of the user while the device housing is manually positioned within the field of view of the user relative to the surface. In one embodiment, the display shows the 2D images of the surface acquired by the imager and, in another embodiment, the display shows a representation of the 3D surface data generated by the processor.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and further advantages of this invention may be better understood by referring to the following description in conjunction with the accompanying drawings, in which like numerals indicate like structural elements and features in the various figures. The drawings are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the invention.

FIG. 1 illustrates a 3D imaging device that projects a structured light pattern onto an object.

FIG. 2 is a flowchart representation of an embodiment of a measurement procedure using a hand-held 3D imaging device according to the invention.

FIG. 3 illustrates an embodiment of a user-manipulated imaging device according to the invention.

FIG. 4A illustrates an embodiment of a user-manipulated imaging device according to the invention and showing a display panel in an open position.

FIG. 4B illustrates the user-manipulated imaging device of FIG. 4A showing the display panel in a closed position.

DETAILED DESCRIPTION

In brief overview, the invention relates to a user-manipulated 3D metrology device such as a hand-held camera or scanning device. The device includes an integrated display monitor that provides the user with convenient access to control options, acquired images, and operator assistance indications within a field of view of the user. Advantageously, the location of the operating tip of the device relative to the object being measured can be viewed without the need to redirect the view of the user to

a display monitor. For medical and dental 3D metrology devices, the user positions and aligns the device to a patient while simultaneously viewing a display of the acquired images or data. As a result, measurement data are obtained with less time and operator effort than is required for conventional user-manipulated 3D metrology devices.

The present teaching will now be described in more detail with reference to exemplary embodiments thereof as shown in the accompanying drawings. While the present teaching is described in conjunction with various embodiments and examples, it is not intended that the present teaching be limited to such embodiments. On the contrary, the present teaching encompasses various alternatives, modifications and equivalents, as will be appreciated by those of skill in the art. Those of ordinary skill in the art having access to the teaching herein will recognize additional implementations, modifications and embodiments, as well as other fields of use, which are within the scope of the present disclosure as described herein.

In a typical dental or medical 3D camera or scanner imaging system, a series of 2D intensity images of an object surface is acquired where the illumination for each image can vary. In some systems, structured light patterns are projected onto the surface and detected in each 2D intensity image. FIG. 1 shows an example of a 3D imaging system 10 in which the structured light pattern is generated by a projector 14 as a pair of overlapping coherent optical beams 16A and 16B that illuminate the object 18. The 3D imaging system 10 may be constructed to operate in accordance with the principles described in U.S. Patent No. 5,870,191, titled "Apparatus and Methods for Surface Contour Measurement," incorporated herein by reference in its entirety. A CCD camera 22 is used to acquire images of the illuminated object 18. The fringe pattern 26 resulting from the interference of the two beams 16 is varied between successive 2D images acquired by the camera 22. For example, the fringes in the fringe pattern 26 can be shifted by changing the phase difference between the two beams 16.

A processor 30 calculates the distance from the camera 22 to the object surface for each image pixel based on the intensity values for the pixel in the 2D images. Thus the process creates a set of 3D coordinates, that is, a "point cloud," for the object surface.

In a dynamic 3D imaging system, a series of point clouds is acquired while the camera or scanner is in motion relative to the object surface. For example, the imaging system can be a handheld device that a user manually positions relative to the object surface. In some applications, multiple objects surfaces are measured by moving the device relative to the objects so that surfaces obscured from view of the device in one position are observable by the device in another position. A processor registers the overlapped region of adjacent point clouds, using a 3D correlation technique or other registration technique, to transform each successive point cloud into an initial coordinate space. The successive point clouds are thus "stitched" into a common reference space.

Referring to FIG. 2, at the start of an embodiment of a measurement procedure 100 according to the invention, the user aligns and positions (step 110) the hand-held imaging device relative to the patient while acquiring 2D images of a patient area of interest. The 2D images are processed (step 120) to generate 3D surface data of the area of interest. The user simultaneously observes measurement images in a display while controlling (step 130) the positioning and motion of the handheld imaging device with respect to the patient. The images in the display can be the acquired 2D images. Alternatively, the displayed images can be 3D surface representations generated by processing the acquired 2D images. By way of examples, the 3D surface representations can be 3D wire-mesh representations of point clouds or artificial surface displays that comprise simple geometrical shapes (e.g., triangles) between neighboring points in point clouds.

Providing a display that is in communication with the processor and mounted to or otherwise integrated with the 3D imaging device according to the principles of the invention permits the user to see the acquired 2D images, 3D surface representation, other display information or combinations of such images and information simultaneous with the observation and continued manipulation of the 3D imaging device relative to the patient. Thus the user can more easily and rapidly complete the measurement procedure than would be possible using a conventional handheld dental or medical imaging device. Other displayed information can include operator assistance information such as a slide bar shown along the edge of the display to indicate measured position within a usable imaging range, the distance to a surface of the object being measured, and a color box to indicate the current mode of the device, such as idle, preview and scan modes.

In one embodiment, the display includes a touchscreen that permits the user to input selection data while maintaining the handheld device in proper position relative to the patient. Control options shown on the touchscreen display can include, by way of example, preview, scan and stop function activation "buttons;" save and redo buttons presented at the completion of a scan, and input data buttons. For example, in dental applications, the input data buttons can be used to indicate the jaw to be imaged (upper or lower) or particular teeth to be imaged for a partial jaw scan.

In another embodiment illustrated in FIG. 3, the imaging device 34 includes a miniature display 38 similar to the displays typically used in mass-produced cell phones for consumers. The miniature display 38 can be embedded in a side of the device housing 42 and optionally has a viewing surface that is flush with the housing 42. By way of a specific example, the miniature display 38 may have a 1.8 inch diagonal viewing area. In one embodiment, the display is a compact liquid crystal display (LCD).

In an alternative embodiment, a display 46 is integral to a panel 50 that is pivotally attached to a side of a device housing 54 for the 3D imaging device 58 shown in FIG. 4A and FIG. 4B. The panel 50 is small enough to be compatible with the overall dimensions of the device 58 and yet include a display 46 that is large enough to present detailed images to the user. By way of a specific example, the display 46 can have a four inch diagonal viewing area. FIG. 4A shows the panel 50 in an open position in which the user views the displayed images, 3D representations and information. FIG. 4B shows the panel 50 in a closed position such that the panel 50 is substantially parallel and adjacent to the side of the device housing 54. The closed position is intended for when the device 58 is stored or otherwise not in use for extended periods of time.

In the embodiments described above, the device according to the invention is generally described as a handheld device; however, the invention also contemplates that the device can be manually adjusted or manipulated by a user without being directly held by hand.

While the invention has been shown and described with reference to specific embodiments, it should be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the invention.

What is claimed is:

CLAIMS

1. A method of displaying information for a user-manipulated three-dimensional imaging device, the method comprising:

acquiring a plurality of two-dimensional images of a surface of an object with an imaging device manipulated by a user in position relative to the surface of the object and within a field of view of the user;

processing the two-dimensional images to generate three-dimensional surface data for the surface of the object; and

displaying measurement information to the user within the field of view of the user during continued manual manipulation of the imaging device.

2. The method of claim 1 wherein the displayed measurement information comprises the two-dimensional images acquired by the imaging device.

3. The method of claim 1 wherein the displayed measurement information comprises a representation of the three-dimensional surface data.

4. The method of claim 1 wherein the displayed measurement information comprises operator assistance information.

5. The method of claim 4 wherein the operator assistance information comprises a distance to the surface of the object.

6. A user-manipulated imaging device for measuring a three-dimensional surface of an object, comprising:

an imager configured for acquiring two-dimensional images of a surface of an object;

a device housing coupled to the imager and configured for manipulation by a user to position the imager relative to the surface of the object;

a processor in communication with the imager and configured to generate three-dimensional surface data for the surface based on the two-dimensional images; and

a display coupled to the device housing and in communication with at least one of the imager and the processor, the display showing images of the surface observable within a field of view of the user while the device housing is manually positioned within the field of view of the user relative to the surface.

7. The user-manipulated device of claim 6 wherein the images shown in the display are the two-dimensional images of the surface acquired by the imager.

8. The user-manipulated device of claim 6 wherein the images shown in the display are representations of the three-dimensional surface data generated by the processor.

9. The user-manipulated device of claim 6 wherein the display shows operator assistance information.

10. The user-manipulated device of claim 9 wherein the operator assistance information includes a distance to the surface of the object.

11. The user-manipulated device of claim 6 wherein the display is a touchscreen display configured to receive data input from the user.

12. The user-manipulated device of claim 6 wherein the display comprises a liquid crystal display (LCD).

13. The user-manipulated device of claim 6 wherein the display comprises a display panel pivotably secured to a side of the device housing, the display panel extending away from a surface of the device housing while in an open position and extending substantially parallel to the surface of the device housing while in a closed position, and wherein images of the surface are observable to the user while the display panel is in the open position.

14. The user-manipulated device of claim 6 wherein the display comprises a viewing surface that is substantially flush with a side of the device housing.

15. The user-manipulated device of claim 6 further comprising a projector in communication with the processor and configured for projecting a structured light pattern onto the surface of the object.

16. The user-manipulated device of claim 15 wherein the projector comprises a source of coherent optical beams for illuminating the surface of the object with a fringe pattern.

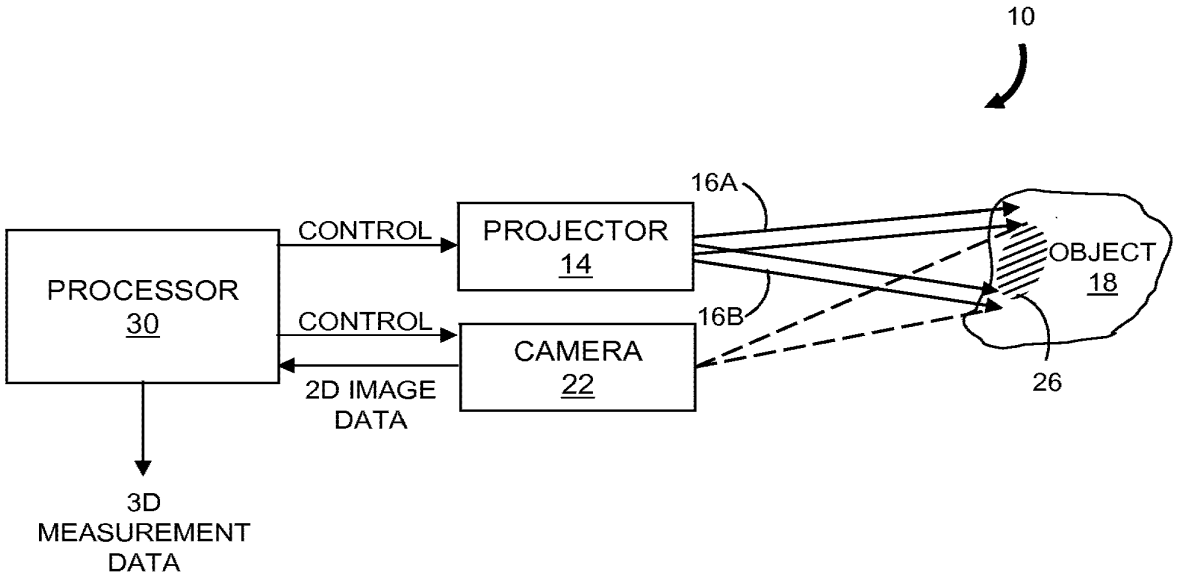

10
16A
PROCESSOR
30
CONTROL
PROJECTOR
14
CONTROL
CAMERA
22
2D IMAGE
DATA
16B
OBJECT
18
26
3D
MEASUREMENT
DATA

FIG. 1

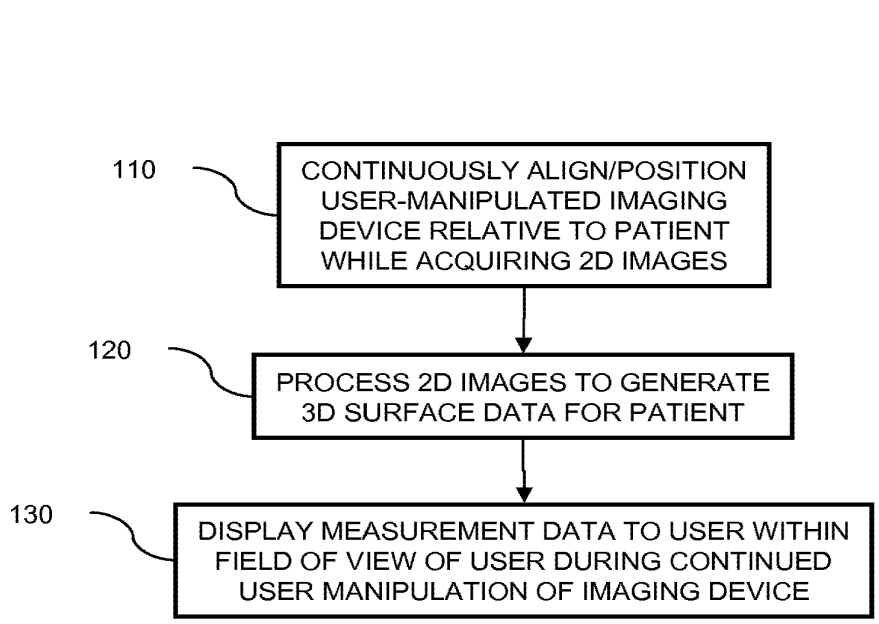

100
110
CONTINUOUSLY ALIGN/POSITION USER-MANIPULATED IMAGING DEVICE RELATIVE TO PATIENT WHILE ACQUIRING 2D IMAGES
120
PROCESS 2D IMAGES TO GENERATE 3D SURFACE DATA FOR PATIENT
130
DISPLAY MEASUREMENT DATA TO USER WITHIN FIELD OF VIEW OF USER DURING CONTINUED USER MANIPULATION OF IMAGING DEVICE

FIG. 2

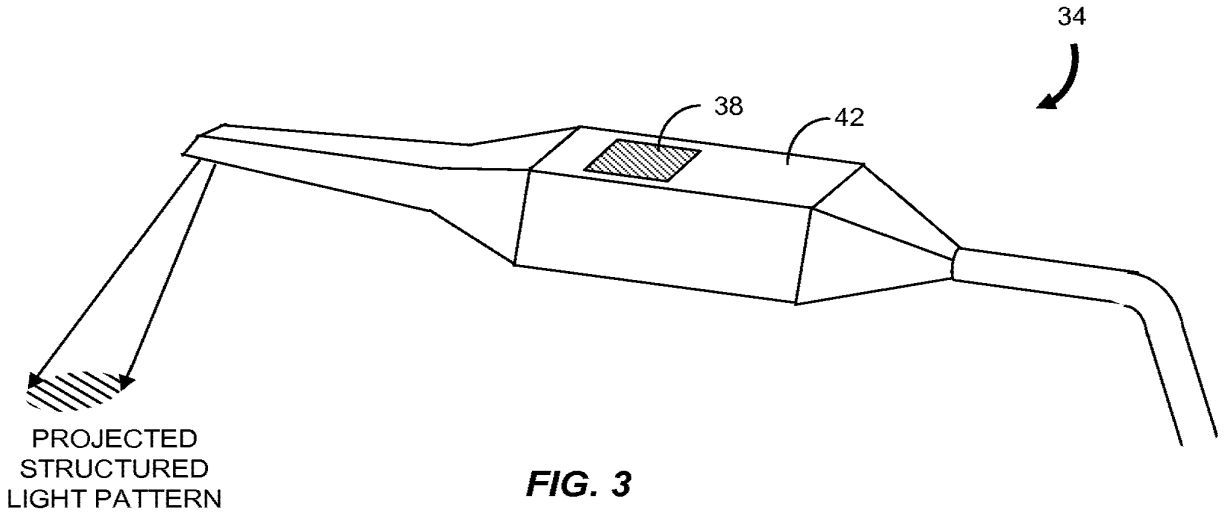


FIG. 3

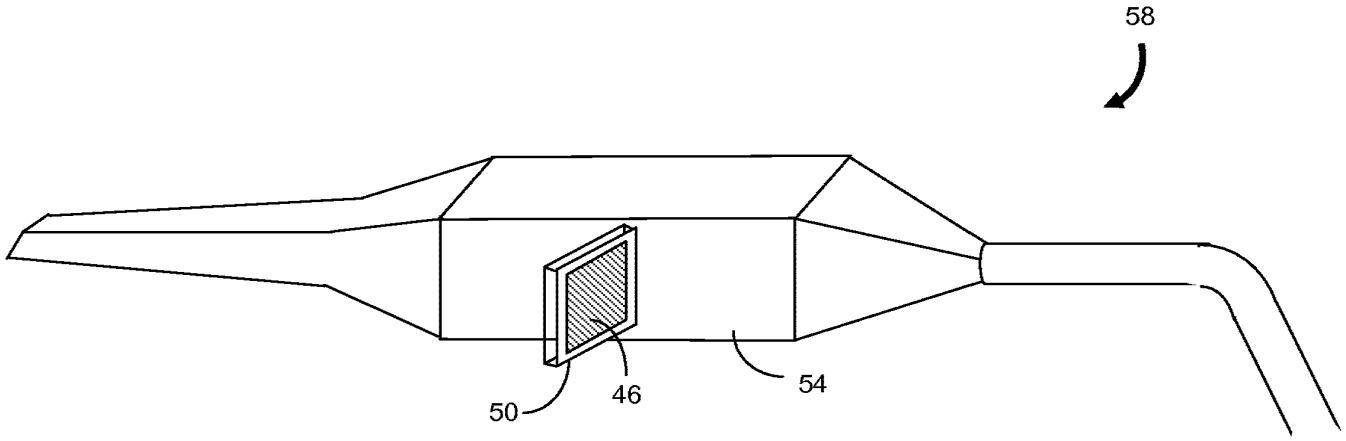


FIG. 4A

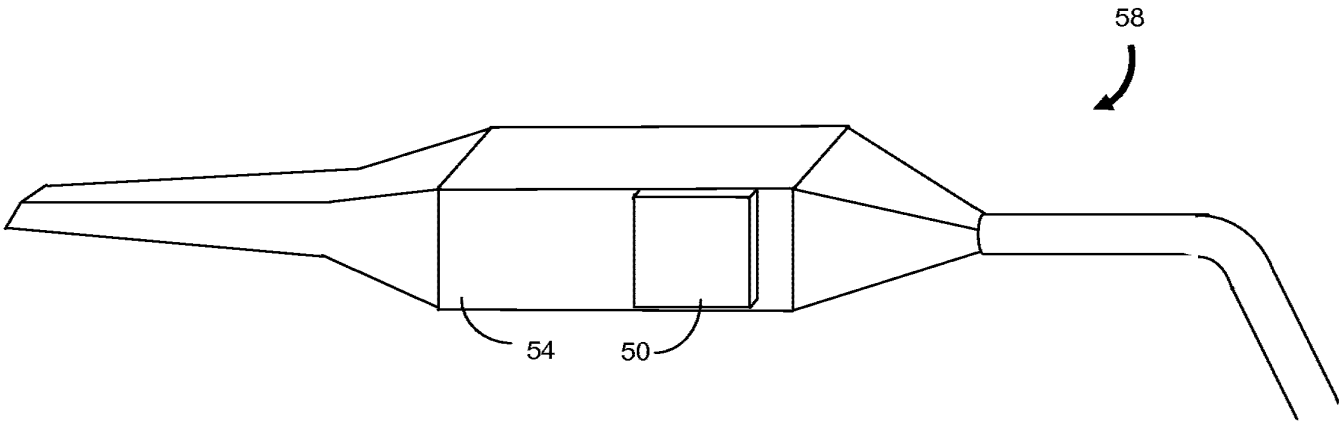


FIG. 4B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 10/41045

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - A61C 3/00 (2010.01)
USPC - 433/29
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC - A61C 3/00 (2010.01)
USPC - 433/29

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC - 345/419,420,421,422,423,424,426,427

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PubWEST (PGPB,USPT,USOC,EPAB,JPAB); Google Scholar
Search terms - display, screen, touch screen, fringe patter, two dimension$, three dimension$, pivot$, hinge$, control$, distance, surface, contour

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US 2005/0237581 A1 (KNIGHTON et al.) 27 October 2005 (27.10.2005) entire document, especially para [0025]-[0035,] [0047]-[0048], [0052]-[0054]; Fig 1, 6	1-12, 14 --- 13, 15-16
Y	US 7,046,286 B1 (KOBAYASHI et al.) 16 May 2006 (16.05.2006) Fig 4-6	13
Y	US 6,438,272 B1 (HUANG et al.) 20 August 2002 (20.08.2002) col 5, ln 4-34	15-16

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
16 September 2010 (16.09.2010)	27 SEP 2010
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Authorized officer: Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

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Published:

— *with international search report (Art. 21(3))*

(54) **Title**: SCANNING OF CAVITIES WITH RESTRICTED ACCESSIBILITY

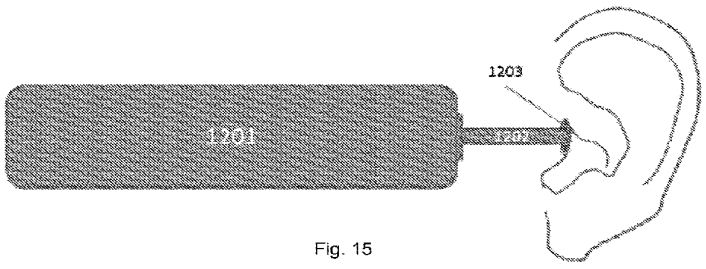


Fig. 15

(57) **Abstract**: Disclosed is a method and a scanner system for scanning interior surfaces, where the method comprises: - providing a probe shaped scanner having an axis, where the probe shaped scanner comprises: • at least one light source configured to create and project structured light, and • at least one camera configured to record 2D images; - entering said probe shaped scanner into a cavity of an object, where said cavity is bounded by an interior surface of the object; - creating and projecting structured light from said light source of the probe producing a pattern on the interior surface of the object; - recording a series of 2D images of the reflection of the pattern from the interior surface using said camera; - combining said series of 2D images to obtain 3D real world coordinates of the interior surface; and - providing data and processing said data such that surface information for areas of the surface, where image scanning is not complete, is created. The scanner system may comprise a probe shaped scanner, a data conversion device and a data processing device, optionally all integrated in one device. (fig.15 should be published)

WO 2011/120526 A1

Scanning of cavities with restricted accessibility

The invention relates to the creation of high precision three-dimensional replicas of real objects. The invention specifically concerns the three-dimensional scanning of interior surfaces or cavities of limited dimensions or with restricted accessibility. Furthermore, the invention relates in particular to scanning the human ear and ear canal.

Systems for three-dimensional optical scanning are well known in the prior art. They typically comprise one or more light sources projecting a structured light pattern on the object to be scanned, one or more cameras and data processing equipment to convert the recorded image coordinates to three dimensional coordinates using state of the art software. Usually, only a part of the object is scanned in a single scan. To create a full scan the object, camera and light source need to be move relative to each other.

Accuracy and precision are of utmost importance in many applications, e.g. when the scan data is used to model an object that must fit precisely into another part. Such applications are e.g. devices for the ear canal such as hearing aids, dental implants and other prostheses for the body. For hearing aid shells, sub-millimeter precision is required lest the shell cause irritation, acoustic feedback and possibly infection to the epidermis of the ear canal. For dental implants the precision requirement is even greater, since a human being can detect differences less than 1/10 of a millimeter when biting. Therefore systematic or random errors in the calibration and/or performance of scanners for these uses can be serious. This has hitherto limited the use of scanning in the modeling of such implants and shells.

Disclosed is a method for scanning interior surfaces, where the method comprises:

- providing a probe shaped scanner having an axis, where the probe shaped scanner comprises:
  - at least one light source configured to create and project structured light, and
  - at least one camera configured to record 2D images;
- entering said probe shaped scanner into a cavity of an object, where said cavity is bounded by an interior surface of the object;
- creating and projecting structured light from said light source of the probe producing a pattern on the interior surface of the object;
- recording a series of 2D images of the reflection of the pattern from the interior surface using said camera;
- combining said series of 2D images to obtain 3D real world coordinates of the interior surface; and
- providing data and processing said data such that surface information for areas of the surface, where image scanning is not complete, is created.

The method may in particular be suitable for scanning partly obstructed interior surfaces, where visual access to part of the interior surface is blocked due to e.g. impurities and/or due to the geometrical form of the interior surface where e.g. bends may prevent visual access to a part of the interior surface.

The method may also be applicable to the scanning of interior surfaces where visual access is provided over the entire scanned surface.

In some embodiments, the method comprises:

- providing that the camera comprises a plurality of sensor elements or a plurality of groups of sensor elements;

- varying the focus plane of the pattern over a range of focus plane positions while maintaining a substantially fixed spatial relation of the camera and said interior surface,

where the combining of 2D images comprises determining by analysis of said 2D images the in-focus position(s) of the focus plane for:

a) each of a plurality of sensor elements in the camera for said range of focus plane positions, or

b) each of a plurality of groups of the sensor elements in the camera for said range of focus planes,

and where said 3D real world coordinates are from said in-focus positions.

Disclosed is a scanner system for three-dimensional scanning of interior surfaces, said scanner comprising:

- a probe shape scanner configured to be entered into a cavity, said probe shaped scanner comprising

- at least one light source adapted to create and project structured light producing a pattern on the interior surface of an object, where said light source emits light from a point of emission; and
- at least one camera, adapted to record 2D images of the pattern, where the camera accumulates light at a point of accumulation;

- a data conversion device adapted to convert 2D images into 3D real world coordinates,

- a data processing device configured to create surface information for areas of the surface, where image scanning is not complete.

Disclosed is a method for scanning interior surfaces comprising the

- entering a probe shaped scanner having an axis into a cavity,
- creating and projecting structured light from a light source on the probe producing a pattern on an interior surface of an object, and at a camera of the probe, recording 2D images of the pattern reflected from the interior surface, thereby performing a scan around the axis of the probe,
- determining 2D coordinates of the images of the pattern,
- combining a series of images to obtain 3D real world coordinates of the interior surface, and
- processing data such that surface information from areas of the surface, where image scanning is not complete, is created.

Consequently, it is an advantage that surface information can be obtained for e.g. areas where there are no 2D images recorded, due to e.g. holes of surface information, by e.g. using kinds of data other than image data.

In some embodiments, the data that are provided and processed to create surface information, are obtained from the recorded 2D images.

In some embodiments, the probe shaped scanner has an axis and where a scan around the axis is performed.

In the context of the present invention, the phrase "hole in the surface information" may relate to a part of the surface where data is lacking. Such a lack of data may e.g. occur when visual access to the interior surface is blocked. The holes may also be referred to as occluded holes when caused by an object that blocks the visual access to the interior surface of the object

Furthermore it is an advantage that surface information can be obtained even if the surface in e.g. the ear is not clean, such that 2D images do not correctly show the recorded surface, e.g., if there are foreign objects, such as ear wax

in the ear covering parts of the surface, or if there are other foreign objects such as hair, scars or animals in the ear diminishing the quality of the scanning. Thus foreign object may be hair, ear wax, small animals such as insects, eggs from insects, pearls, sand, dirt, pimples, scars etc.

Consequently, it may be an advantage that prior to scanning, the patient's ear need not be rinsed to remove foreign objects such as cerumen or ear wax. Hereby the patient does not need to visit a doctor to have his/her ear rinsed. In some cases it may be advantageous to apply a diffusively reflecting material to the surface of the ear canal if the appearance is too glossy.
Both the ear canal and the external part of the ear, called the pinna, may be scanned.

It is an advantage that one scan can be performed in less than 1 minute.

The axis of the scanner may be the longitudinal axis of the scanner and/or the optical axis of the scanner. The optical axis of the scanner may be defined by the optical axis of the camera or the optical axis of the light source

It is an advantage to scan the ear and the ear canal directly with a scanner, instead of providing an impression of the ear canal, and then scanning the impression. The silicone used when making an impression expands the ear and may thus not give a correct impression.

It is a further advantage with regard to ear scanning that the improved fit of the hearing aid shells according to the present invention compared to prior art hearing aid shells means that the frequent problem of acoustic feedback in hearing aids is minimized.

Furthermore it is an advantage that the direct scanning of the ear significantly reduces the production cost of hearing aids, since the impressions used

today are rendered superfluous. Obviating the impression removes the handling and mailing cost and cuts down the production time and improves flexibility.

Thus it is an advantage that the method allows for easy scanning of interior surfaces of objects which cannot be scanned with high precision using prior art scanning methods.

Preferably the method is carried out with a scanner according to the invention.

According to one aspect the invention relates to a method for 3D modeling and production comprising obtaining 3D real world coordinates of an interior surface of a cavity provided using the method according to the invention, and creating a piece adapted to fit into the cavity.
Thereby, the steps for manufacturing the piece are reduced to the absolute minimum and an essentially perfect fit of the piece can be obtained. The interior surface may be scanned a number of times, such as under different conditions affecting the geometry of the interior surface. Thereby the variations in the dimensions of the interior surface can be recorded. This is very cumbersome using the prior art techniques.

Once the data are recorded the piece may be manufactured using any automatic manufacturing technique such as milling. More preferably the modeling technique comprises 3Dimensional printing, stereo lithography, selective laser sintering, laminated object modeling, inkjet modeling, fused deposition modeling, or nano-printing. A common feature of these techniques is that only the required amount of material is used and that it is easier to produce complex models such as devices for the ear and/or ear canal and/or dental implants.

The devices for the ear may comprise a hearing aid, a mobile phone, a loud speaker, noise protection, a microphone, communication devices, a tinnitus masker or a tinnitus masking device such as the ones described in US 5,325,872 and WO 91/17638.

In some embodiments holes in the surface information are registered.
When holes in the surface information of the physical object are registered, other ways of determining the surface or the contour of the surface at these areas can be applied such that all areas will be covered, imaged, detected, or interpolated in one way or the other for acquiring surface information.

In some embodiments holes in the surface information are closed by fitting to higher-order mathematical surfaces, such as second-order, third--order, fourth-order etc.
The information from neighbour areas etc can be used to infer the contour at holes. Thus the artificial hole closing may be performed by fitting parametric surface such as spline surface or higher-order mathematical surfaces.

In some embodiments holes in the surface information are closed by using information about where there exists no surface.
If complete image data are missing from a region of the ear canal, then knowledge about the ear anatomy indicating that there exists no surface in said particular part of the region can be used to determine where the surface then should be arranged or interpolated. Thus the surface should not be in an area where it is positively detected that there is no surface. Thus it is an advantage to exclude a volume from scans or 2D images where it is certain that there exists no surface.

In some embodiments holes in the surface information are closed by combing image data with data other than image data.

It is an advantage to combine image data with other types of data, e.g. data from other sources or sensors than the image sensor or camera, such as data from a touch sensor, such that the image data can be verified, assisted or supported by the other data.

In some embodiments holes in the surface information are closed by using other data than image data.
It is an advantage to use data from other sources or sensors than the camera providing the image data, if there exist no image data covering an area of the surface.

In some embodiments the surface model obtained from the scan is processed, for example smoothed. Processing can remove noise and outliers in the raw scan data.

In some embodiments other data than image data comprises color, interference, angle of reflected light, and/or data from one or more other sensors than the camera.

In some embodiments the one or more other sensors comprise touch sensor, contact sensor, sonic sensor, and/or temperature sensor.

In some embodiments a part of the data of surface information of the left ear is used as a part of the data of surface information for the right ear, if there are parts of the right ear where surface information has not been acquired, and vice versa.
It is an advantage to use corresponding scan data from one ear to the other ear, because of symmetry between a person's two ears.

A part of the data of surface information of the left ear may be used for verifying data obtained from one the right ear even though no data are missing for that ear, and vice versa.

In some embodiments holes or missing areas in a scan are inferred or interpolated based on previous scans of the person's ear. It is an advantage because especially children with hearing loss require refitted hearing aids frequently as they grow, but the shape of their ear canal may not change as rapidly as its size.

In some embodiments foreign objects in the ear canal are identified.

In some embodiments identifying foreign objects comprises detecting reflections from the foreign object.
It is an advantage because foreign objects such as hair may reflect light very well, and thus the reflections from hair and other foreign objects may be distinct from reflections from skin in the ear.

In some embodiments a foreign object is identified by analyzing the difference in the reflected light from the skin and the foreign object, respectively.
The difference in the reflected light may be the difference in contrast of the reflected light.

In some embodiments a foreign object is identified if it has an overall higher or lower reflectivity than the skin.

In some embodiments the foreign object is identified if there is a sudden change in reflectivity at the boundary between the foreign object and the skin.

In some embodiments the foreign object is identified by means of a combination of its overall higher or lower reflectivity than the skin and the sudden change in reflectivity at the boundary between the foreign object and the skin.

It is an advantage to detect the foreign object by its different reflectivity, because it allows monochromatic or near-monochromatic light to be used. Thus detection of the contrast is better according to the present method than described in prior art US7529577B, which discloses "analyzing the output with respect to spectral composition of the light received at the light sensitive element and identifying foreign object based on the spectral composition of the received light", see claim 1. According to the present method a monochromatic or near-monochromatic light may be used.

In some embodiments the method comprises using monochromatic light to illuminate the surface for analyzing reflected light.
The light or illumination may alternatively be semi-monochromatic or light having more wavelengths.

In some embodiments the method comprises identifying foreign objects by correlating surface data with the 3D position of the specific data.
It is an advantage because the places in the ear where hair and ear wax are typically present may be known in advance. Likewise the places in the ear where hair or ear wax seldom or never are present may also be known in advance. Thus by correlating the predefined knowledge about typical places for hair and ear wax, respectively, with the actual scan, it is possible to either rule out that a foreign object can be hair or ear wax, or possible to determine with a high probability that a detected foreign object is hair or ear wax.

In some embodiments detecting hair comprises having predefined information in the system about where hair normally is arranged in the ear.

It is an advantage because if inconclusive data is obtained from a place in the ear, and this place typically contains hair, then the inconclusive data is likely to stem from hair.

In some embodiments foreign objects in the ear are filtered out from the images of the ear.
It is an advantage that the ear shall not be cleansed and rinsed before scanning the ear, because foreign object such as ear wax is filtered out from the images.

In some embodiments foreign objects are presented to the operator on a display.

In some embodiments the operator can assist in detecting foreign objects by reacting to the data presented on the display. This may be by pointing toward foreign objects or by pointing toward borders between the foreign objects and the skin.

In some embodiments the foreign objects are colored in a different color on the display than the rest of the surface on the image.

In some embodiments detecting hair comprises detecting and deleting single points on the images.
It is an advantage because hair may appear as single points on the images, because a hair is normally not thick enough to provide a real image of it.

In some embodiments detecting hair comprises detecting the root of the hair in the skin.
It is an advantage to detect the root of a hair, because it ends in an enlargement, the hair bulb, which is whiter in color and softer in texture than the shaft, and is lodged in a follicular involution called the hair follicle in the

epidermis layer of the skin, and therefore it may be easier to detect the root of a hair than the hair itself, because the skin is different at the point where a hair is growing out.

In some embodiments detecting hair comprises detecting the thickness of the hair.
It is an advantage because hereby it can be determined whether a hair is so thick that it may influence the measurements or whether the hair is thin enough to be disregarded.

In some embodiments detecting hair comprises detecting the movement of hair when the probe touches the hair.

In some embodiments the method comprises determining whether scar tissue is fresh or old, when detecting a foreign object in the form of scar tissue,
It is an advantage because if the scar is fresh, the scar should heal before the ear scanned and a hearing device is applied in the ear.
On the other hand if the scar is old, then a hearing device can be fitted by avoiding that the hearing device applies pressure on the scar, which will be uncomfortable for the user.

The light source may be configured to create and project structured light such that a pattern is produced on a surface exposed to light from the light source.

In some embodiments color filters are applied to the light source.
It is an advantage to use color filters such as red, green and blue, since hereby different colors to be emitted to the surface can be produced using only a single light source.

In some embodiments the light source is adapted to emit different colors.

It is an advantage since the different colors can be used to detect different objects or features of the surface. The wavelengths of the different colors may be close to each other to obtain a good result.

In some embodiments the light source emits multi-colored light.
It is an advantage to use multi-colored light in combination with the patterned light, e.g. chessboard pattern, because each period or region in the pattern can be analysed for each different color.

Furthermore, it is an advantage to use multi-colored light in combination with a pattern with differently colored periods or regions because each period or region in the pattern can be analyzed for each different color without analyzing the spectral composition of the light reflected from the surface.

In some embodiments the light source emits monochromatic or near-monochromatic light but switches between different colors in time. It is an advantage to use light varying in color over a period of time because the pattern can be analyzed for each different color without analyzing the spectral composition of the light reflected from the surface.

In some embodiments the size of regions of the emitted light pattern is 20x20 mm.

In some embodiments the size of the regions of the emitted light pattern is 10x10 mm.

It is an advantage to use a pattern which is two times smaller, since hereby there are four squares within one area instead of one square within the same area, and hereby a better resolution can be achieved.

In some embodiments light with different polarisation is used, such that light with different polarisations is projected onto the interior surface of the object.

In some embodiments the polarization state of the emitted and/or the detected light is controlled.

It is an advantage to control the polarization because hereby skin and in particular hair, which has a high degree of specular reflection, can be distinguished from surfaces with a low degree of specular reflection. Surfaces with a high degree of specular reflection reflect light with a specific relationship between the polarization of the incident and reflected light. In this way surfaces with high degree of specular reflection may be distinguished from surfaces with low degree of specular reflection.

The polarization of reflected light may be controlled by means of e.g. a linear polarization filter or quarter wave plate or filter, which can be added and/or removed from the light path and/or rotated in the light path.

In some embodiments the light source is a laser and light from said laser is guided to impinge on the surface in a small spot.

In some embodiments there is more than one light source in the probe shaped scanner and the different light sources are alternately turned on and turned off.

In some embodiments the light source emits infrared light.

It is an advantage because it may be possible to see right through hair using infrared light.

In some embodiments the optical resolution of the scanner is 100 μm.

It is an advantage to have such a high resolution since hereby as many details of the surface as possible can be resolved. Alternatively, the resolution of the scanner may be 200 μm.

In some embodiments the method comprises detecting the hardness under the skin in different parts of the ear canal.
It is an advantage because a soft part of the ear canal is likely to be tissue, and a hard part of the ear canal is likely to be bone, and if the hearing device has a very tight fit in the ear canal where there is bone, it may be very unpleasant for the user. On the other hand, the hearing device can have a tight fit where there is soft tissue under the skin in the ear canal. So by detecting where there is soft tissue and hard bone in the ear canal, the hearing device can be made to fit very comfortably in the user's ear.

In some embodiments light with different wavelengths is used to detect the hardness under the skin in the ear canal.
It is an advantage because the different layers of skin, bone, tissue etc has different properties regarding absorption and/or scattering for different light wavelengths.

In some embodiments the light used for scanning comprises one or more narrow laser beams co-propagating with a broader light beam. The co-propagating laser beams may be light that is reflected and/or refracted from a prism or a beam-combining element. It is an advantage because the narrow laser beams may be of a different color than the broader light beam. The light from the narrow laser beams reflected from the surface may be used to determine the amount of absorption and/or scattering in the tissue in the regions where the narrow beams impinge. A region of large absorption may result in reflection of a small amount of light compared to a region of small absorption. A region of large scattering may result in reflection of a considerably broadened beam compared to a region of small sub-surface

scattering. Soft or hard tissue in the ear may differ in the amount of light absorption and/or scattering. Thus this may be used to identify soft or hard regions in the ear.

In some embodiments the hardness under the skin is evaluated by detecting the reflected pattern of light, calculating the size of the regions of the pattern, and comparing this size with the regular or emitted size of the regions of the pattern.

In some embodiments the scanner comprises guide means adapted to assist the operator in holding the scanner in the correct distance and/or position relative to the ear.

The distance may be relative to an external part of the ear, the pinna, or relative to a part of the ear canal.

In some embodiments the guide means comprises two laser beams, and when the two laser beams are crossing each other at a point on the ear, the distance between scanner and ear is correct for scanning.

The point on the ear may a point on the external part of the ear.

In some embodiments the guide means comprises a first and a second set of two laser beams, and when the first set of laser beams are crossing each other at a first point on the ear, the distance between scanner and ear is correct for scanning of a first region of the ear, and when the second set of laser beams are crossing each other at a second point on the ear the distance between the scanner and ear is correct for scanning of a second region of the ear.

The points on the ear may be one point or two different points on the external part of the ear. The first and the second point may indicate the distance the scanner probe should be moved in/out of the ear.

The two sets of two laser beams may be of different color.

In some embodiments the ear is scanned in a first configuration where the mouth is closed, and in a second configuration, where the mouth is open.
It is an advantage because then the two extreme configurations of the jaw and mouth and thereby the ear are recorded.

Thus with regard to ear scanning it is possible to record a number of scans of one ear, and ask the patient to deliberately vary the size of the ear canal by swallowing, yawning, chewing, and drinking. In this way a series of scans of the ear canal can be recorded and the magnitude of the variation of the patient's ear canal can be detected.

In some embodiments the image data of the first and the second configurations are merged into one image by means of CAD.
Thus it is possible to superimpose the scans on one another to create a combined image or model, which will fit the patient's ear under all conditions. Such a model is naturally made as a combination of or a compromise between the different sizes of the ear canal.

In some embodiments a touch sensor is arranged in connection with the scanner, such that the touch sensor is adapted to register contact with the skin.

In some embodiments the touch sensor comprises a tactile component at the probe tip.
It is an advantage to also perform a touch or contact measurement to thereby obtain a double check of the real time image detection, and to acquire further data which can be used to obtain a complete scan of the ear canal.

In some embodiments the touch sensor is a capacitive sensor.

In some embodiments the direction of the ear canal towards the ear drum is determined by means of image data and/or one or more other data.

It is an advantage because when the direction of the ear canal towards the ear drum is known, the speaker or transceiver in a hearing aid can be arranged such that it points directly towards the ear drum, whereby the user of the hearing aid will receive the sounds directly at the ear drum, whereby the sound quality is improved for the user.

In some embodiments a motion sensor is arranged in connection with the scanner, such that the motion sensor is adapted to perform a motion measurement of the scanner.

It is an advantage also to perform motion measurement, since this can be used in registration.

In some embodiments an orientation sensor is arranged in connection with the scanner, such that the orientation sensor is adapted to perform an orientation measurement of the scanner.

In some embodiments the scanner comprises a number of marks in its cover, such that an operator can visually determine how far the scanner must be moved into the ear canal.

It is an advantage because when the scanner is moved into an ear canal, the operator may not be able to see the tip of the scanner. When the operator can see the marks of the scanner cover, he thereby has a guide to how far the scanner is moved into the ear, and when it should not be moved any further into the ear, in order not to be touching the ear drum. The marks may e.g. be three lines arranged with a distance from each other on the scanner cover.

In some embodiments a user interface of the scanner is adapted to direct the operator to insert the probe a certain distance into the ear canal.

It is an advantage since it may be used in registration.

In some embodiments a user interface of the scanner is adapted to direct the operator to move the probe a certain distance in any three-dimensional direction.
It is an advantage since it may be used in registration.

In some embodiments the shape of the probe prevents it from reaching the ear drum. It is an advantage because the ear drum or tympanic membrane is very sensitive. For example, the probe can have a conical longitudinal cross section, or a bulge.

In some embodiments a camera, such as a second camera or a video camera, is arranged in relation to the scanner such that it is configured to record images, from where the position of the scanner relative to the ear is adapted to be determined.
It is an advantage to record the scanner position relative to the ear by means of a regular camera capturing photographs or by means of a video camera.

In some embodiments the method comprises the steps of:
- varying the focus plane of the pattern over a range of focus plane positions while maintaining a fixed spatial relation of the camera and the surface,
- determining the in-focus position(s) of:
a) each of a plurality of sensor elements in the camera for said range of focus plane positions, or
b) each of a plurality of groups of the sensor elements in the camera for said range of focus planes, and
transforming in-focus data into 3D real world coordinates.

One object of the invention is to provide a scanner which may be integrated in a manageable housing, such as a handheld housing. One object of the invention is to discriminate out-of-focus information. One object of the invention is to provide a fast scanning time.

The focus scanning may be achieved by a scanner for obtaining and/or measuring the 3D geometry of at least a part of the surface of an object, said scanner comprising:

- means for generating a probe light incorporating a pattern,
- at least one camera accommodating an array of sensor elements,
- means for transmitting the probe light towards the object thereby illuminating at least a part of the object with said pattern,
- means for imaging light reflected from the object to the camera,
- means for varying the position of the focus plane of the pattern on the object while maintaining a fixed spatial relation of the scanner and the object, and
- data processing means for:
    a) determining the in-focus position(s) of:
        - each of a plurality of the sensor elements for a range of focus plane positions, or
        - each of a plurality of groups of the sensor elements for a range of focus plane positions, and
    b) transforming in-focus data into 3D real world coordinates.

The method and apparatus relating to focus scanning is for providing a 3D surface registration of objects using light as a non-contact probing agent. The light is provided in the form of an illumination pattern to provide a light oscillation on the object. The variation / oscillation in the pattern may be spatial, e.g. a static checkerboard pattern, and/or it may be time varying, for example by moving a pattern across the object being scanned.

Focus scanning provides for a variation of the focus plane of the pattern over a range of focus plane positions while maintaining a fixed spatial relation of the scanner and the object. It does not mean that the scan must be provided with a fixed spatial relation of the scanner and the object, but merely that the focus plane can be varied (scanned) with a fixed spatial relation of the scanner and the object. This provides for a hand held scanner solution based on focus scanning.

Some embodiments comprises a first optical system, such as an arrangement of lenses, for transmitting the probe light towards the object and a second optical system for imaging light reflected from the object to the camera. In some embodiments only one optical system images the pattern onto the object and images the object, or at least a part of the object, onto the camera, e.g. along the same optical axis, however along opposite optical paths.

In some embodiments an optical system provides a confocal imaging of the pattern onto the object being probed and from the object being probed to the camera. The focus plane may be adjusted in such a way that the image of the pattern on the probed object is shifted along the optical axis, e.g. in equal steps from one end of the scanning region to the other. The probe light incorporating the pattern provides a pattern of light and darkness on the object. Specifically, when the pattern is varied in time for a fixed focus plane then the in-focus regions on the object will display an oscillating pattern of light and darkness. The out-of-focus regions will display smaller or no contrast in the light oscillations.

When a time varying pattern is applied a single sub-scan can be obtained by collecting a number of 2D images at different positions of the focus plane and at different instances of the pattern. As the focus plane coincides with the scan surface at a single pixel position, the pattern will be projected onto the

surface point in-focus and with high contrast, thereby giving rise to a large variation, or amplitude, of the pixel value over time. For each pixel it is thus possible to identify individual settings of the focusing plane for which each pixel will be in focus. By using knowledge of the optical system used, it is possible to transform the contrast information vs. position of the focus plane into 3D surface information, on an individual pixel basis.

Thus, in one embodiment the focus position is calculated by determining the light oscillation amplitude for each of a plurality of sensor elements for a range of focus planes.

For a static pattern a single sub-scan can be obtained by collecting a number of 2D images at different positions of the focus plane. As the focus plane coincides with the scan surface, the pattern will be projected onto the surface point in-focus and with high contrast. The high contrast gives rise to a large spatial variation of the static pattern on the surface of the object, thereby providing a large variation, or amplitude, of the pixel values over a group of adjacent pixels. For each group of pixels it is thus possible to identify individual settings of the focusing plane for which each group of pixels will be in focus. By using knowledge of the optical system used, it is possible to transform the contrast information vs. position of the focus plane into 3D surface information, on an individual pixel group basis.

Thus, in one embodiment the focus position is calculated by determining the light oscillation amplitude for each of a plurality of groups of the sensor elements for a range of focus planes.

The 2D to 3D conversion of the image data can be performed in a number of ways known in the art. I.e. the 3D surface structure of the probed object can be determined by finding the plane corresponding to the maximum light oscillation amplitude for each sensor element, or for each group of sensor

elements, in the camera's sensor array when recording the light amplitude for a range of different focus planes. Preferably, the focus plane is adjusted in equal steps from one end of the scanning region to the other. Preferably the focus plane can be moved in a range large enough to at least coincide with the surface of the object being scanned.

Handheld embodiments of the invention preferably include motion sensors such as accelerometers and/or gyros. Preferably, these micro electro mechanical systems (MEMS) should measure all motion in 3D, i.e., both translations and rotations for the three principal coordinate axes. The benefits are:

A) Motion sensors can detect vibrations and/or shaking. Scans such affected can be either discarded or corrected by use of image stabilization techniques.

B) Motion sensors can help with stitching/ registering partial scans to each other. This advantage is relevant when the field of view of the scanner is smaller than the object to be scanned. In this situation, the scanner is applied for small regions of the object (one at a time) that then are combined to obtain the full scan. In the ideal case, motion sensors can provide the required relative rigid-motion transformation between partial scans' local coordinates, because they measure the relative position of the scanning device in each partial scan. Motion sensors with limited accuracy can still provide a first guess for a software-based stitching/ registration of partial scans based on, e.g., the Iterative Closest Point class of algorithms, resulting in reduced computation time.

C) Motion sensors can be used (also) as a remote control for the software that accompanies the invention. Such software, for example, can be used to visualize the acquired scan. With the scanner device now acting as a remote control, the user can, for example, rotate

and/or pan the view (by moving the remote control in the same way as the object on the computer screen should "move"). Especially in clinical application, such dual use of the handheld scanner is preferable out of hygienic considerations, because the operator avoids contamination from alternative, hand-operated input devices (touch screen, mouse, keyboard, etc).

The present invention relates to different aspects including the method described above and in the following, and corresponding apparatus, methods, devices, uses and/or product means, each yielding one or more of the benefits and advantages described in connection with the first mentioned aspect, and each having one or more embodiments corresponding to the embodiments described in connection with the first mentioned aspect and/or disclosed in the appended claims.

In particular, disclosed herein is a scanner for three-dimensional scanning of interior surfaces, comprising:

- at least one light source adapted to create and project structured light producing a pattern on the interior surface of an object,
- at least one camera, adapted to record 2D images of the pattern,
- data processing means adapted to convert 2D image information into 3D real world coordinates,
- the point of emission of light as well as the point of accumulation of reflected light for the camera being located on a probe having an axis,
- the at least one light source and the at least one camera being adapted to perform a scan around the axis,
- the probe being adapted to be entered into a cavity, and

wherein the scanner comprises:

- means for processing data such that surface information from areas of the surface, where image scanning is not complete, is created.

The probe of the scanner may be either rigid of flexible.

This scanner has the advantage that it may be able to cover the whole circumference without moving the scanner thus being able to scan the whole inner surface of an object. With this layout it is possible to scan interior surfaces such as the ear canal, tubes, pipes and bores with non-contact scanning and obtain high precision scan data of the whole interior surface of the object.

Furthermore, the dimensions of the scanner can be very small thus allowing scanning and 3D mapping of interior surfaces with small cross section, which are inaccessible to prior art scanners.

It is an advantage that the scanner is equipped with a position sensor, which allows the relative position and orientation of the scanner and the object to be determined for successive scans. This greatly facilitates the combination of data from successive scans and makes it possible to combine these with much higher precision irrespective of the position and orientation of the scanner during scanning.

The compact layout of the scanner allows for easy scanning of interior surfaces of objects of extremely small size. The ease of operation of the scanners according to the invention means that practitioners without experience in scanning can easily perform the scanning operations, which is required especially in the case of scanning of body cavities and scanning for archaeological purposes.

In some embodiments, the probe shaped scanner has an axis and the at least one light source and the at least one camera are adapted to perform a scan around the axis

In some embodiments, the data conversion device and said probe shaped scanner are integrated in one device.
In some embodiments, the data conversion device is part of a separate unit, such as part of a personal computer connected to the probe shaped scanner.

In some embodiments, the said data processing device and said probe shaped scanner are integrated in one device.
In some embodiments, the data processing device is part of a separate unit, such as part of a personal computer connected to said probe shaped scanner.

In some embodiments, the data processing device and said data conversion device are comprised in one integrated conversion and processing device. The integrated conversion and processing device and the probe shaped scanner may be integrated in one device

In some embodiments, the scanner system comprises a nontransitory computer readable medium having one or more computer instructions stored thereon, where said computer instructions comprises instructions for conversion of 2D images and/or for processing data.

Disclosed is a hearing aid device obtained by from a 3D model of the interior surface of an ear, where said 3D model is obtained by the method according to the invention and/or by the scanner according to the invention.

Disclosed is a nontransitory computer readable medium storing thereon a computer program, where said computer program is configured for causing computer-assisted scanning of partly obstructed interior surfaces.

Disclosed is a computer program product comprising program code means for causing a data processing system to perform the method described above when said program code means are executed on the data processing system, and a computer program product comprising a computer-readable medium having stored there on the program code means.

Brief description of the drawings

The above and/or additional objects, features and advantages of the present invention, will be further elucidated by the following illustrative and non-limiting detailed description of embodiments of the present invention, with reference to the appended drawings, wherein:

Figure 1 illustrates an embodiment of the interior surface scanner according to the invention.

Figure 2 shows a cross section of an embodiment of the interior surface scanner according to the invention.

Figure 3 illustrates another embodiment of the interior surface scanner with a mirror in front of the camera.

Figure 4 shows a cross section of another embodiment of the interior surface scanner with a mirror in front of the camera.

Figure 5 shows how a structured light pattern is projected onto the interior surface. In this case the pattern is a single cone. This pattern is then reflected from the surface into the camera.

Figure 6 illustrates an example of the use of mirrors and/or prisms. A structured light pattern is reflected in a mirror before being projected onto the interior surface. In this case the pattern is a single cone. This pattern is then reflected from the surface into a mirror that reflects the pattern into the camera.

Figure 7 shows a cross section of a model of the interior surface scanner according to the invention. Note that the camera has been moved out of the probe and a lens system is used to guide the image to the camera.

Figure 8 shows a cross section of a model of the interior surface scanner according to the invention. Note that the camera has been moved out of the probe and optical fibres are used to guide the image to the camera.

Figure 9 illustrates different positions sensors, which can be applied within the invention.

Figure 10 shows an embodiment of a hollow calibration object used for calibration of the camera and light sources. Note the symmetric 3D object feature curves on the object, which are utilised in the calibration.

Figure 11 shows a schematic sketch of a scanner according to the invention adapted for scanning of the ear and ear canal.

Figure 12 shows a schematic sketch of another embodiment of the scanner for the ear and ear canal.

Figure 13 shows a scan of an ear and an ear canal seen from two different views.

Figure 14 illustrates an embodiment of the scanner being able to scan the surface lying behind the end of the probe.

Fig. 15 shows an example of a scanner with a probe in an ear.

Fig. 16 shows an example of scanner with an extra camera mounted.

Fig. 17 shows examples of laser beams for guiding the position and orientation of the scanner.

In the following description, reference is made to the accompanying figures, which show by way of illustration how the invention may be practiced.

Figure 1 to Figure 4 illustrates two embodiments of the invention. The first part 101 of the scanner is the probe, which is inserted into the cavity. The second part 102 is a handle. The scanner in Figure 1 and Figure 2 comprises a cover 103, a scan button 104, a disposable cover 105, light guides 201, a light source 202, a position sensor 203, optics and mirrors and/or prisms 204, a camera 205 and a protector/collision detector 206. A rotating mirror and/or prism with a micro motor 301 is also added to the component list in the embodiment shown in Figure 3 and Figure 4. As illustrated in Figure 5, the scanner works by projecting a structured light pattern 501 onto the interior surface of the object 502. The camera 503 acquires images of the reflection 504 of the light pattern from the surface. By locating the light pattern in the images, the corresponding 3D surface positions can be reconstructed applying well-known projective geometry. The scanner only scans limited

parts of the surface at each position and usually it has to be moved around handheld or automatically to scan the full interior surface.

The light is generated by one or more light sources such as lasers, variable output-powered laser, light emitting diodes (LED), halogen spots or other spotlights and travels through the light guides such as optical fibers. In some applications it might be relevant to use monochromatic, coherent or polarized light. At the end of the light guides optics and mirrors and/or prisms may create the desired pattern. Examples of optics are filters, lenses or prisms. An alternative to the use of light guides is to place the light source near the tip of the scanner. Note that the projection of light, even lasers, onto the surface does not damage the surface.

The light sources for some applications preferably are as small as possible to minimize the dimensions of the scanner. It is thus contemplated that the light source may have a cross section perpendicular to the direction of emitted light of less than 5 mm^2, preferably less than 4 mm^2, for example less than 3 mm^2, such as less than 2 mm^2, for example less than 1 mm^2, such as less than 0.5 mm^2, for example less than 0.25 mm^2.

The scanner may work with only one light source, but for many purposes it is advantageous to have several such as at least two light sources, such as at least three light sources, for example at least four light sources, such as at least five light sources, such as at least six light sources, for example at least seven light sources, such as at least eight light sources, for example at least ten light sources, such as at least twelve light sources, for example at least sixteen light sources, such as at least twenty light sources.

Depending on the desired pattern one, two, three or more optics and one, two, three, four or more mirror and/or prisms are required. The structured light pattern may be a number of rays forming a grid of spots on the surface

consisting of one, two, three, four or more rows of points, one, two, three or more cones of light forming contours on the surface, one, two, three of more planes of light forming contours on the surface, one, two, three of more thick planes of light forming thick contours on the surface, a number of rectangular shaped rays forming a distorted checker board pattern on the surface or more complex shapes.

Thus, when projecting a pattern of rays, pattern may comprise at least 10 rays, such as at least 25 rays, for example at least 100 rays, such as at least 1000 rays, for example at least 10,000 rays, such as at least 100,000 rays, for example at least 1,000,000 rays.

Figure 5 illustrates how a single light cone 501 is projected onto the object surface 502 using optics 503. Figure 6 shows how the emission angle of the light cone can be increased significantly by reflecting the emitted light 601 into a cone mirror and/or prism 602 after the optics 603. Any type of mirrors such as coplanar mirrors and cone mirrors can be used to reflect the light. Applying mirrors and/or prisms make it possible to change the emission direction invariant of the orientation of the light guides. The light pattern can also be moved over the surface without moving the actual scanner by rotating and/or tilting the mirrors and/or prisms. The rotation and/or tilting of the mirrors and/or prisms may be carried out by a motor.

Preferably the location of the point of emission of light and the point of recording reflected light as well as the angle of emission and recording with respect to the axis of the probe are chosen to give an angle between incident light on the object and light reflected from the object of approximately 20-30 degrees. An example of this embodiment is illustrated in figure 6.

Occlusion effects represent a problem for some types of scanning of interior surfaces. Some of these can be overcome by selecting a direction of emission and recording of light with respect to the axis of the scanner, which

ensures that light is projected on and recorded from all parts of the interior surfaces. One embodiment of the scanner is designed, wherein the location of the point of emission of light and the point of recording reflected light as well as the angle of emission and recording with respect to the axis of the probe are chosen to give a scan of the surface lying ahead of the end of the probe. An example of such a scanner is shown in Figure 5. Alternatively the location of the point of emission of light and the point of recording reflected light as well as the angle of emission and recording with respect to the axis of the probe may be chosen to give a scan of the surface lying approximately around the end of the probe. An example of this is shown in figure 6. Alternatively, the location of the point of emission of light and the point of recording reflected light as well as the angle of emission and recording with respect to the axis of the probe may be chosen to give a scan of the surface lying behind the end of the probe. Figure 14 illustrates an example of such a scanner. These alternative embodiments may be obtained with one scanner by tilting mirrors and/or prisms.

The light source intensities are preferably varied depending on the surface and color of the object to be scanned. Preferably the intensity should be determined automatically using automatic light source intensity calibration.

The intensity calibration may be performed by inserting the scanner into the object and calculate a number of histograms from the acquired images. First a histogram is calculated with the light source turned off. A second histogram is the calculated when the light source is turned on with an arbitrary intensity. The first histogram is then subtracted from the second to remove the background intensity. The intensity is then adjusted until the requested quantile corresponds to a predefined intensity. The background could also be removed by subtracting the image corresponding to the light source turned off from the image with light. The histogram used to determine the intensity could then be calculated from this difference image.

The images are acquired by the one or more cameras. Preferably the cameras comprise a lens and a sensor array such as a CCD or CMOS chip. Usually the camera also comprises a filter placed in front of the sensor array. The effect of the filter is that only light with approximately the desired wavelength passes the filter. This makes it feasible to separate different light sources in the scanner and remove most of the background light. Alternatively, the camera may be color sensitive.

The scanner may comprise just one camera or comprise several such as at least 2 cameras, such as at least 3 cameras, for example at least 4 cameras, such as at least 6 cameras, for example at least 7 cameras, such as at least 8 cameras, for example at least 10 cameras, such as at least 12 cameras, for example at least 16 cameras, such as at least 20 cameras.

Preferably the cameras are arranged such that reflected light is recorded from different directions covering the 360 degrees around the probe, as seen in Figures 11 and 12, right side.

Preferably the camera part of the scanner is as small as possible. The size of commercially available cameras is reduced almost every year, and it is estimated that the lower limit for camera size and pixel size have not been reached at all yet. Irrespective of the future development within this area, any camera smaller than the cameras presently available will be suitable for use in the present invention. Therefore the light detecting component of the camera may have a cross section in a direction perpendicular to the direction of incident light of less than 10 mm^2, such as less than 9 mm^2, for example less than 8 mm^2, such as less than 7 mm^2, for example less than 6 mm^2, such as less than 5 mm^2, for example less than 4 mm^2, such as less than 3 mm^2, for example less than 1 mm^2, such as less than 0.5 mm^2, for example less than 0.25 mm^2, such as less than 0.1 mm^2, for example less than 0.01 mm^2.

The number of pixels of the camera is a question of the size of the camera, depending on the size of the pixels, the computing power used for processing the results of the scans and the cost of the camera. No upper limit for the number of pixels can be set, since precision is increased whenever the number of pixels is increased. Accordingly, the camera may comprise an array of at least 125x125 pixels, more preferably at least 250x250 pixels, more preferably more than 500x500 pixels, more preferably more than 1000x1000 pixels, such as more than 2000x2000 pixels, for example more than 4000x4000 pixels, such as more than 8000x8000 pixels, for example more than 10,000x10,000 pixels, such as more than 25,000x25,000 pixels, for example more than 50,000x50,000 pixels, such as more than 100,000x100,000 pixels, for example more than 250,000x250,000 pixels, such as more than 500,000x500,000 pixels, for example more than 1,000,000x1,000,000 pixels. Similarly, the pixel size may be the smallest available on the market, for example wherein a cross section of a pixel is less than 100 micrometres, such as less than 50 micrometres, for example less than 25 micrometres, such as less than 20 micrometres, for example less than 15 micrometres, such as less than 10 micrometres, for example less than 7.5 micrometres, such as less than 5 micrometres, for example less than 2.5 micrometres, such as less than 2 micrometres, for example less than 1.5 micrometres, such as less than 1 micrometres, for example less than 0.5 μ, such as less than 0.25 micrometres, for example less than 0.1 micrometres, such as less than 0.01 micrometres.

The light pattern may be reflected from the surface directly into the camera or into one or more light reflecting means such as mirrors or prisms before ending up in the camera. In the embodiment of the scanner in Figure 1 no mirrors are applied, since the scanner only needs to "look" forward with respect to the camera, i.e. the direction of the view is always parallel with the optical axis of the camera. Figure 5 illustrates the simple emission of the light pattern 501 and its reflections 504 from the object surface 502 into the

camera 505 without the use of mirrors. Figure 5 is a simplified illustration of the principle used in the scanner in Figure 1.

Applying one or more mirrors and/or prisms for reflecting the light into the camera gives full freedom to select the direction of the view invariant of the orientation of the camera. Figure 6 illustrates how the emitted light pattern 601 is reflected using a cone mirror and/or prism 602 before it hits the object surface 605. The reflected light 604 is likewise reflected into a mirror and/or prism 606 before entering the camera 607. Figure 6 is a simplified illustration of the principle used in the scanner in Figure 3. Static mirrors such as coplanar or cone mirrors can be applied directly in the invention. Static mirrors have the advantage of being simple and mechanically stable.

In the embodiment of the scanner shown in Figure 3 the mirror and/or prism in front of the camera is coplanar, circular and able to rotate. The advantage of a rotating mirror and/or prism compared to a static mirror and/or prism, such as a cone mirror and/or prism, is that the image resolution and the field of view of the camera are significantly increased. Indeed resolution and field of view are seriously limited due to the small dimensions of the scanner, which directly affect the accuracy and flexibility. Tilting the mirror and/or prism further increases the accuracy and flexibility. In practice, the same mirror and/or prism can be used to generate the light pattern and reflecting the light into the camera. However, applying different mirrors and/or prisms for light and cameras, as presented in Figure 3, increase the flexibility of the scanner especially with respect to direction of view, depth of field and point reconstruction quality.

In the case of very small dimensions of the cavity and/or high requirements for accuracy it is infeasible to place the camera on the head of the scanner. The problem is solved by moving the cameras out of the probe. The image/light is then directed into the cameras by the use of light guides such as a lens system or optical fibres. An embodiment of the invention where a

lens system 701 and optical fibres 801 are used as light guides are illustrated in Figure 7 and Figure 8, respectively. The lens system might be similar to the lens systems used in periscopes and endoscopes. At the moment the lens system is superior to optical fibres with respect to smallest dimensions and image quality. The disadvantage of the lens system is that it requires the probe be rigid, whereas the optical fibres are fully flexible, i.e. the probe can be flexible.

The objective of the position sensor is to determine the relative position and orientation of the probe head with respect to the object to be scanned. Knowing this position is extremely advantageous in combining the individual scans when the scanner or object is moved. Errors in the position measures will directly affect the quality of the scan. In the case of non-fixed objects such as the ear canal of humans are scanned, it is extremely advantageous to measure the position with respect to the object, e.g. the ear canal, and not to a fixed coordinate system, since the object might move during the scanning.

The position sensor is only used to combine the individual scans. The position sensor can be rendered superfluous by a registration of the individual scans. The output of the registration is the relative position of the scans. Knowing the relative positions of the scans makes it straightforward to combine the scans. For the registration to be successful the interior surface needs to contain a proper number of distinct features, which is not always the case.

The position sensor can be a magnetic sensor as shown in Figure 9, where the receiver 902 usually is in the scanner and the transmitter 903 is secured to the object 901, e.g. the head of a human. Magnetic sensors have the advantage of not suffering for occlusion problems. Alternative sensors might be optical or sonic sensors. Figure 9 illustrates an optical sensor where markers 904 are placed on the object and a sensor 905 on the scanner.

Likewise Figure 9 illustrates a sonic sensor, where an emitter 906 is placed on the object and a detector 907 is placed on the scanner. Both optical and sonic sensors suffer from occlusion problems, but their cost is often lower and the precision superior to those of magnetic sensors. In the case of a fixed object or an object, which can be fixed, a mechanical position sensor becomes attractive. As illustrated in Figure 9 these sensors usually consist of a number of joints 908 connected by encoders. Many mechanical sensors are highly accurate, but they tend to be bulky or cumbersome to use.

In general, the position needs to be determined with respect to the head of the scanner. More precisely, the position of the focal point of the camera has to be determined when the camera is placed on the probe head. In the case where light guides are used in front of the camera, the position should correspond to the tip of the guides. With a rigid design of the scanner cover as in Figure 1 to Figure 4 the position sensor can be placed anywhere on the scanner, since the relative distance between the scan head and the position sensor is constant. With a flexible design of the probe the position sensor needs to be placed on the scan head, e.g. at the front as on the scanner in Figure 11 and Figure 12.

In the design of the scanner show in Figure 1 and Figure 3 only the probe 101 is supposed to move into the cavity. The main objective of the design has been to minimize the width of this part, since it determines the minimal size of the cavity, which can be scanned. In general the width of the probe can be varied freely down to approximately 0.1 mm, e.g. the width can be 30, 20, 15, 10, 8, 6, 5, 4, 3, 2, 1 or 0.1 mm. However the final design is a trade-off between size, accuracy and mechanical stability. In general the application determines the desirable design.

In the case of scanning the human ear canal the width of the part is requested to be below 4 mm. Figure 3 shows a scanner designed for scanning ear canals, where the width of the probe is 3.5 mm. The length of

the probe can also be varied freely down to approximately 5 mm, e.g. the length can be 20, 35, 50, 100, 200, 300 or 500 mm. The length of the probe shown in Figure 1 and Figure 3 is 55 mm.

The rest of the scanner's cover is basically a handle. For optimal handling this part should preferably be 10-30 mm width and 100-150 mm long. The dimension can however be varied freely. As in Figure 1 and Figure 3 the width of the handle may be extended to make room for the components, e.g. the position sensor. The dimensions of this extension should however be minimized if the objective is to create the smallest and lightest scanner. The width and length of the extension shown in Figure 1 and Figure 3 is 40 mm and 30 mm, respectively. Note that larger light sources such as halogen spots may be moved to the extension.

In another embodiment of the scanner it is possible to rotate the probe around its axis. The advantage of this design compared to only rotating the mirrors and/or prisms as in Figure 3 is that the motor can be placed in the handle. Likewise another embodiment comprises a linear drive, which is able to translate the probe along its axis. The scanner can also be mounted on a robot, or another device, which is able to position the scanner with any orientation and position within its workspace.

The choice of material for the cover depends on the actual application, especially whether the probe needs to be rigid or flexible. Preferably the cover should be produced in stainless steel or from a material selected from a group consisting of alloy, aluminum, a plastic polymer, Kevlar (R), ceramics or carbon.

In some application it might be necessary to protect the components such as cameras, mirrors and/or prisms and lenses against dust and other dirt. In practice this is done by inserting a window of transparent material such as glass or a plastic polymer in the holes in front of the relevant components.

Other features in the preferred embodiment are a protector/collision detector, a scan button, and a disposable scanner cover. The protector consists of soft material such as rubber, silicone or a plastic polymer and ensures that the tip of the probe and the surface are not damaged in the case of a collision. In the case of scanning an ear canal it is crucial that the scanner does not damage the eardrum. In the case of very fragile surfaces, a collision detector adapted to measure the distance from the tip of the scanner to the bottom of the interior surface is added to the protector. When surfaces are scanned for which the scanner is subject to hygiene requirements, a disposable cover is desirable to minimize the need for cleaning. The disposable cover will usually only cover the probe or parts of it, but can be fit to the specific requirements. The scan button is used to start and stop the scan operation.

The acquired images may be analyzed real-time in a digital signal processor or microprocessor, which is placed in the scanner handle or in a separate processing box. The first step in the analysis of an image may be to detect the light pattern in the image using a standard tracking algorithm. When the light pattern is known, potentially with sub-pixel precision, the corresponding 3D coordinates can be reconstructed using well-known projective geometry. A precise reconstruction of the 3D coordinates requires a very high quality of the camera and light calibration. The next step may be to combine the 3D coordinates from different images acquired at the same or at different positions. The merging may simply be performed by combining the individual points sets positioned with respect to their relative position. Finally the points may be triangulated using a standard triangulation algorithm to form the final surface of the 3D model. The 3D model may then be transferred over a network to the destination for further use.

The scanner according to the invention is especially adapted for scanning interior surfaces, such as body cavities and other interior surfaces with narrow openings, into which light from an external scanner cannot enter due to occlusion effects.

It is thus envisaged that the scanner is advantageous for scanning body cavities such as the internal surfaces of the ear, nose, mouth, teeth, stomach, lungs, alveoli, throat, rectum, vagina, veins, blood vessels, urinary tract. Scanning of teeth can be used in connection with correction of teeth and manufacture of dental implants. Scanning the blood vessels may be useful in connection with surgery. Scanning the vagina can be used in connection with pregnancy and delivery and also for measuring and modeling an individually adapted diaphragm. Figure 13 shows a scan of the interior surface of an ear and an ear canal 1301.

The scanner can also be used for industrial purposes such as for scanning internal surfaces of engines, fuel canals, bore, internal thread, pipes, tubes and containers. In this way the exact dimensions, such as volume and/or cross section and/or location of features, of the devices can be measured. When using a scanner with a position sensor, this can be done more precisely than with any of the known scanners. Furthermore, the present scanners are not sensitive to small deviations in the orientation of the axis of the scanner with respect to the axis of the object being scanned.

Another use is for archaeological purposes such as for scanning internal surfaces of jars, skulls and other archaeological items.

Furthermore, the scanners are very useful in industrial design especially in connection with computer assisted 3D modeling.

A possibility according to the invention is to scan the ear canal directly. This can be done by building the components of the scanner into an apparatus, which can be inserted into the ear of the patient. Embodiments of this scanner are shown in Figure 11. Preferably, the light source, e.g. the laser, and the camera are located outside the ear. The laser light can be carried into the scanner by light guides 201, and similarly, the reflected signals can be carried to a camera by another light guide 801. The scanner also consists

of a position sensor 203, which measures the relative position of the scanner with respect to the object. During the scan, the scanner preferably rests on the edge of the ear canal, most preferably in those places where bones are closest to the skin surface. This is in order to obtain the highest stability and is very important, since the scanner itself works with an accuracy of less than 0.05 mm. The length of the ear canal can be scanned by moving the scanner in or out and record a series of overlapping images of the ear canal. The scanner may comprise only one laser source and one camera as the one shown in the left of Figure 11. In that case the scanner has to rotate while the camera records images. The scanner may comprise multiple laser sources such as four as shown in the scanner in the right part of Figure 11. The presence of multiple laser sources and cameras removes the need for rotation of the scanner in the ear canal. In the laser scanner disclosed in Figure 11, the laser source or sources project a ray of laser light on the surface of the ear canal.

Another type of ear canal laser scanner is shown in Figure 12. Here the laser light is projected as laser sheets producing a laser contour on the surface of the ear canal. Thereby, more rapid scanning can be performed compared to the above laser scanner. In the scanner shown in the right part of Figure 12, four laser sheets and four cameras are present. Thereby the laser sheets cover the whole circumference and rotation of the scanner is not required.

The same types of variation of the ear canal scanner can be used as in other cases of three-dimensional scanners according to this invention. Thus, the scanner may comprise at least two cameras, such as 4 cameras, such as for example 6 cameras. Likewise, there may be several laser sources such as for example 2 lasers creating laser sheets with an offset of 180 degrees, such as 3 laser sheets with an offset of 120 degrees, or 4 laser sheets with an offset of 90 degrees.

Currently hearing aids are created in a silicon mould, made with an ear impression.

It is possible to scan and create very detailed and accurate copies of ear impressions with the developed system as described in 3Shape's prior art document "Method for modeling customized earpieces" with publication number WO02071794 published in 2002.

Apart from hearing aids, other devices could also be inserted into a shell made to fit the ear canal of an individual. Such devices that could advantageously be incorporated into a shell manufactured according to the disclosed method include mobile phones, communication devices, loud speakers, tinnitus masking devices, or devices recording vibrations in the skull and transforming these into an audio signal.

Devices that may be incorporated into a shell in the ear also comprise devices related to Man Machine Interface (MMI) products, such as custom made ear microphone or receivers that enable reliable and clear communication even in the noisiest environments, or products related to wireless internet applications.

Speech not only creates sound waves, it also generates vibrations within the skull of the speaker. These vibrations can be picked up in the ear, but they may be picked up other places too, but by far the most convenient method is to do it in the ear. In one piece, a device thus may comprise a microphone to pick up the speech of the person wearing it, and a loudspeaker to transmit the speech of the communication partner. It is important that such devices are made to fit the ear.

Devices based on detection of vibration instead of sound can be used in the noisiest environments, since they only pick up the speech of the wearer and they allow for quiet communication, since the speaker can speak with a low

voice when needed. The devices allow for completely hand-free communication.

Such a device is naturally also devoid of any kind of acoustic feedback if manufactured using the present invention.

The precision of the light sources and cameras is very high today and so is that of the software developed to detect the intersection of the light sheet with the object and to convert the two-dimensional data to three-dimensional coordinates. Therefore differences in precision and hence improvement of the precision primarily resides in the calibration of the systems. Recall that precision is of utmost importance in many applications.

To obtain the highest precision both the light pattern and the camera need to be calibrated. Preferably the calibration should be performed using a calibration object with symmetrical 3D object feature curves and the corresponding methods as described below and in 3Shape's prior art document "Method for modeling customized earpieces" with publication number WO02071794 published in 2002. The main advantage of this type of calibration objects is that the light pattern can be calibrated independently of the calibration of the camera. An embodiment of the hollow calibration object used for calibration of the scanner is shown in Figure 10. Note the symmetric 3D object feature curves 1001 on the calibration object, which are utilized in the calibration.

Preferably, a light pattern is projected onto the calibration object to produce 2D image feature curves in the acquired images.

When preferred, the image feature curves may be determined using the Hough transformation, filter search, max intensity, threshold, center of gravity, derivatives or other procedures.

The image feature coordinates are found as the intersection between image feature curves. These intersections could be seen in the images as corners or sharp edges of the image feature curves. The image feature coordinates may be found as the intersection between the image feature curves such as the intersection between two n^{th} order curves, as the intersection between two first order curves, as the intersection between two second order curves, as the intersection between two third order curves, as the intersection between a fist order curve and a second order curve, as the intersection between a first order curve and a third order curve, or as the intersection between a second order curve and a third order curve or as the intersection between any other possible combination of curves.

Preferably, the calibration method comprises plotting of a mathematical combination of image feature points or features derived from these points against the angle of rotation or the translation of the calibration object. By plotting this function and optionally estimating a mathematical function describing the relationship between the function of an image coordinate and the angle of rotation or the translation, estimation of the light parameters and angle or rotation and/or translation becomes especially precise. The method may comprise determination of the mean plane of symmetry in the plot.

The mean plane of symmetry can be determined by calculating the mean angle of rotation / mean translation for pairs of image feature points having the same value in the mathematical combination. Doing this produces multiple estimates for the encoder offset and light pattern displacement allowing also for the estimate of the laser sheet angle.

Light pattern calibration may also comprise selecting symmetric points, plotting of the rotation angle and/or the translation for the first point against the difference in the rotation angle and/or the translation between the two symmetric points, deriving a mathematical formula for the plotted lines and estimating the light pattern parameters.

Alternatively, mathematical formulas can be derived for the curves that appear in some of the plots of the mathematical combination as a function of the angle of rotation or the translation. Given these curves and the corresponding formulas, the encoder offset, the light pattern displacement, and the light pattern angle can be estimated.

Preferably, light pattern coordinates of the 3D object feature curves are estimated corresponding to a discrete number of values of angle of rotation and/or translations. These values should preferably cover the whole circumference and/or length of the calibration object.

2D coordinates of the 3D object feature curves corresponding to a discrete number of values of angle or rotation and/or translation may be calculated from mathematical functions determining the 3D object feature curves. In order to determine the calibration parameters such as camera position, camera orientation, and camera optic parameters, pairs of 2D light pattern coordinates are compared to calculated 2D coordinates for a discrete number of values of angle or rotation and/or translation. This comparison preferably comprises using the Tsai or the Heikkilae algorithm. The advantage of the Tsai and the Heikkilae algorithms in this context is that they provide rapid and precise estimation of the calibration parameters such as radial lens distortion.

Alternative methods for calibration comprise direct linear transformation and direct non-linear matrix transformation optionally in combination with an optimization procedure such as least squares to minimize the error. In these cases initial calibration parameters may be estimated to facilitate the convergence of the parameters during optimization.

To improve calibration, precision outliers may be excluded from the calibration. Outliers can e.g. be identified in the plot of the mathematical combination of image feature coordinates against the angle of rotation / the translation or by back projection of coordinates after an initial calibration.

Two percent of the feature points deviating most from the back-projected 2D image feature curves may be excluded from the calibration or at least 3 percent, such as at least 5 percent, for example at least 10 percent, for example at least 12 percent, such as at least 15 percent for example at least 20, preferably at least 25 percent, for example at least 30 percent, more preferably at least 33 percent may be excluded to improve calibration precision.

In order to cover the whole circumference of the calibration object the discrete number of values for angle of rotation / translation may be at least 100, preferably at least 240, for example at least 500, such as at least 750, for example at least 1000, such as at least 1200, for example at least 1500, such as at least 1800, for example at least 2000, such as at least 2400, for example at least 3000, for example at least 3600, such as at least 4200. The higher the discrete number of values of angle of rotation / translation, the higher the calibration precision.

The highest calibration precision is obtained when using a rigid setup, which comprises mounting the calibration object onto mounting means.

Fig. 15 shows an example of a scanner with a probe in an ear.

The scanner 1201 comprises a probe 1202, where the tip of the probe 1202 is shown to be partly inserted in the ear canal of a patient. Light 1203 is emitted from the probe tip of the scanner 1201 in order to scan the ear and/or the ear canal.

Fig. 16 shows an example of scanner with an extra camera mounted.
The scanner 1601 is arranged such that the ear 1604 and/or ear canal of a patient can be scanned. The scanner 1601 comprises a probe 1602, which

comprises a probe tip 1605 from where light 1603 is emitted from the scanner.

The scanner 1601 is shown with a cut-off section such that the components inside the scanner 1601 can be viewed. The scanner comprises a light source 1606 which emits light 1603, a pattern 1607 which produces structured light from the light source 1606, a beam splitter (not shown), optical lenses 1608, and a camera or image sensor 1609 for capturing optical images. On the external portion of the scanner 1601 a camera 1610 is arranged, which is adapted to record images, for example as still photographs or video. The field of view 1611 of the camera 1610 is shown to be in the direction of the probe tip, such that the camera 1610 records images of, for example, the external part of the ear 1604. These recordings may be used as reference images for detecting the position and/or orientation of the scanner for example for coupling the scanned 2D images to a 3D position, and from this the position of the scanner 1601 relative to the ear 1604 is adapted to be determined.

Fig. 17 shows examples of laser beams for guiding the position and orientation of the scanner.

Both fig. 17a) and fig. 17b) shows the scanner 1601 and the ear 1604.

In fig. 17a) two laser beams 1613 from two light sources 1612 arranged on the external part of the scanner 1601 guide the scanner operator (not shown) to hold the scanner 1601 in the correct distance from the ear 1604 for scanning. The laser beams 1613 cross each other at a point 1614, and for example when this point 1614 is at the external surface of the ear, then the scanner 1601 is in the correct distance from the ear 1604.

In fig. 17b) two sets of two laser beams 1613, 1616 from two sets of light sources 1612, 1615, respectively, guide the scanner operator (not shown) to hold the scanner 1601 in the correct distance from the ear 1604 for scanning. The two sets of light sources 1612, 1615 are arranged on the external part of

the scanner 1601. The two laser beams 1613 cross each other at a first point 1614, and the two other laser beams 1616 cross each other at a second point 1617. When for example the first point 1614 is at the external surface of the ear, then the scanner 1601 is in a correct first distance from the ear 1604, and when for example the second point 1617 is at the external surface of the ear, then the scanner 1601 is in a correct second distance from the ear 1604. The first distance may be the distance in which a first set of scanning images are made, and afterwards the scanner 1601 may be moved into the ear to the second distance to capture a second set of scanning images or vice versa such that the scanner 1601 is first arranged at the second distance to capture images and then the scanner is moved out of the ear to the first distance to capture images there.

Although some embodiments have been described and shown in detail, the invention is not restricted to them, but may also be embodied in other ways within the scope of the subject matter defined in the following claims. In particular, it is to be understood that other embodiments may be utilised and structural and functional modifications may be made without departing from the scope of the present invention.

In device claims enumerating several means, several of these means can be embodied by one and the same item of hardware. The mere fact that certain measures are recited in mutually different dependent claims or described in different embodiments does not indicate that a combination of these measures cannot be used to advantage.

It should be emphasized that the term "comprises/comprising" when used in this specification is taken to specify the presence of stated features, integers, steps or components but does not preclude the presence or addition of one or more other features, integers, steps, components or groups thereof.

The features of the method described above and in the following may be implemented in software and carried out on a data processing system or other processing means caused by the execution of computer-executable instructions. The instructions may be program code means loaded in a memory, such as a RAM, from a storage medium or from another computer via a computer network. Alternatively, the described features may be implemented by hardwired circuitry instead of software or in combination with software.

References

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Claims:

1. A method for scanning partly obstructed interior surfaces, where the method comprises:

- providing a probe shaped scanner having an axis, where the probe shaped scanner comprises:
    - at least one light source configured to create and project structured light, and
    - at least one camera configured to record 2D images;
- entering said probe shaped scanner into a cavity of an object, where said cavity is bounded by an interior surface of the object;
- creating and projecting structured light from said light source of the probe producing a pattern on the interior surface of the object;
- recording a series of 2D images of the reflection of the pattern from the interior surface using said camera;
- combining said series of 2D images to obtain 3D real world coordinates of the interior surface; and
- providing data and processing said data such that surface information for areas of the surface, where image scanning is not complete, is created.

2. The method for scanning according to the preceding claim, wherein the method comprises:

- providing that the camera comprises a plurality of sensor elements or a plurality of groups of sensor elements;

- varying the focus plane of the pattern over a range of focus plane positions while maintaining a substantially fixed spatial relation of the camera and said interior surface,

where the combining of 2D images comprises determining by analysis of said 2D images the in-focus position(s) of the focus plane for:

a) each of a plurality of sensor elements in the camera for said range of focus plane positions, or

b) each of a plurality of groups of the sensor elements in the camera for said range of focus planes,

and where said 3D real world coordinates are from said in-focus positions.

3. The method for scanning according to any of the preceding claims, wherein holes in the surface information are registered.

4. The method for scanning according to any of the preceding claims, wherein holes in the surface information are closed by fitting to higher order mathematical surfaces, such as second order, third orders, fourth order etc.

5. The method for scanning according to any of the preceding claims, wherein holes in the surface information are closed by using information about where there exists no surface.

6. The method for scanning according to any of the preceding claims, wherein holes in the surface information are closed by combining image data with other data than image data.

7. The method for scanning according to any of the preceding claims, wherein holes in the surface information are closed by using other data than image data.

8. The method for scanning according to any of the preceding claims, wherein other data than image data comprises color, interference, angle of reflected light, and/or data from one or more other sensors than the camera.

9. The method for scanning according to any of the preceding claims, wherein the one or more other sensors comprise a touch sensor, contact sensor, sonic sensor, and/or temperature sensor.

10. The method for scanning according to any of the preceding claims, wherein part of the data of surface information of the left ear is used as a part of the data of surface information for the right ear, if there are parts of the right ear where surface information has not been acquired, and vice versa.

11. The method for scanning according to any of the preceding claims, wherein holes in a scan are inferred or interpolated based on previous scans of the person's ear.

12. The method for scanning according to any of the preceding claims, wherein foreign objects in the ear canal are identified.

13. The method for scanning according to any of the preceding claims, wherein identifying foreign objects comprises detecting reflections from the foreign object.

14. The method for scanning according to any of the preceding claims, wherein a foreign object is identified by analyzing the difference in the reflected light from the skin and the foreign object, respectively.

15. The method for scanning according to any of the preceding claims, wherein the method comprises using monochromatic light to illuminate the surface for analyzing reflected light.

16. The method for scanning according to any of the preceding claims, wherein the method comprises identifying foreign objects by correlating surface data with the 3D position of the specific data.

17. The method for scanning according to any of the preceding claims, wherein foreign objects in the ear are filtered out from the images of the ear.

18. The method for scanning according to any of the preceding claims, wherein foreign objects are presented to the operator on a display.

19. The method for scanning according to any of the preceding claims, wherein the foreign objects are coloured in a different colour on the display than the rest of the surface on the image.

20. The method for scanning according to any of the preceding claims, wherein detecting hair comprises detecting and deleting single points on the images.

21. The method for scanning according to any of the preceding claims, wherein detecting hair comprises having predefined information in the system about where hair normally grows in the ear.

22. The method for scanning according to any of the preceding claims, wherein detecting hair comprises detecting the root of the hair in the skin.

23. The method for scanning according to any of the preceding claims, wherein detecting hair comprises detecting the thickness of the hair.

24. The method for scanning according to any of the preceding claims, wherein detecting hair comprises detecting the movement of hair when the probe touches the hair.

25. The method for scanning according to any of the preceding claims, wherein determining whether scar tissue is fresh or old, when detecting a foreign object in the form of scar tissue.

26. The method for scanning according to any of the preceding claims, wherein color filters are applied to the light source.

27. The method for scanning according to any of the preceding claims, wherein the light source is adapted to emit different colors.

28. The method for scanning according to any of the preceding claims, wherein the light source emits multi-colored light.

29. The method according to any of the preceding claims, wherein the light source emits monochromatic or near-monochromatic light but switches between different colors in time.

30. The method for scanning according to any of the preceding claims, wherein the size of regions of the emitted light pattern is 20x20 mm.

31. The method for scanning according to any of the preceding claims, wherein the size of the regions of the emitted light pattern is 10x10 mm.

32. The method for scanning according to any of the preceding claims, wherein light with different polarization is used.

33. The method for scanning according to any of the preceding claims, wherein the polarization state of the emitted and/or the detected light is controlled.

34. The method for scanning according to any of the preceding claims, wherein the light source is a laser and light from said laser is guided to impinge on the surface in a small spot.

35. The method for scanning according to any of the preceding claims, wherein there is more than one light source in the probe shaped scanner and the different light sources are alternately turned on and turned off.

36. The method for scanning according to any of the preceding claims, wherein the light source emits infrared light.

37. The method for scanning according to any of the preceding claims, wherein the optical resolution of the scanner is 100 μm or higher.

38. The method for scanning according to any of the preceding claims, wherein the method comprises detecting the hardness under the skin in different parts of the ear canal.

39. The method for scanning according to any of the preceding claims, wherein light with different wavelengths is used to detect the hardness under the skin in the ear canal.

40. The method for scanning according to any of the preceding claims, wherein the light used for scanning comprises one or more narrow laser beams co-propagating with a broader light beam.

41. The method for scanning according to any of the preceding claims, wherein the hardness under the skin is evaluated by detecting the reflected pattern of light, calculating the size of the regions of the pattern, and comparing this size with the regular size.

42. The method for scanning according to any of the preceding claims, wherein the scanner comprises guide means adapted to assist the operator in holding the scanner in the correct distance and/or position relative to the ear.

43. The method for scanning according to any of the preceding claims, wherein the guide means is two laser beams, and when the two laser beams are crossing each other at a point on the ear, the distance between scanner and ear being correct for scanning.

44. The method for scanning according to any of the preceding claims, wherein the guide means comprises a first and a second set of two laser beams, and when the first set of laser beams are crossing each other at a first point on the ear, the distance between scanner and ear is correct for scanning of a first region of the ear, and when the second set of laser beams are crossing each other at a second point on the ear the distance between the scanner and ear is correct for scanning of a second region of the ear.

45. The method for scanning according to any of the preceding claims, wherein the ear is scanned in a first configuration where the mouth is closed, and in a second configuration, where the mouth is open.

46. The method for scanning according to any of the preceding claims, wherein the image data of the first and the second configurations are merged into one image by means of CAD.

47. The method for scanning according to any of the preceding claims, wherein a touch sensor is arranged in connection with the scanner, such that the touch sensor is adapted to register contact with the skin.

48. The method for scanning according to any of the preceding claims, wherein the touch sensor comprises a tactile component at the probe tip.

49. The method for scanning according to any of the preceding claims, wherein the touch sensor is a capacitive sensor.

50. The method for scanning according to any of the preceding claims, wherein the direction of the ear canal towards the ear drum is determined by means of image data and/or one or more other data.

51. The method for scanning according to any of the preceding claims, wherein a motion sensor is arranged in connection with the scanner, such that the motion sensor is adapted to perform a motion measurement of the scanner.

52. The method for scanning according to any of the preceding claims, wherein an orientation sensor is arranged in connection with the scanner, such that the orientation sensor is adapted to perform an orientation measurement of the scanner.

53. The method for scanning according to any of the preceding claims, wherein the scanner comprises a number of marks in its cover, such that an operator can visually determine how far the scanner must be moved into the ear canal.

54. The method for scanning according to any of the preceding claims, wherein a user interface of the scanner is adapted to direct the operator to insert the probe a certain distance into the ear canal.

55. The method for scanning according to any of the preceding claims, wherein a user interface of the scanner is adapted to direct the operator to move the probe a certain distance in any three-dimensional direction.

56. The method for scanning according to any of the preceding claims, wherein the shape of the probe prevents it from reaching the ear drum.

57. The method for scanning according to any of the preceding claims, wherein a camera, such as a second camera or a video camera, is arranged in relation to the scanner such that it is configured to record images, from where the position of the scanner relative to the ear is adapted to be determined.

58. The method according to any of the preceding claims, comprising determining the relative position and orientation of the scanner during successive scans with at least one sensor.

59. The method according to any of the preceding claims, where the data that are provided and processed to create surface information, are obtained from the recorded 2D images.

60. The method according to any of the preceding claims, where the probe shaped scanner has an axis and where a scan around the axis is performed.

61. A scanner system for three-dimensional scanning of interior surfaces, said scanner comprising:

- a probe shape scanner configured to be entered into a cavity, said probe shaped scanner comprising

- at least one light source adapted to create and project structured light producing a pattern on the interior surface of an object, where said light source emits light from a point of emission; and
- at least one camera, adapted to record 2D images of the pattern, where the camera accumulates light at a point of accumulation;

- a data conversion device adapted to convert 2D images into 3D real world coordinates,

- a data processing device configured to create surface information for areas of the surface, where image scanning is not complete.

62. The scanner system according to claim 61, wherein the probe shaped scanner has an axis and the at least one light source and the at least one camera are adapted to perform a scan around the axis

63. The scanner system according to claim 61 or 62, wherein said data conversion device and said probe shaped scanner are integrated in one device.

64. The scanner system according to claim 61 or 62, wherein said data conversion device is part of a separate unit, such as part of a personal computer connected to said probe shaped scanner.

65. The scanner system according to any of claims 61 to 64, wherein said data processing device and said probe shaped scanner are integrated in one device.

66. The scanner system according to any of claims 61 to 64, wherein said data processing device is part of a separate unit, such as part of a personal computer connected to said probe shaped scanner.

67. The scanner system according to any of claims 61 to 66, wherein said data processing device and said data conversion device are comprised in one integrated conversion and processing device, where this integrated conversion and processing device and the probe shaped scanner may be integrated in one device.

68. The scanner system according to any of claims 61 to 67, where the system comprises a nontransitory computer readable medium having one or more computer instructions stored thereon, where said computer instructions comprises instructions for conversion of 2D images into 3D real world coordinates and/or for processing data.

69. A hearing aid device obtained by from a 3D model of the interior surface of an ear, where said 3D model is obtained by the method according to any of claims 1-60 or by the scanner according to any of claims 61-67.

70. A computer program product comprising program code means for causing a data processing system to perform the method of any one of claims 1-60, when said program code means are executed on the data processing system.

71. A computer program product according to claim 70, comprising a computer-readable medium having stored thereon the program code means.

71. A nontransitory computer readable medium storing thereon a computer program, where said computer program is configured for causing computer-assisted scanning of partly obstructed interior surfaces.

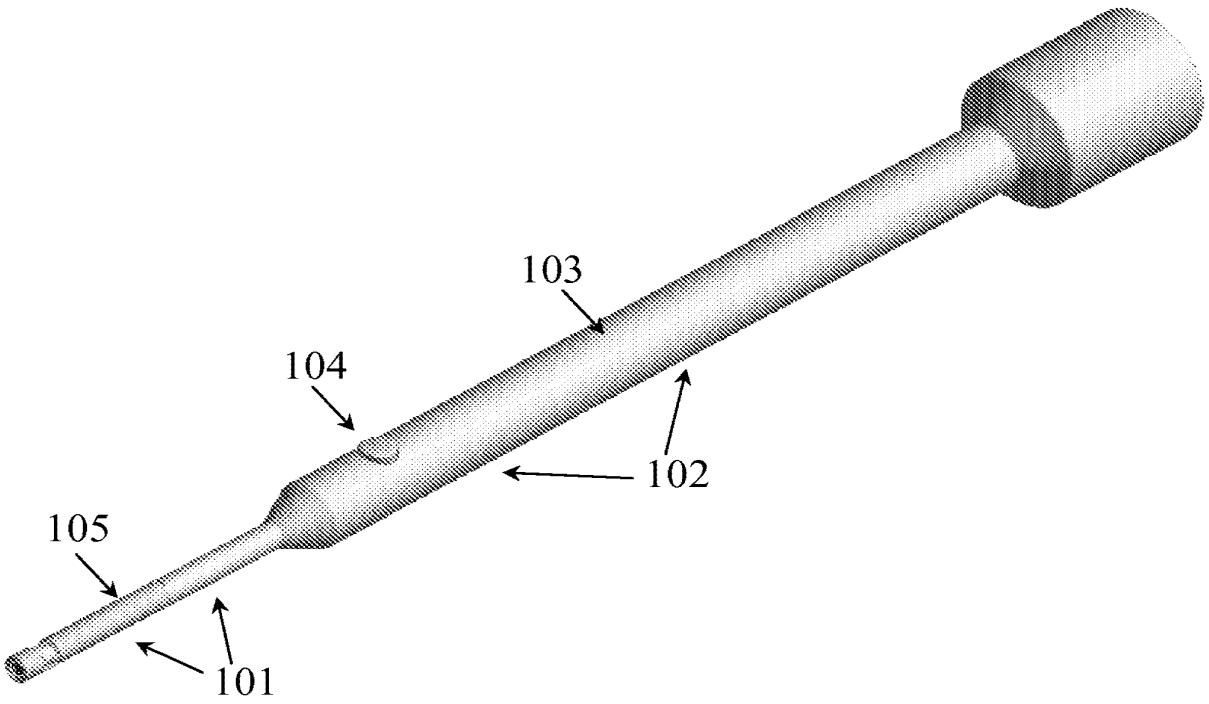


Figure 1

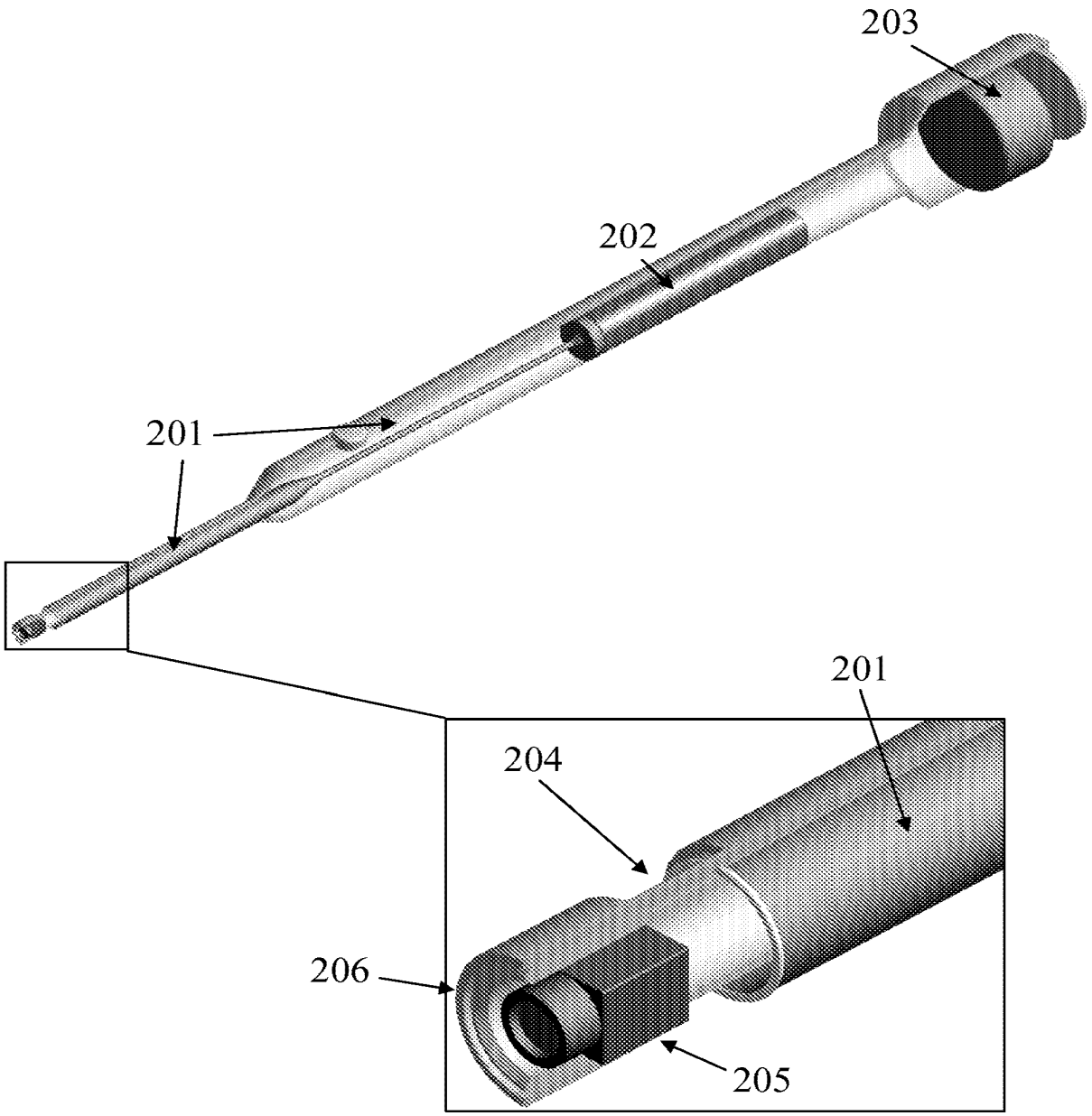


Figure 2

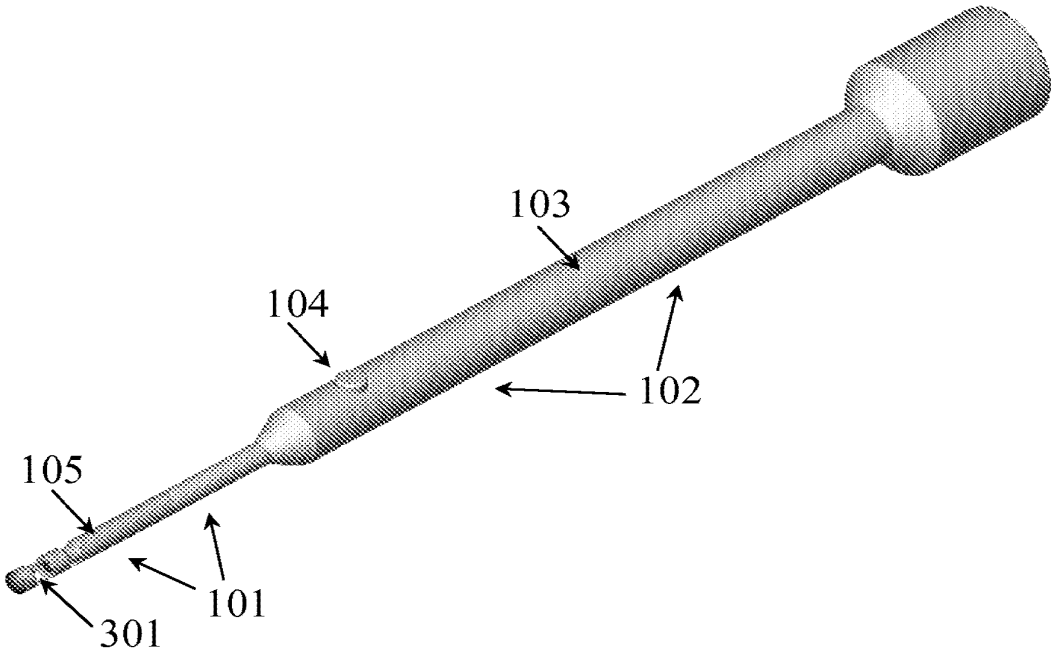


Figure 3

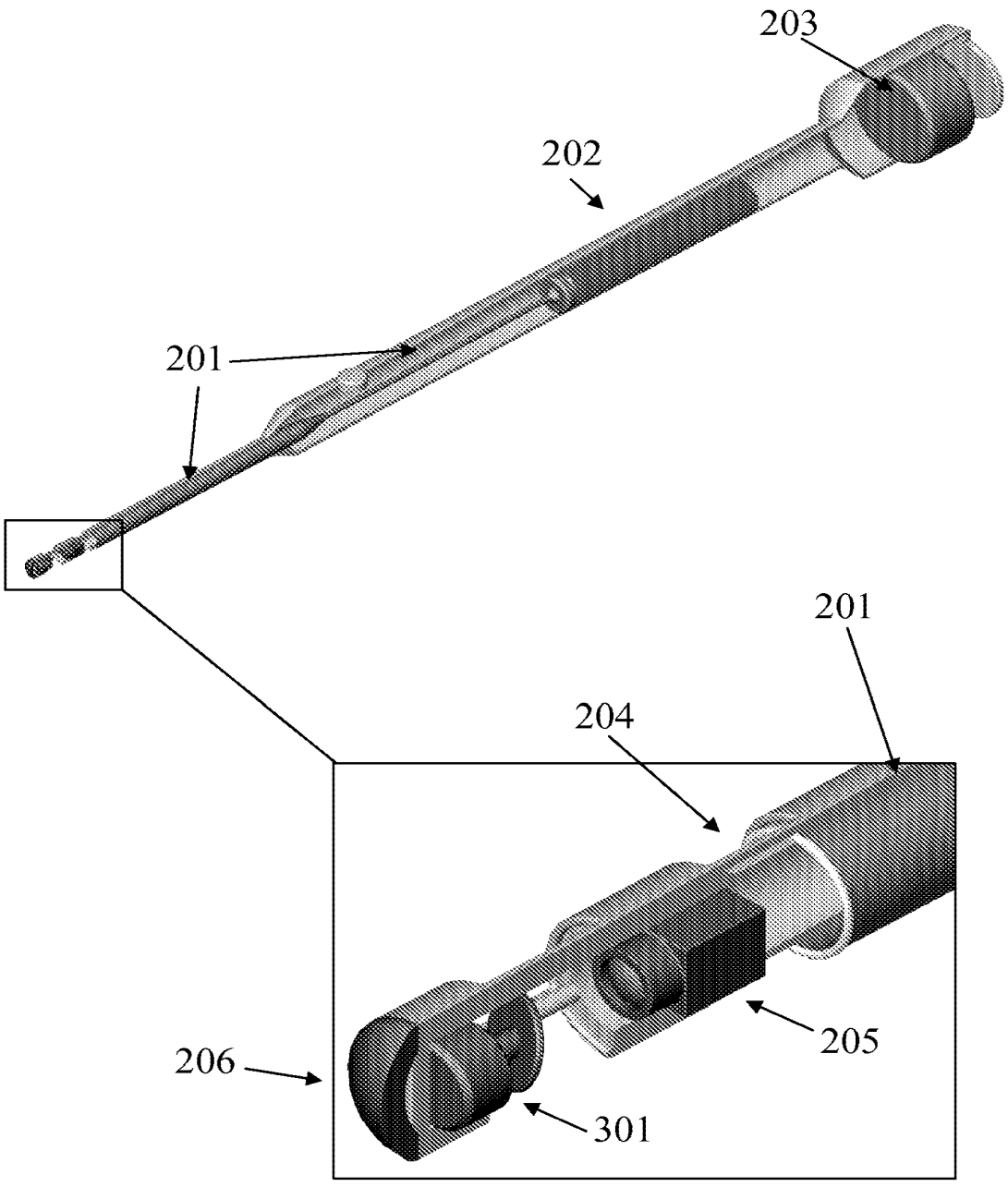


Figure 4

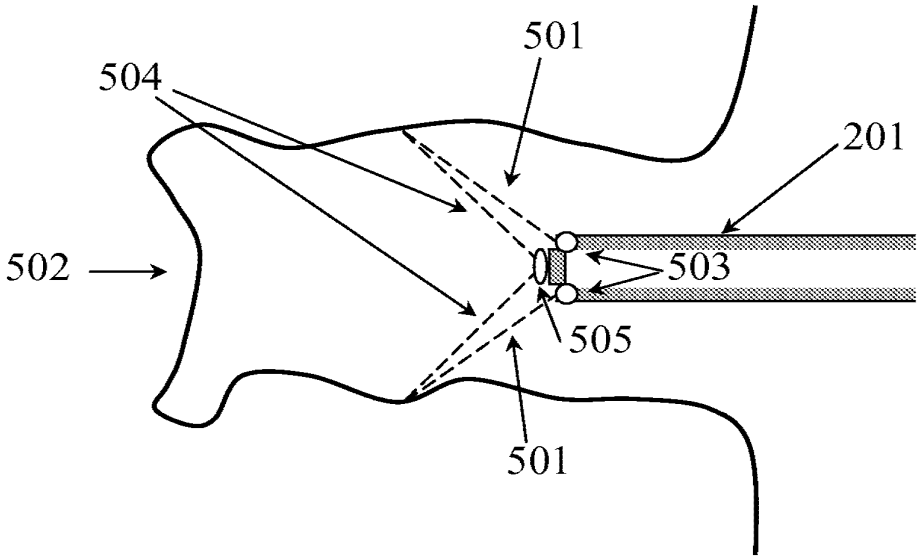


Figure 5

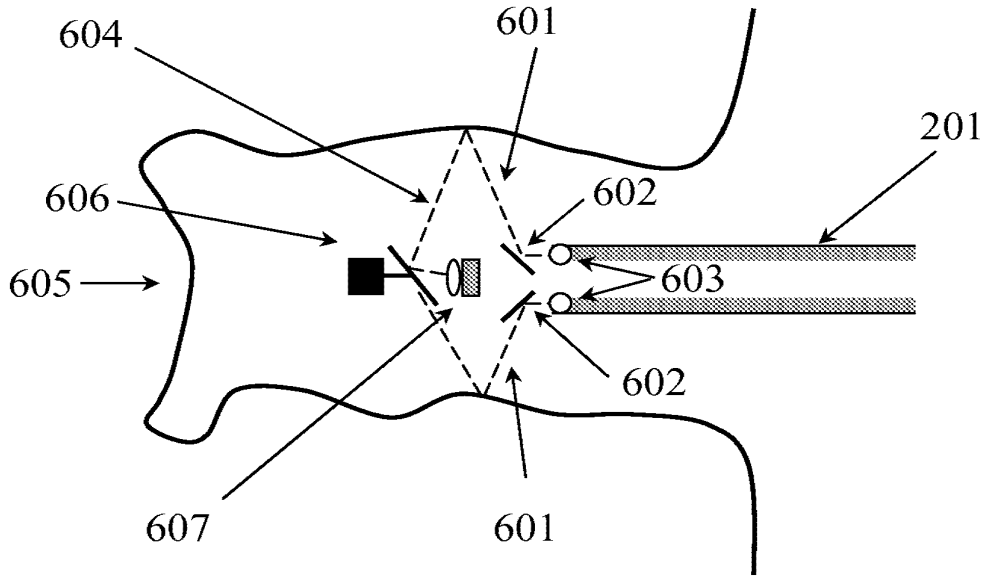


Figure 6

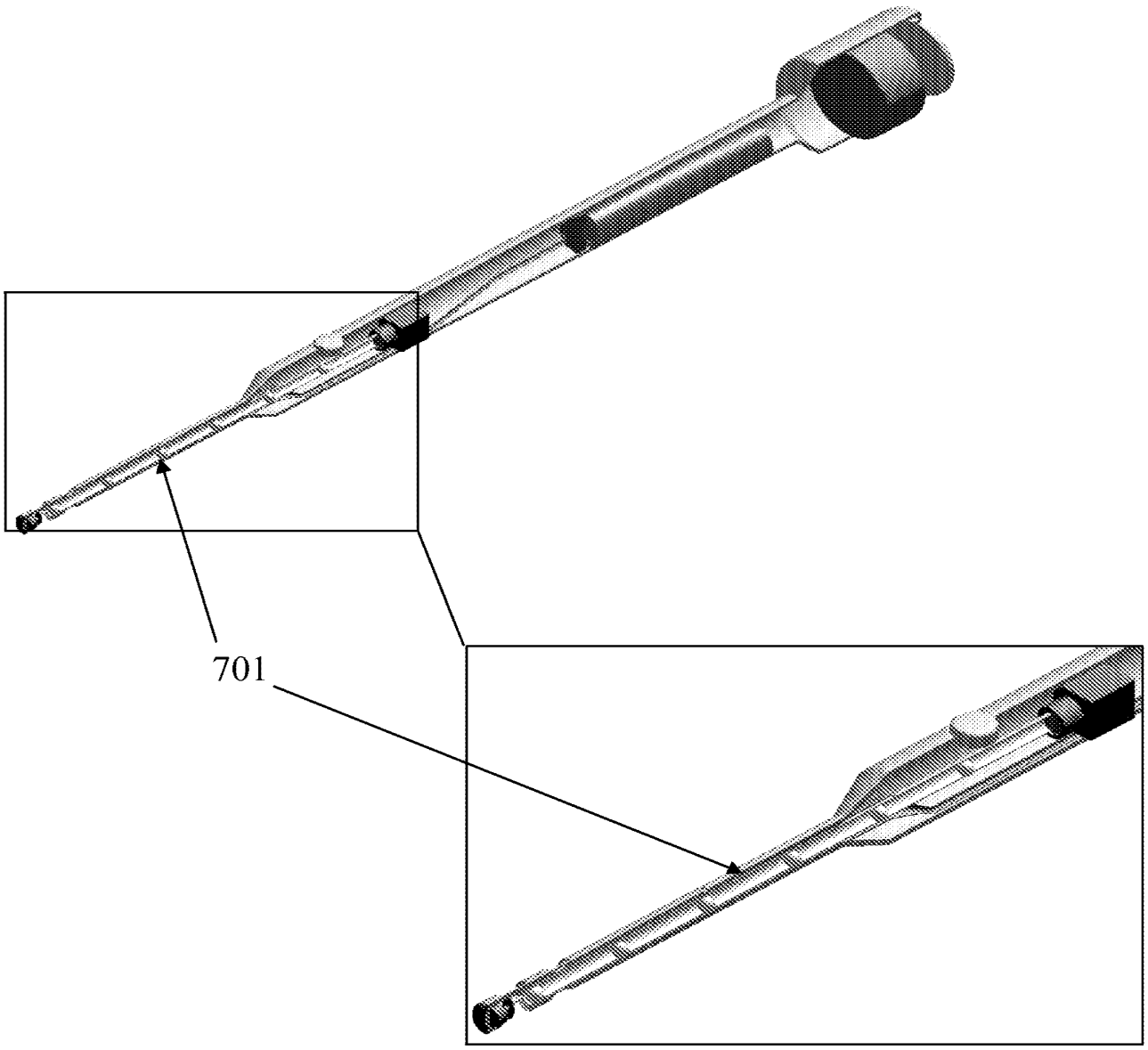


Figure 7

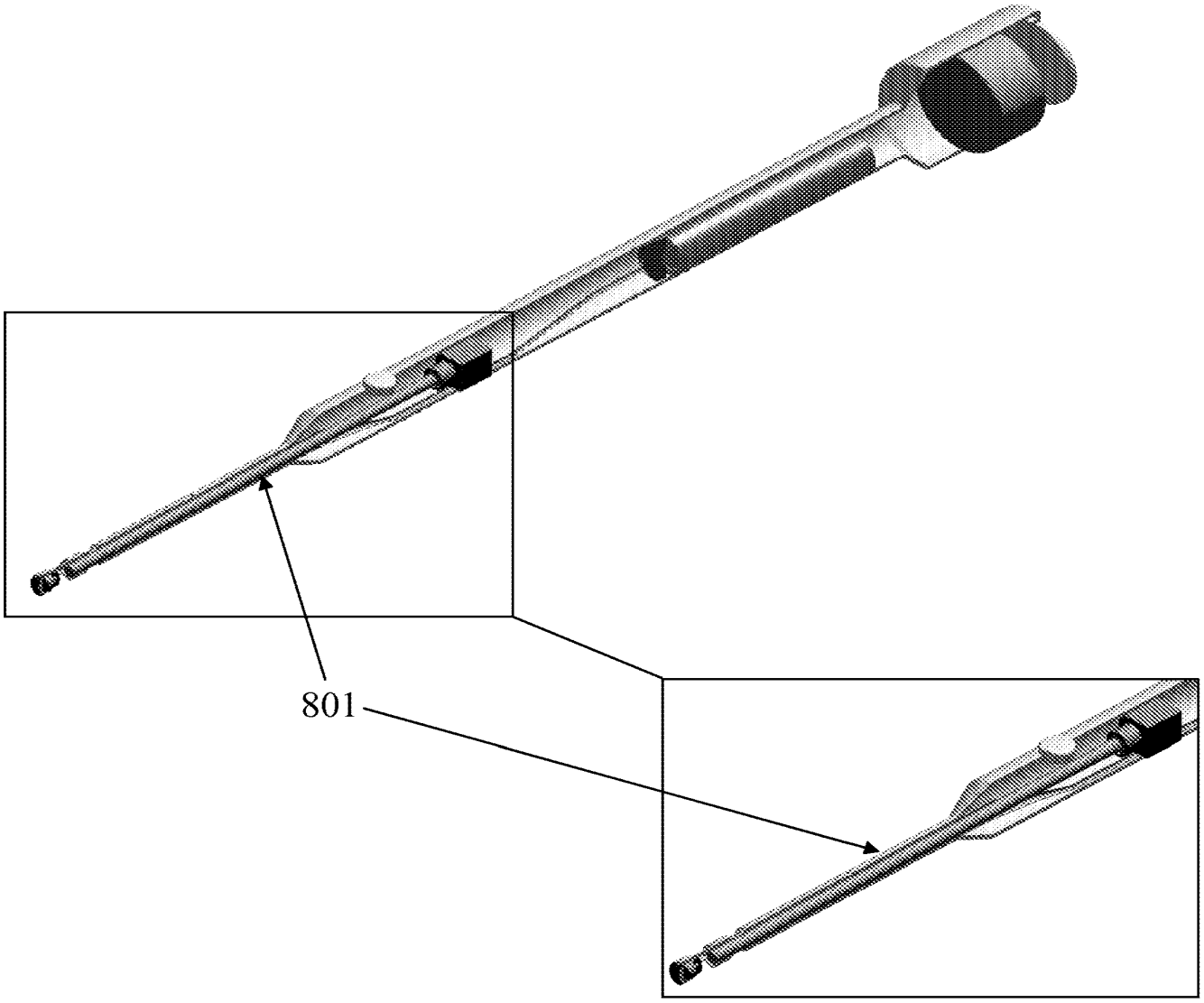


Figure 8

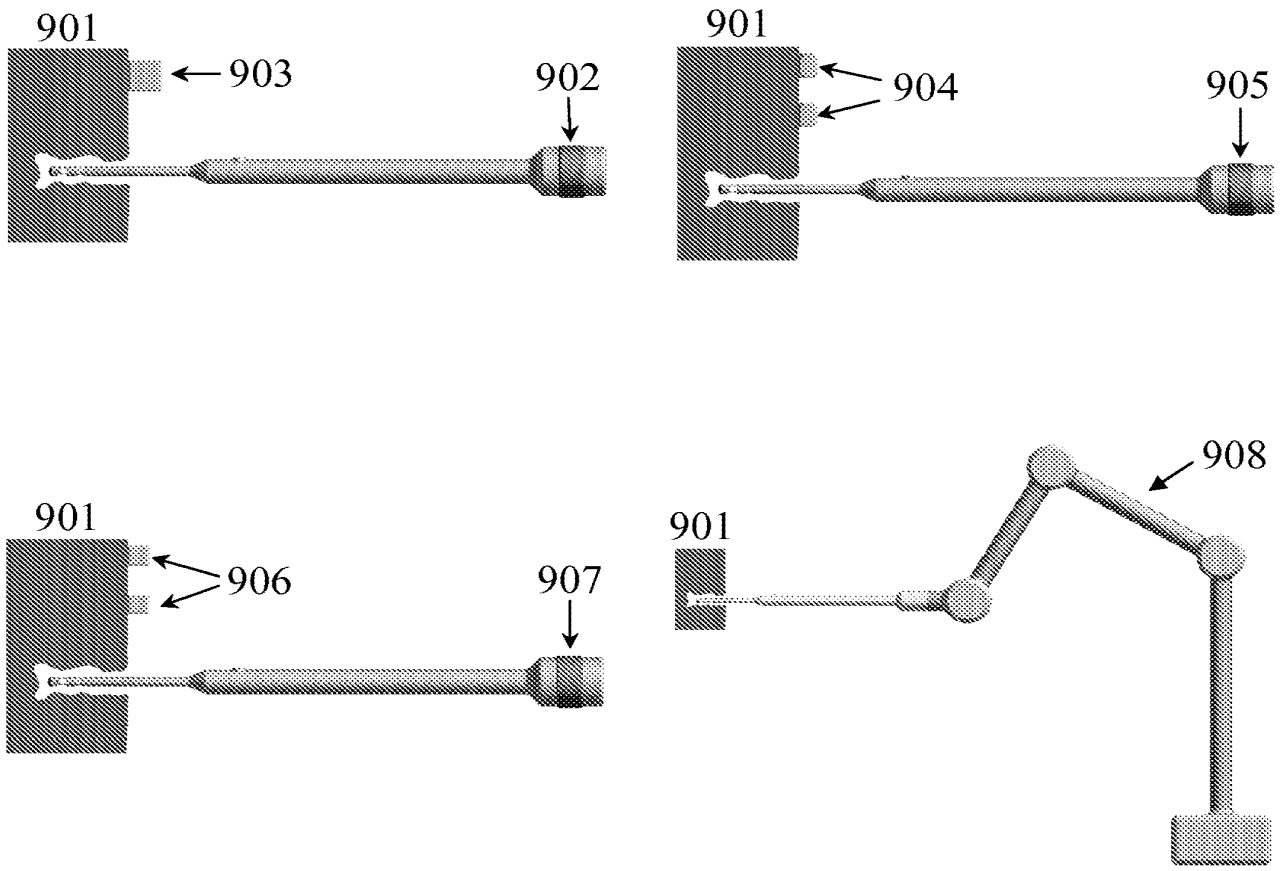


Figure 9

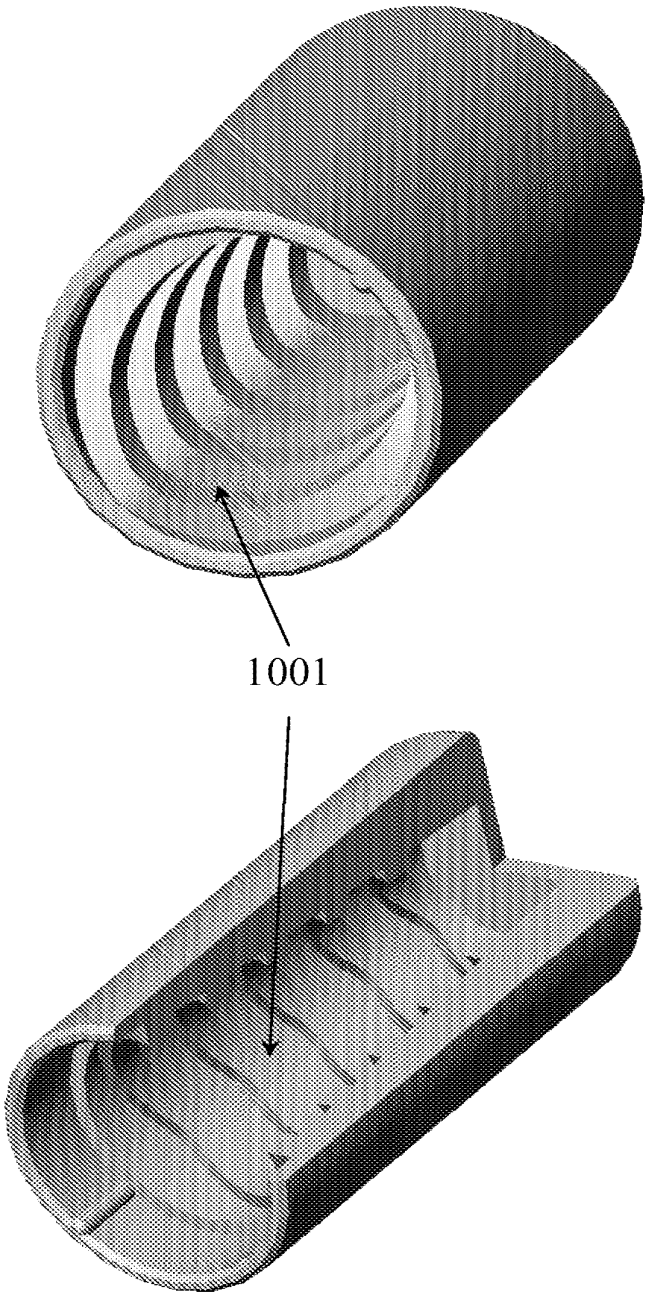


Figure 10

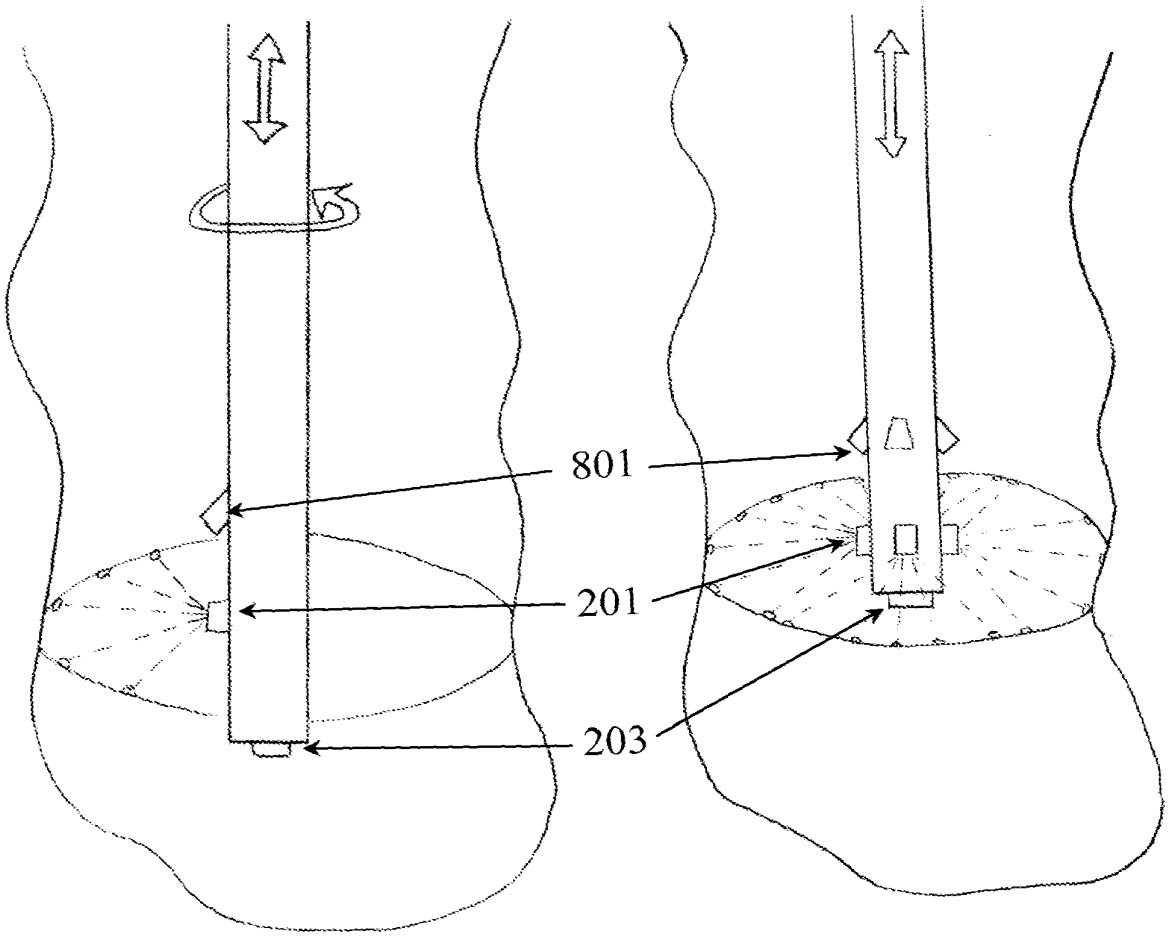


Figure 11

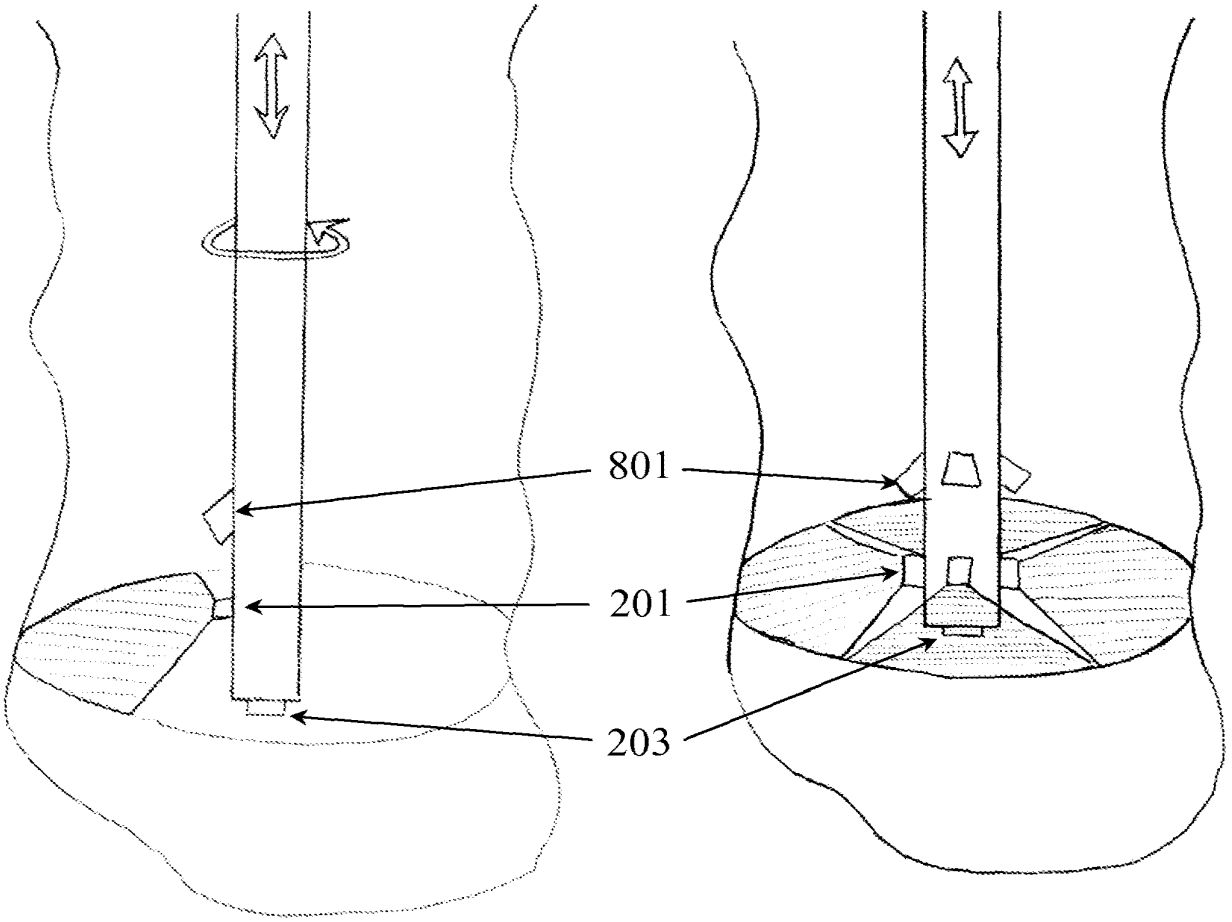


Figure 12

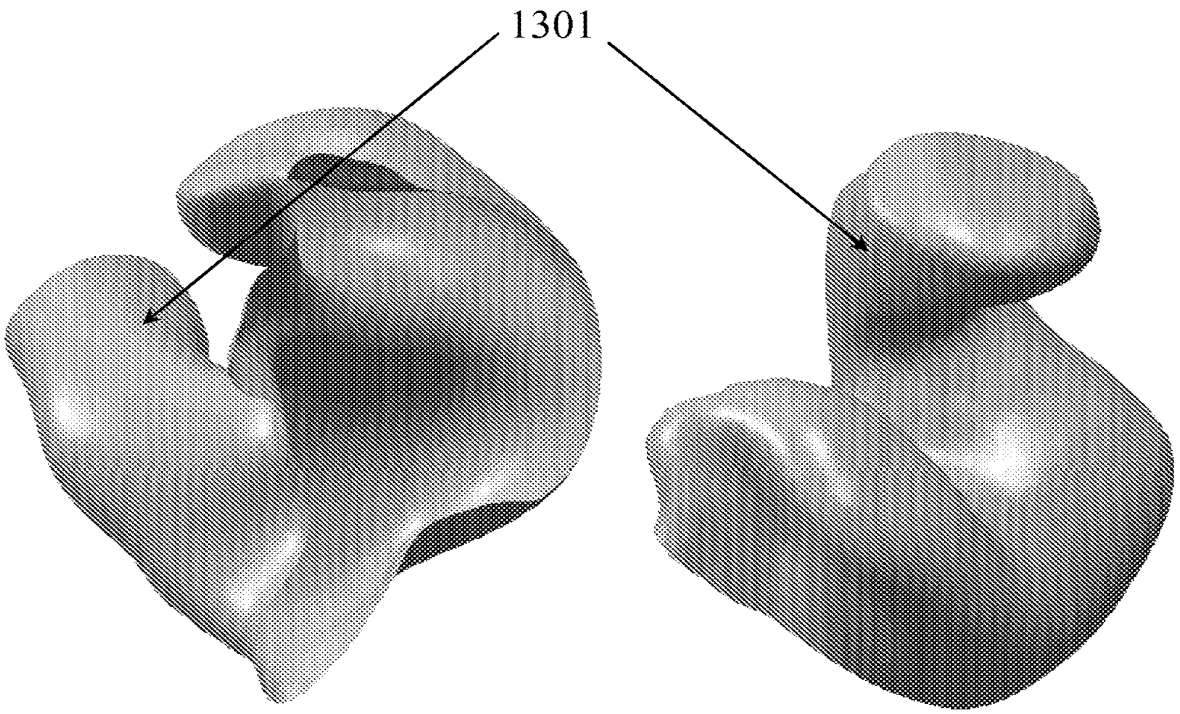


Figure 13

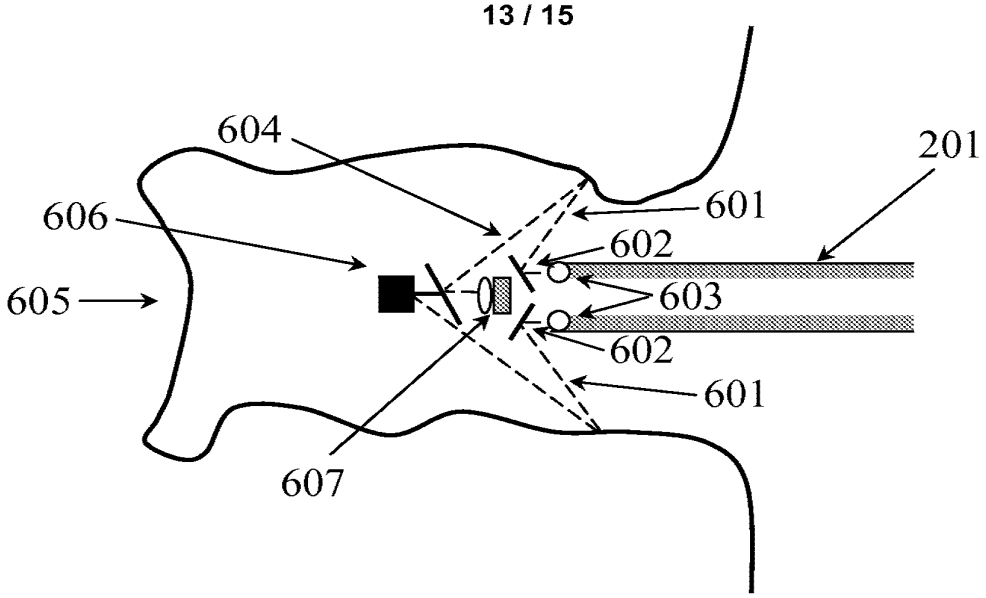


Figure 14

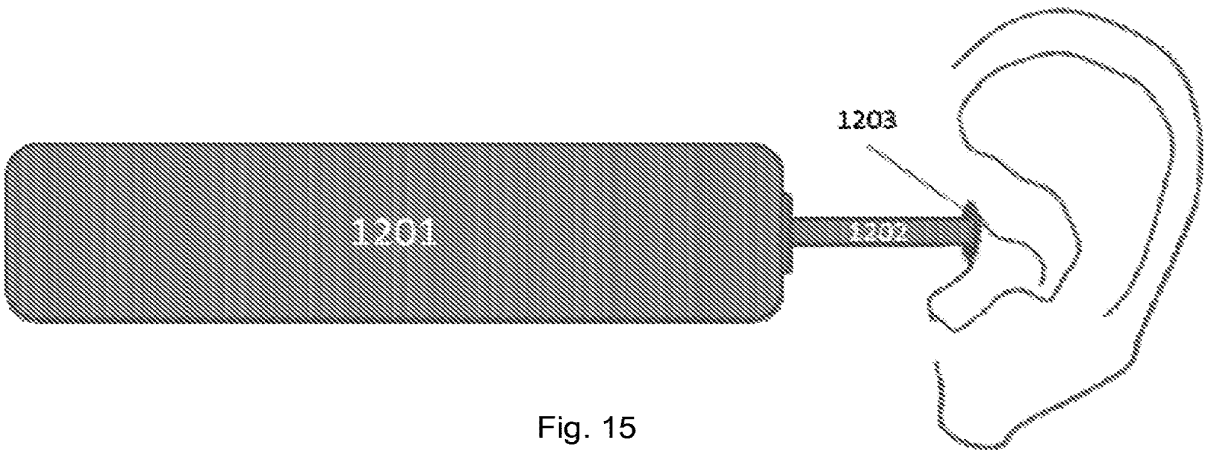

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1202

Fig. 15

Fig. 16

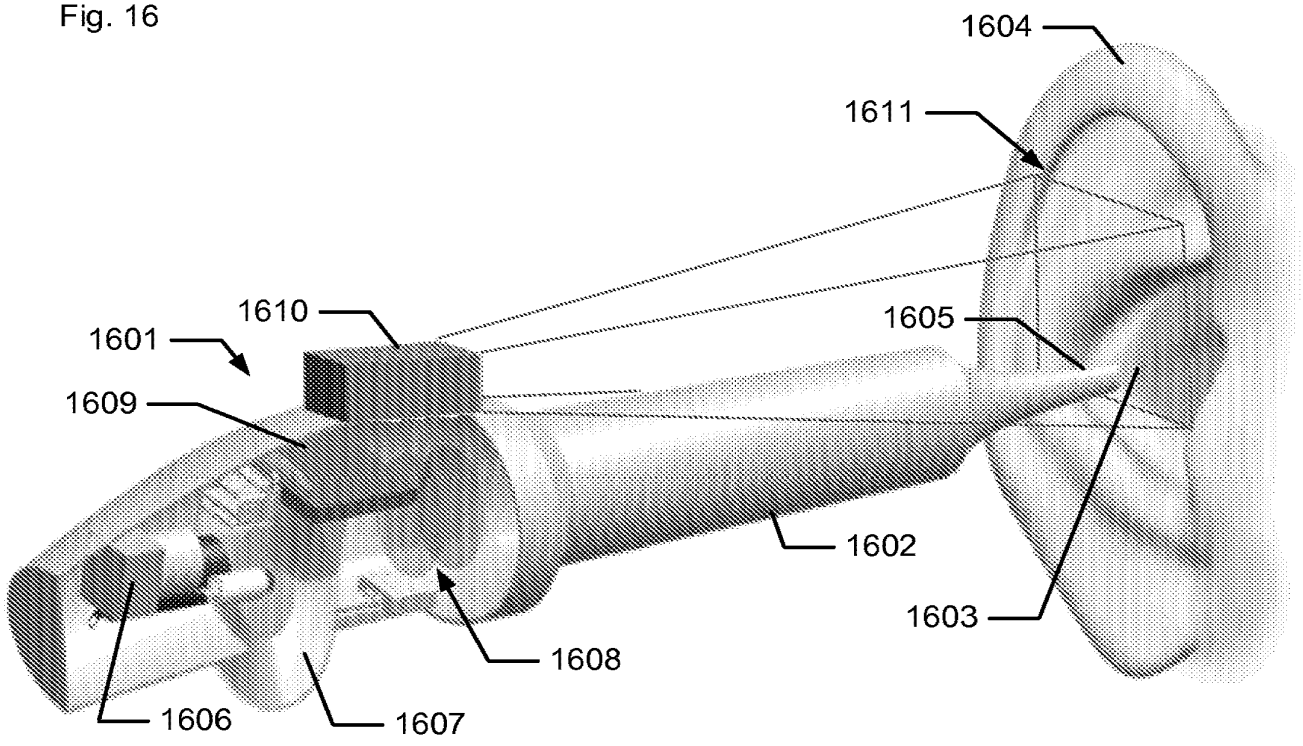

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Fig. 17a)

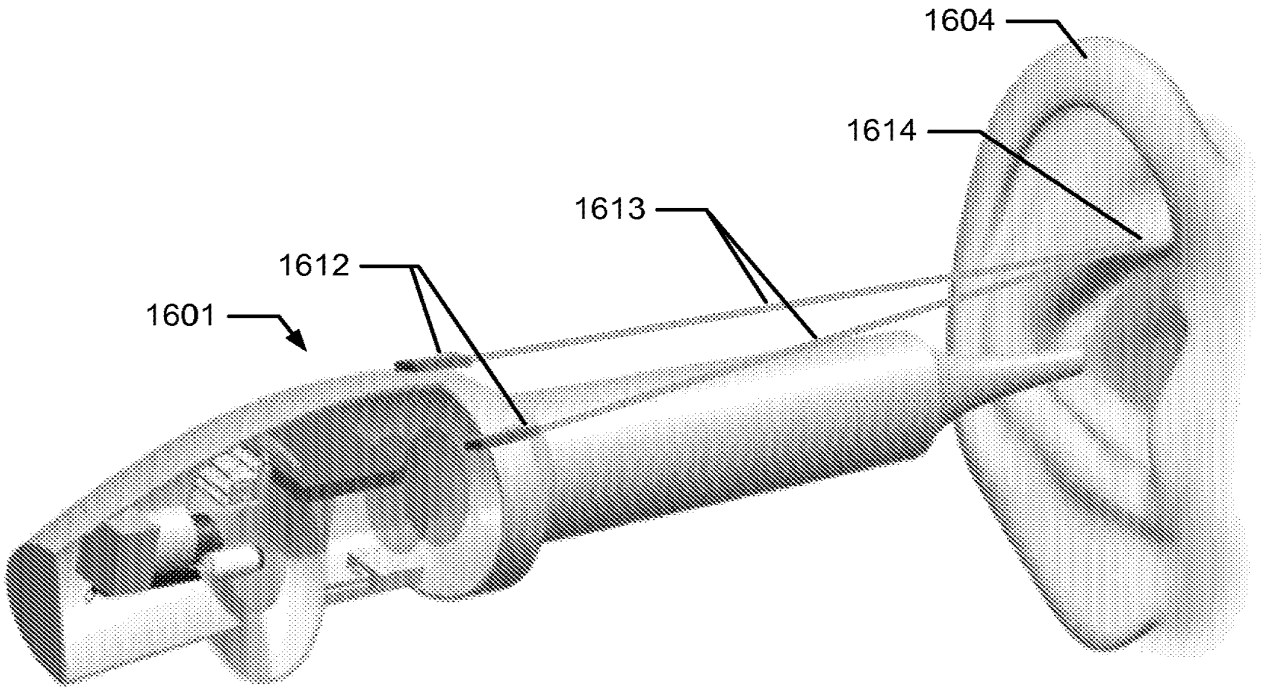
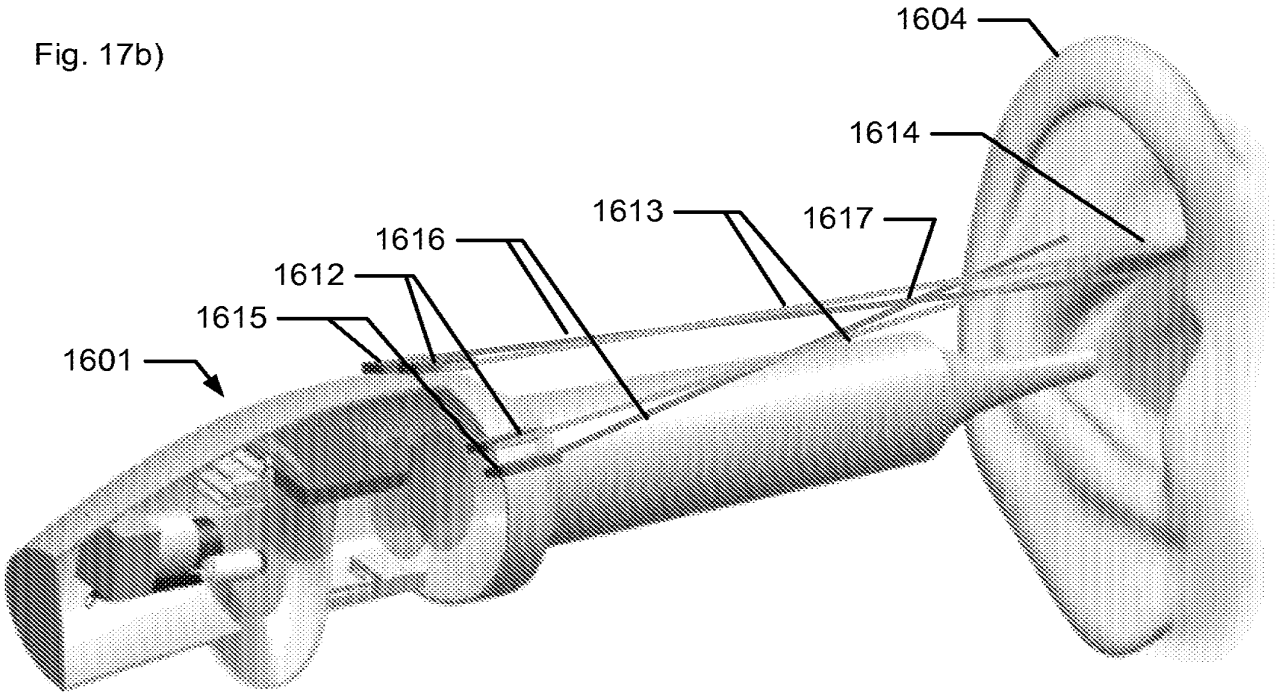


Fig. 17b)



INTERNATIONAL SEARCH REPORT

International application No.
PCT/DK2011/050103

A. CLASSIFICATION OF SUBJECT MATTER
A61B1/227 (2006.01), A61B1/06 (2006.01), A61B5/107 (2006.01), G01B11/25 (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC, ECLA: A61B, G01B.

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPODOC, WPI, TXTE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 0216865 A2 (3SHAPE) 28. February 2002.	1-9, 37, 42, 45-49, 60-61, 69-71.
A		10-36, 38-41, 43-44, 50-59.
X	WO 02071794 A1 (3SHAPE) 12. September 2002.	1, 3-23, 26-37, 42,53-56, 60-61, 69-71.
A		2, 24-25, 38-41, 42-52, 57-59.
X	WO 0216867 A1 (3SHAPE) 28. February 2002.	1, 11-23, 26-35, 37, 42, 45, 60-61, 69-71.
A		2-10, 24-25, 36, 38-41, 43-44.
X,P	WO 2010145669 A1 (3SHAPE) 23. December 2010.	1-2, 60-61

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
10/05/2011	20/06/2011
Name and mailing address of the ISA/ Nordic Patent Institute, Helgeshøj Allé 81, DK-2630 Taastrup, Denmark Facsimile No.	Authorized officer Jørgen Olsen Telephone No. +45 43 50 81 24

Form PCT/ISA/210 (second sheet) (July 2009)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/DK2011/050103

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:
There are at least 3 unrelated inventions (See explanation on extra sheet):

A: Claims 1-60, 69-71. A method for scanning partly obstructed interior surfaces for creating a 3D model and a hearing aid device obtained using this method and a computer program product executing the method.

B: Claims 61-68. A scanner system for carrying out three dimensional scanning of interior surfaces.

C: Claim 72 (numbered 71 in the application). A nontransitory computer readable medium storing a computer program for causing scanning of partly obstructed interior surfaces.

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-61, 69-71

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/DK2011/050103

Patent document cited in search report	Publication date	Patent family member(s)	publication date
WO0216865 A2	20020228	US2003164952 A1 US7625335 B2 ES2327212T T3 EP1314000 A1 WO0216865 A3 WO0216867 A1 DK1314000T T3 AU8381201 A AU8176101 A AT431541T T	20030904 20091201 20091027 20030528 20020620 20020228 20090817 20020304 20020304 20090515
WO02071794 A1	20020912	US2004107080 A1 EP1368986 A1	20040603 20031210
WO0216867 A1	20020228	US2003164952 A1 US7625335 B2 ES2327212T T3 EP1314000 A1 WO0216865 A2 DK1314000T T3 AU8381201 A AU8176101 A AT431541T T	20030904 20091201 20091027 20030528 20020228 20090817 20020304 20020304 20090515
WO2010145669 A1	20101223	NONE	

(Continuation of box III)

There are at least 3 unrelated inventions:

A: Claims 1-60, 69-71. A method for scanning partly obstructed interior surfaces for creating a 3D model and a hearing aid device obtained using this method and a computer program product executing the method.

B: Claims 61-68. A scanner system for carrying out three dimensional scanning of interior surfaces.

C: Claim 72 (numbered 71 in the application). A nontransitory computer readable medium storing a computer program for causing scanning of partly obstructed interior surfaces.

From the document WO 0216865 A2 (3SHAPE) 28. February 2002 (hereinafter denoted D1) it is known to make a direct scan of the ear canal of an individual in order to establish three dimensional model of the dimensions of the ear canal (see page 17, lines 5-13 and page 58, line 16 to page 59 line 29). The scanner system used for the method may comprise a probe shaped scanner (figures 3 1-35) having an axis, where the scanner further comprises a light source to create and project structured light (se page 59, line 15-16) and a camera recording 2D images of the reflected pattern from the interior surface. Series of the 2D images are used for obtaining 3D plots of the interior surface. Further, from D1 it is known to fill in "holes" in information by interpolation. Therefore, the method of claim 1 and the apparatus of claim 61 are both known from D1.

Hereinafter, claim 2 and claim 62 do not share any inventive feature beyond what is known from D1 because claim 2 is related to a method where the scanner system is varying the focus plane of the pattern while claim 62 relates to a scanner being able to perform a scan around its axis.

Accordingly, there is no inventive concept binding the to claims together and unity can not be acknowledged between inventions A and B.

Invention C does not in anyway relate to invention A because it merely discloses a nontransitory computer readable medium without defining any computer program steps/algorithms for carrying out the method disclosed in claim 1.

Accordingly, unity can not be acknowledged between invention A and C.

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
14 June 2012 (14.06.2012)

WIPO | PCT

(10) International Publication Number
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(22) **International Filing Date**:
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(25) **Filing Language**: English

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(30) **Priority Data**:
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61/420,138 6 December 2010 (06.12.2010) US

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(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

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(54) **Title**: SYSTEM WITH 3D USER INTERFACE INTEGRATION

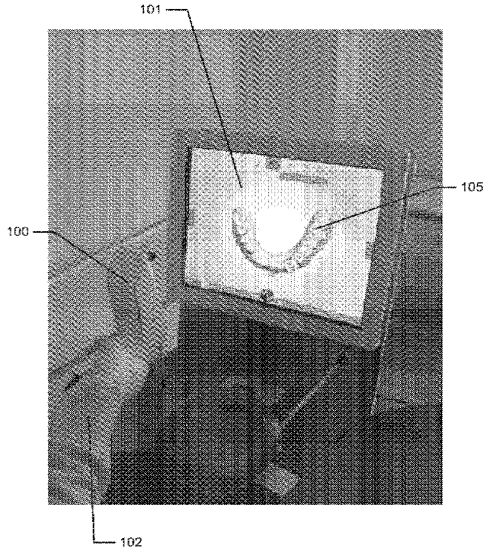


Fig. 2a)

(57) **Abstract**: Disclosed is a system comprising a handheld device (100) and at least one display (101), where the handheld device (100) is adapted for performing at least one action in a physical 3D environment. The actions include measuring, modifying, manipulating, recording, touching, sensing, scanning, moving, transforming, cutting, welding, chemically treating, cleaning. The display (101) is adapted for visually representing the physical 3D environment, and where the handheld device (100) is adapted for remotely controlling the view with which the 3D environment is represented on the display (101).

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System with 3D user interface integration

Field of the invention

This invention generally relates to a method and a system comprising a handheld device and at least one display.

Background of the invention

3D visualization is important in many fields of industry and medicine, where 3D information is becoming more and more predominant.

Displaying and inspecting 3D information is inherently difficult. To fully understand a 3D object or entire environment on a screen, the user should generally be able to rotate the object or scene, such that many or preferentially all surfaces are displayed. This is true even for 3D displays, e.g. stereoscopic or holographic, where from a given viewing position and with a given viewing angle, the user will only see some surfaces of an arbitrary 3D environment. Often, the user will also want to zoom into details or zoom out for an overview.

Various user interaction devices are in use for software that displays 3D data; these devices are: 3D mice, space balls, and touch screens. The operation of these current interaction devices requires physically touching them.

Physically touching a user-interaction device can be a disadvantage in medical applications due to risks of cross-contamination between patients or between patient and operator, or in industrial applications in dirty environments.

Several non-touch user interfaces for 3D data viewing in medical applications have been described in the literature. Vogt et al (2004) describe a touchless interactive system for in-situ visualization of 3D medical imaging data. The user interface is based on tracking of reflective markers, where a camera is mounted on the physician's head. Graetzel et al (2004) describe a touchless system that interprets hand gestures as mouse actions. It is based on stereo vision and intended for use in minimally invasive surgery.

It remains a problem to improve systems that require user interfaces for view control, which for example can be used for clinical purposes.

Summary

Disclosed is a system comprising a handheld device and at least one display, where the handheld device is adapted for performing at least one action in a physical 3D environment, where the at least one display is adapted for visually representing the physical 3D environment, and where the handheld device is adapted for remotely controlling the view with which said 3D environment is represented on the display.

The system may be adapted for switching between performing the at least one action in the physical 3D environment, and remotely controlling the view with which the 3D environment is represented on the display.

The system disclosed here performs the integration of 3D user interface functionality with any other handheld device with other operating functionality, such that the operator ideally only touches this latter device that is intended to be touched. A particular example of such a handheld device is one that records some 3D geometry, for example a handheld 3D scanner.

The handheld device is a multi-purpose device, such as a dual-purpose or two-purpose device, i.e. a device both for performing actions in the physical 3D environment, such as measuring and manipulating, and for remotely controlling the view of the 3D environment on the display.

Geometrically, a view is determined by the virtual observer's/camera's position and orientation relative to the 3D environment or its visual representation. If the display is two-dimensional, the view is also determined by the type of projection. A view may also be determined by a magnification factor.

The virtual observer's and the 3D environment's position and orientation are always relative to each other. In terms of user experience in software systems with 3D input devices, the user may feel that for example, he/she is moving the 3D environment while remaining stationary himself/herself, but there is always an equivalent movement of the virtual observer/camera that gives the same results on the display. Often, descriptions of 3D software systems use the expression "pan" to indicate an apparent translational movement of the 3D environment, "rotate" to indicate a rotational movement of the 3D environment, and "zoom" to indicate a change in magnification factor.

Graphically, a view can represent a 3D environment by means of photographs or as some kind of virtual representation such as a computer graphic, or similar. A computer graphic can be rendered for example with texture and/or shading and/or virtual light sources and/or light models for surface properties. A computer graphic can also be a simplified representation of the 3D environment, for example a mesh, an outline, or an otherwise simplified representation. All or parts of the 3D environment can also be rendered with some degree of transparency. A view may represent the 3D environment in total or only parts thereof.

All of the touch-less prior art systems are 3D user interface devices only. In many prior art applications, the operator using such user interface device will also hold and work with another device that really is the central device in the overall application, e.g. a medical instrument.

It is thus an advantage of the present system that the 3D user-interface functionality is integrated in the central device, which is used for performing some kind of action.

In some embodiments the handheld device is adapted for remotely controlling the magnification with which the 3D environment is represented on the display.

In some embodiments the handheld device is adapted for changing the rendering of the 3D environment on the display.

In some embodiments the view is defined as viewing angle and/or viewing position.

In some embodiments the at least one action comprises one or more of the actions of:

- measuring,
- recording,
- scanning,
- manipulating,
- modifying.

In some embodiments the 3D environment comprises one or more 3D objects.

In some embodiments the handheld device is adapted to be held in one hand by an operator.

In some embodiments the display is adapted to represent the 3D environment from multiple views.

In some embodiments the display is adapted to represent the 3D environment from different viewing angles and/or viewing positions.

In some embodiments the view of the 3D environment in the at least one display is at least partly determined by the motion of the operator's hand holding said device.

In some embodiments the magnification represented in the at least one display is at least partly determined by the motion of the operator's hand holding said device.

In some embodiments the handheld device is adapted to record the 3D geometry of the 3D environment.

Thus the handheld device may be an intraoral dental scanner, which records the 3D geometry of a patient's teeth. The operator may move the scanner along the teeth of the patient for capturing the 3D geometry of the relevant teeth, e.g. all teeth. The scanner may comprise motion sensors for taking the movement of the scanner into account while creating the 3D model of the scanned teeth.

The 3D model of the teeth may be shown on a display, and the display may for example be a PC screen and/or the like.

The user interface functionality may comprise incorporating motion sensors in the scanner to provide that the user can determine the view on the screen by moving the scanner. Pointing the scanner down can provide that the scanned teeth are shown given a downward viewing angle. Holding the scanner in a horizontal position can provide that the viewing angle is likewise horizontal.

In some embodiments the handheld device comprises at least one user-interface element. A user-interface element is an element which the user may manipulate in order to activate a function on the user interface of the software. Typically the use interface is graphically presented on the display of the system.

The handheld device may furthermore be provided with an actuator, which switches the handheld device between performing the at least one action and remotely controlling the view. By providing such a manual switching function that enables the operator to switch between performing the at least one action and remotely controlling the view, the operator may easily control what is performed.

Such an actuator can for example be in the form of a button, switch or contact. In other embodiments it could be a touch sensitive surface or element.

In another embodiment the actuator could be a motion sensor provided in the handheld device that function as the actuator when it registers a specific type of movement, for example if the operator shakes the handheld device. Examples of such motion sensors will be described herein with respect to the user-interface element, however, the person skilled in the art will based on the disclosure herein understand that such motion sensors may also be used as actuators as discussed.

For example, the handheld device can in one embodiment be an intra-oral 3D scanner used by a dentist. The scanner is set to be performing the action of scanning a dental area when the actuator is in one position. When the actuator is switched into a second position the handheld is set to control the view with which the 3D environment is represented on the display. This could for example be that when the dentist have scanned a part of or the complete desired area of an dental arch he can activate the actuator which then allows the dentist to remotely control the view of the 3D representation of the scanned area on the display by using the handheld device.

For example, the actuator could be a button. When the button is pressed quickly the handheld device is prepared for scanning, i.e. it is set for performing at least one action, the scanning procedure, in the physical 3D environment. The scanning is stopped when the button is pressed quickly a second time.

While the scanning is performed a virtual 3D representation is visually built on the display.

The user can now press and hold the button. This will put the handheld in a controller mode, where the handheld device is adapted for remotely controlling the view with which the 3D environment, such as scanned teeth, is represented on the display. While holding the button pressed the system will use signals from a motion sensor in the handheld device to determine how to present the view of the virtual 3D environment. Thus, if the user turns or otherwise moves the hand that holds the handheld device the view of the virtual 3D environment on the display will change accordingly.

Thus, the dentist may use the same handheld device for both scanning an area and subsequently verifying that the scan has been executed correctly

without having to move away from the patient or touching any other equipment than already present in his hands.

In one embodiment the user-interface element is the same as the actuator, or where several user-interface elements are present at least one also functions as an actuator.
The system may be equipped with a button as an additional element providing the user-interface functionality.

In an example the handheld device is a handheld intraoral scanner, and the display is a computer screen. The operator or user may be a dentist, an assistant and/or the like. The operation functionality of the device may be to record some intraoral 3D geometry, and the user interface functionality may be to rotate, pan, and zoom the scanned data on the computer screen.

In some embodiments the at least one user-interface element is at least one motion sensor.

Thus the integration of the user interface functionality in the device may be provided by motion sensors, which can be accelerometers inside the scanner, whose readings determine the orientation of the display on the screen of the 3D model of the teeth acquired by the scanner. Additional functionality, e.g. to start/stop scanning, may be provided by a button. The button may be located where the operator's or user's index finger can reach it conveniently.

Prior art intraoral scanners use a touch screen, a trackball, or a mouse to determine the view in the display. These prior art user interface devices can be inconvenient, awkward and difficult to use, and they can be labor-intensive, and thus costly to sterilize or disinfect. An intraoral scanner should always be disinfected between scanning different patients, because the

scanner is in and may come in contact with the mouth or other parts of the patient being scanned.

The operator or user, e.g. dentist, may use one hand or both hands to hold the intraoral scanner while scanning, and the scanner may be light enough and comfortable to be held with just one hand for a longer time while scanning.

The device can also be held with one or two hands, while using the device as remote control for e.g. changing the view in the display. It is an advantage of the touchless user interface functionality that in clinical situations, the operator can maintain both hands clean, disinfected, or even sterile.

An advantage of the system is that it allows an iterative process of working in a 3D environment without releasing the handheld device during said process. For the above intraoral scanning system example, the operator, e.g. dentist, can record some teeth surface geometry with a handheld device that is an intraoral scanner, inspect coverage of the surface recording by using that same handheld device to move, e.g. rotate, the recorded surface on the display, e.g. a computer screen, detect possible gaps or holes in the coverage of the scanned teeth, and then for example arrange the scanner in the region where the gaps were located and continue recording teeth surface geometry there. Over this entire iterative cycle, which can be repeated more than once, such as as many times as required for obtaining a desired scan coverage of the teeth, the dentist does not have to lay the handheld intraoral scanner out of his or her hands.

In some embodiments, the 3D user interface functionality is exploited in a separate location than the operation functionality. For the above intraoral scanning system example, the scanning operation is performed in the oral cavity of the patient, while the user interface functionality is more flexibly

exploited when the scanner is outside the patient's mouth. The key characteristic and advantage of the system, again, is that the dentist can exploit the dual and integrated functionality, that is operation and user interface, of the scanner without laying it out of his or her hands.

The above intraoral scanning system is an example of an embodiment. Other examples for operation functionality or performing actions could be drilling, welding, grinding, cutting, soldering, photographing, filming, measuring, executing some surgical procedure etc..

The display of the system can be a 2D computer screen, a 3D display that projects stereoscopic image pairs, a volumetric display creating a 3D effect, such as a swept-volume display, a static volume display, a parallax barrier display, a holographic display etc.. Even with a 3D display, the operator has only one viewing position and viewing angle relative to the 3D environment at a time. The operator can move his/her head to assume another viewing position and/or viewing angle physically, but generally, it may be more convenient to use the handheld device with its built-in user interface functionality, e.g. the remote controlling, to change the viewing position and/or viewing angle represented in the display.

In some embodiments the system comprises multiple displays, or one or more displays that are divided into regions. For example, several sub-windows on a PC screen can represent different views of the 3D environment. The handheld device can be used to change the view in all of them, or only some of them.

In some embodiments the user interface functionality comprises the use of gestures.

Gestures made by e.g. the operator can be used to change, shift or toggle between sub-windows, and the user-interface functionality can be limited to an active sub-window or one of several displays.

In some embodiments the gestures are adapted to be detected by the at least one motion sensor. Gestures can alternatively and/or additionally be detected by range sensors or other sensors that record body motion.

The operator does not have to constantly watch the at least one display of the system. In many applications, the operator will shift between viewing and possible manipulating the display and performing another operation with the handheld device. Thus it is an advantage that the operator does not have to touch other user interface devices. However, in some cases it may not be possible for the operator to fully avoid touching other devices, and in these cases it is an advantage that fewer touches are required compared to a system where a handheld device does not provide any user interface functionality at all.

In some embodiments the at least one display is arranged separate from the handheld device.

In some embodiments the at least one display is defined as a first display, and where the system further comprises a second display.

In some embodiments the second display is arranged on the handheld device.

In some embodiments the second display is arranged on the handheld device in a position such that the display is adapted to be viewed by the operator, while the operator is operating the handheld device.

In some embodiments the second display indicates where the handheld device is positioned relative to the 3D environment.

In some embodiments the first display and/or the second display provides instructions for the operator.

The display(s) can be arranged in multiple ways. For example, they can be mounted on a wall, placed on some sort of stand or a cart, placed on a rack or desk, or other.

In some embodiments at least one display is mounted on the device itself. It can be advantageous to have a display on the device itself because with such an arrangement, the operator's eyes need not focus alternatingly between different distances. In some cases, the operating functionality may require a close look at the device and the vicinity of the 3D environment it operates in, and this may be at a distance at most as far away as the operator's hand. Especially in crowded environments such as dentist's clinics, surgical operation theatres, or industrial workplaces, it may be difficult to place an external display closely to the device.

In some embodiments visual information is provided to the operator on one or more means other than the first display.

In some embodiments audible information to the operator is provided to the operator.

Thus in some embodiments, the system provides additional information to the operator. In some embodiments, the system includes other visual clues shown on means other than the display(s), such as LEDs on the device. In some embodiments, the system provides audible information to the operator, for example by different sounds and/or by speech.

Said information provided to the operator can comprise instructions for use, warnings, and the like.

The information can aid with improving the action performance or operation functionality of the device, for example by indicating how well an action or operation is being performed, and/or instructions to the operator aimed at improving the ease of the action or operation and/or the quality of the action or operation's results. For example, a LED can change in color and/or flashing frequency. In a scanner, the information can relate to how well the scanned 3D environment is in focus and/or to scan quality and/or to scan coverage. The information can comprise instructions on how best to position the scanner such as to attain good scan quality and/or scan coverage. The instructions can be used for planning and/or performing bracket placement. The instructions can be in the form of a messenger system to the operator.

In some embodiments, some 3D user interface functionality is provided by at least one motion sensor built into the device. Examples of motion sensors are accelerometers, gyros, and magnetometers and/or the like. These sensors can sense rotations, lateral motion, and/or combinations thereof. Other motion sensors use infrared sensing. For example, at least one infrared sensor can be mounted on the device and at least one infrared emitter can be mounted in the surroundings of the device. Conversely, the at least one emitter can be mounted on the device, and the at least one sensors in the surroundings. Yet another possibility is to use infrared reflector(s) on the device and both sensor(s) and emitter(s) on the surroundings, or again conversely. Thus motion can be sensed by a variety of principles.

Through proper signal processing, some sensors can recognize additional operator actions; for example gestures such as taps, waving, or shaking of the handheld device. Thus, these gestures can also be exploited in the 3D user interface functionality.

In some embodiments the handheld device comprises at least two motion sensors providing sensor fusion. Sensor fusion can be used to achieve a better motion signal from for example raw gyro, accelerometer, and/or magnetometer data. Sensor fusion can be implemented in ICs such as the InvenSense MPU 3000.

In some embodiments the handheld device comprises at least one user-interface element other than the at least one motion sensor.

In some embodiments the at least one other user-interface element is a touch-sensitive element.

In some embodiments the at least one other user-interface element is a button.

In some embodiments the at least one other user-interface element is a scroll-wheel.

In some embodiments, user interface functionality is provided through additional elements on the device. Thus these additional elements can for example be buttons, scroll wheels, touch-sensitive fields, proximity sensors and/or the like.

The additional user interface elements can be exploited or utilized in a workflow suitable for the field of application of the device. The workflow may be implemented in some user software application that may also control the display and thus the view represented thereon. A given interface element can supply multiple user inputs to the software. For example, a button can provide both a single click and a double click. For example, a double click can mean to advance to a subsequent step in a workflow. For the example of

intraoral scanning, three steps within the workflow can be to scan the lower mouth, the upper mouth, and the bite. A touch-sensitive field can provide strokes in multiple directions each with a different effect, etc. Providing multiple user inputs from a user interface elements is advantageous because the number of user interface elements on the device can be reduced relative to a situation where each user interface element only provides one user input.

The motion sensors can also be exploited in a workflow. For example, lifting the device, which can be sensed by an accelerometer, can represent some type of user input, for example to start some action. In a device that is a scanner, it may start scanning. Conversely, placing the device back in some sort of holder, which can be sensed by an accelerometer as no acceleration occur over some period of time, can stop said action.

If the action performed by the device is some kind of recording, for example scanning, for example 3D scanning, the results of the recording can also be exploited as user inputs, possibly along with user inputs from other user interface elements. For example, with a 3D scanner with a limited depth of field, it may be possible to detect whether any objects within the 3D environments are present in the volume corresponding to this depth of field by detecting whether any 3D points are recorded. User inputs can depend on such detected presence. For example, a button click on an intraoral scanner can provide a different user input depending on whether the scanner is in the mouth, where teeth are detectable, or significantly away from and outside the mouth. Also the effect of motion sensor signals can be interpreted differently for either situation. For example, the scanner may only change the view represented on the display when it is outside the mouth.

In some embodiments the handheld device is adapted to change a viewing angle with which the 3D environment is represented on the at least one display.

In some embodiments the handheld device is adapted to change a magnification factor with which the 3D environment is represented on the at least one display.

In some embodiments the handheld device is adapted to change a viewing position with which the 3D environment is represented on the at least one display.

In some embodiments the view of the 3D environment comprises a viewing angle, a magnification factor, and/or a viewing position.

In some embodiments the view of the 3D environment comprises rendering of texture and/or shading.

In some embodiments the at least one display is divided into multiple regions, each showing the 3D environment with a different view.

Thus in some embodiments the user interface functionality comprises changing the view with which the 3D environment is displayed. Changes in view can comprise changes in viewing angle, viewing position, magnification and/or the like. A change in viewing angle can naturally be effected by rotating the device. Rotation is naturally sensed by the aid of gyros and/or relative to gravity sensed by an accelerometer. Zooming, i.e. a change in magnification, can for example be achieved by pushing the handheld device forward and backward, respectively. A translational change of the viewing position, i.e., panning, can for example be achieved by pushing the handheld device up/down and/or sideways.

In some embodiments the user interface functionality comprises selecting or choosing items on a display or any other functionality provided by graphical user interfaces in computers known in the art. The operator may perform the selection. The Lava C.O.S scanner marketed by 3M ESPE has additional buttons on the handheld device, but it is not possible to manipulate the view by these. Their only purpose is to allow navigation through a menu system, and to start/stop scanning.

In some embodiments the user interface functionality comprises manipulating the 3D environment displayed on the screen. For example, the operator may effect deformations or change the position or orientation of objects in the 3D environment. Thus, in some embodiments the user interface functionality comprises virtual user interface functionality, which can be that the 3D data are manipulated, but the physical 3D environment in which the device operates may not be manipulated.

In some embodiments the handheld device is an intraoral scanner and/or an in-the-ear scanner. If the scanner comprises a tip, this tip may be exchanged whereby the scanner can become suitable for scanning in the mouth or in the ear. Since the ear is a smaller cavity than the mouth, the tip for fitting into an ear may be smaller than a tip for fitting in the mouth.

In some embodiments the handheld device is a surgical instrument. In some embodiments, the surgical instrument comprises at least one motion sensor, which is built-in in the instrument.

In some embodiments the handheld device is a mechanical tool. In some embodiments, the tool has at least one motion sensor built in. In other embodiments, other user-interface elements are built in as well, for example buttons, scroll wheels, touch-sensitive fields, or proximity sensors.

In some embodiment the 3D geometry of the 3D environment is known a-priori or a 3D representation of the environment is known a priori, i.e. before the actions (s) are performed. For example in surgery, a CT scan may have been taken before the surgical procedure. The handheld device in this example could be a surgical instrument that a physician needs to apply in the proper 3D position. To make sure this proper position is reached, it could be beneficial to view the 3D environment from multiple perspectives interactively, i.e. without having to release the surgical instrument.

An advantage of the system, also in the above surgery example, is the ability of the handheld device to record the 3D environment at least partially, typically in a 3D field-of-view that is smaller than the volume represented in the a-priori data. The 3D data recorded by the handheld device can be registered in real time with the a-priori data, such that the position and orientation of the device can be detected.

In some embodiments the 3D geometry comprises a 3D surface of the environment.

In some embodiments the 3D geometry comprises a 3D volumetric representation of the environment.

Thus the 3D environment can be displayed as volumetric data, or as surface, or a combination thereof. Volumetric data are typically represented by voxels. Voxels can comprise multiple scalar values. Surface data are typically represented as meshed, such as triangulated meshes, or point clouds.

The scanning may be performed by means of LED scanning, laser light scanning, white light scanning, X-ray scanning, and/or CT scanning.

The present invention relates to different aspects including the system described above and in the following, and corresponding systems, methods, devices, uses, and/or product means, each yielding one or more of the benefits and advantages described in connection with the first mentioned aspect, and each having one or more embodiments corresponding to the embodiments described in connection with the first mentioned aspect and/or disclosed in the appended claims.

In particular, disclosed herein is a method of interaction between a handheld device and at least one display, where the method comprises the steps of:

- performing at least one action in a physical 3D environment by means of the handheld device;
- visually representing the physical 3D environment by the at least one display; and
- remotely controlling the view of the represented 3D environment on the display by means of the handheld device.

Furthermore, the invention relates to a computer program product comprising program code means for causing a data processing system to perform the method according to any of the embodiments, when said program code means are executed on the data processing system, and a computer program product, comprising a computer-readable medium having stored there on the program code means.

According to another aspect, disclosed is a system comprising a handheld device for operating in a 3D environment and at least one display for visualizing said environment, where the display is adapted to represent said environment from multiple perspectives,

where said device is adapted to be held in one hand by an operator, and where the perspective represented in the at least one display is at least partly determined by the motion of the operator's hand holding said device.

According to another aspect, disclosed is a system comprising a handheld device for operating in a 3D environment and at least one display for visualizing said environment, where the display is adapted to represent said environment in multiple views,
where said device is adapted to be held in one hand by an operator, where the view represented in the at least one display is at least partly determined by the motion of the operator's hand holding said device, and where the device has at least one touch-sensitive user interface element.

The motion of the operator's hand is typically determined by a motion sensor arranged in the handheld device.

Definitions

3D geometry: A constellation of matter or its virtual representation in a three-dimensional space.

3D environment: A constellation of physical objects each having a 3D geometry in a three-dimensional space.

View: The way a 3D environment is represented on a display. Geometrically, a view is determined by the virtual observer's/camera's position and orientation. If the display is two-dimensional, the view is also determined by the type of projection. A view may also be determined by a magnification factor. Graphically, a view can show the 3D environment by means of photographs or as some kind of virtual representation such as a computer graphic, or similar. A computer graphic can be rendered for example with texture and/or shading and/or virtual light sources and/or light models for surface properties. A computer graphic can also be a simplified

representation of the 3D environment, for example a mesh, an outline, or an otherwise simplified representation. All or parts of the 3D environment can also be rendered with some degree of transparency. A view may represent the 3D environment in total or only parts thereof.

Functionality: A purpose or intended use.

Performing action(s) or operating functionality: Actions or functionality that includes some type of interaction with a 3D environment, such as measuring, modifying, manipulating, recording, touching, sensing, scanning, moving, transforming, cutting, welding, chemically treating, cleaning, etc. The term "operating" is thus not directed to surgical procedures, but operating may comprise surgical procedures.

User Interface Functionality: Functionality for interaction between a human user and a machine with a display.

Handheld device: An object that has at least one functionality and that is held by a human operator's hand or both hands while performing this at least one functionality.

3D scanner: A device that analyzes a real-world object or 3D environment to collect data on its shape and possibly its appearance.

Coverage of scan: The degree to which a physical surface is represented by recorded data after a scanning operation.

Motion sensor: A sensor detecting motion. Motion can be detected by: sound (acoustic sensors), opacity (optical and infrared sensors and video image processors), geomagnetism (magnetic sensors, magnetometers), reflection of transmitted energy (infrared laser radar, ultrasonic sensors, and

microwave radar sensors), electromagnetic induction (inductive-loop detectors), and vibration (triboelectric, seismic, and inertia-switch sensors). MEMS accelerometers, gyros, and magnetometers are examples of motions sensors.

Workflow: a sequence of tasks implemented in software.

Brief description of the drawings

The above and/or additional objects, features and advantages of the present invention, will be further elucidated by the following illustrative and non-limiting detailed description of embodiments of the present invention, with reference to the appended drawings, wherein:

Fig. 1 shows an example of the system comprising a handheld device and a display.

Fig. 2 shows an example of user interface functionality in the form of remote controlling using the handheld device.

Fig. 3 shows an example of the handheld device.

Fig. 4 shows an example of a flow-chart of a method of interaction between a handheld device and a display.

Detailed description

In the following description, reference is made to the accompanying figures, which show by way of illustration how the invention may be practiced.

Fig. 1 shows an example of the system comprising a handheld device and a display. The handheld device 100 is in this example an intraoral dental scanner, which records the 3D geometry of the patient's teeth. The operator 102 moves the scanner along the teeth of the patient 104 for capturing the 3D geometry of the relevant teeth, e.g. all teeth. The scanner comprises motion sensors (not visible) for taken the movement of the scanner into account while creating the 3D model 105 of the scanned teeth. The display 101 is in this example a PC screen displaying the data recorded by the scanner.

Fig. 2 shows an example of user interface functionality in the form of remote controlling using the handheld device. The motion sensors (not shown) in the handheld device 100, e.g. scanner, provide that the user 102 can determine the view shown on the display 101, e.g. screen, by moving the handheld device 100.

Fig. 2a) shows that pointing the device 100 down can provide that the 3D model 105 of the scanned teeth is shown from a downward viewing angle.

Fig. 2b) shows that holding the scanner in a horizontal position can provide that the viewing angle is likewise horizontally from the front, such that the 3D model 105 of the scanned teeth is shown from the front.

Fig. 3 shows an example of the handheld device.

The handheld device 100 is in this example an intraoral scanner with a pistol-grip. The scanner comprises a housing 106 comprising the pistol-grip part 107, and a tip 108 adapted for insertion in the mouth of the patient. In this example the scanner also is equipped with a button 103 which is an additional element providing user-interface functionality.

The example system as shown in fig. 1, fig. 2 and fig. 3 comprises a device 100 which is a handheld intraoral scanner and a display 101 which is a

computer screen. The operator 102 may be a dentist, an assistant and/or the like. In an example, the action performance or operation functionality of the device 100 is to record some intraoral 3D geometry, and the user interface functionality is to rotate, pan, and zoom the 3D model 105 of the scanned data on the computer screen 101. The integration of the user interface functionality in the device 100 is provided by motion sensors (not visible), which can be accelerometers inside the scanner 100, whose readings determine the orientation, as seen in Figs 2a and 2b, of the display on the screen of the 3D model 105 of the teeth acquired by the scanner 100. Additional functionality, e.g. to start/stop scanning, may be provided by the button 103 as seen in fig. 3. In the example system, the button 103 is located where the user's index finger can reach it conveniently.

In fig. 1 the dentist 102 uses two hands to hold the intraoral scanner 100 while scanning, but it is understood that the scanner 100 can also be held with one hand while scanning. The device 100 can also be held with one or two hands, while changing the perspective of the 3D model 105 in the display 101. The example shown in Figure 1 thus illustrates the advantage of the touchless user interface functionality, because in many clinical situations, the operator 102 should maintain both hands clean, disinfected, or even sterile.

The 3D user interface functionality may be exploited in a separate location than the operation functionality. For the above intraoral scanning system example, the scanning operation is performed in the oral cavity of the patient, see fig. 1, while the user interface functionality is more flexibly exploited when the scanner is outside the patient's mouth, see figs 2 and 3.

Fig. 4 shows an example of a flow-chart of a method of interaction between a handheld device and a display.

In step 101 at least one action in a physical 3D environment is performed by means of the handheld device. This action may the scanning of teeth as shown in fig. 1.

In step 102 the physical 3D environment is visually represented by the at least one display. This may be the display of the 3D model of the scanned teeth as seen in fig 1.

In step 103 the view of the represented 3D environment shown on the display is remotely controlled on the display by means of the handheld device. This may be the control of the viewing angle of the 3D model as seen in fig. 2.

All the steps of the method may be repeated one or more times. The order in which the steps are performed may be different than the order described above, which is indicated by the dotted lines in the figure. If one or more of the steps are performed more times, the order of the steps may also be different.

Although some embodiments have been described and shown in detail, the invention is not restricted to them, but may also be embodied in other ways within the scope of the subject matter defined in the following claims. In particular, it is to be understood that other embodiments may be utilised and structural and functional modifications may be made without departing from the scope of the present invention.

In device claims enumerating several means, several of these means can be embodied by one and the same item of hardware. The mere fact that certain measures are recited in mutually different dependent claims or described in different embodiments does not indicate that a combination of these measures cannot be used to advantage.

It should be emphasized that the term "comprises/comprising" when used in this specification is taken to specify the presence of stated features, integers,

steps or components but does not preclude the presence or addition of one or more other features, integers, steps, components or groups thereof.

The features of the method described above and in the following may be implemented in software and carried out on a data processing system or other processing means caused by the execution of computer-executable instructions. The instructions may be program code means loaded in a memory, such as a RAM, from a storage medium or from another computer via a computer network. Alternatively, the described features may be implemented by hardwired circuitry instead of software or in combination with software.

Literature:

C. Graetzel, T. Fong, S. Grange, and C. Baur. A Non-Contact Mouse for Surgeon-Computer Interaction. Technology and Health Care, 12(3), 2004.

Vogt S., Khamene A., Niemann H., Sauer F., An AR system with intuitive user interface for manipulation and visualization of 3D medical data, Stud. Health Technol. Inform. 2004;98, pp. 397-403.

Embodiments

The following embodiments relates to one aspect of the system as disclosed by the description herein.

1. A system comprising a handheld device and at least one display, where the handheld device is adapted for performing at least one action in a physical 3D environment, where the at least one display is adapted for visually representing the physical 3D environment, and where the handheld device is adapted for remotely controlling the view with which the 3D environment is represented on the display.

2. The system according to any one or more of the preceding embodiments, wherein the view is defined as viewing angle and/or viewing position.

3. The system according to any one or more of the preceding embodiments, wherein the handheld device is adapted for remotely controlling the magnification with which the 3D environment is represented on the display.

4. The system according to any one or more of the preceding embodiments, wherein the handheld device is adapted for changing the rendering of the 3D environment on the display.

5. The system according to any one or more of the preceding embodiments, wherein the at least one action comprises one or more of:

- measuring,
- recording,
- scanning,
- manipulating, and/or
- modifying.

6. The system according to any one or more of the preceding embodiments, wherein the 3D environment comprises one or more 3D objects.

7. The system according to any one or more of the preceding embodiments, wherein the handheld device is adapted to be held in one hand by an operator.

8. The system according to any one or more of the preceding embodiments, wherein the display is adapted to represent the 3D environment from multiple views..

9. The system according to any one or more of the preceding embodiments, wherein the view of the 3D environment represented in the at least one display is at least partly determined by the motion of the operator's hand holding said device.

10. The system according to any one or more of the preceding embodiments, wherein the magnification represented in the at least one display is at least partly determined by the motion of the operator's hand holding said device.

11. The system according to any one or more of the preceding embodiments, wherein the handheld device is adapted to record the 3D geometry of the 3D environment.

12. The system according to any one or more of the preceding embodiments, wherein the 3D geometry of the 3D environment is known a-priori.

13. The system according to any one or more of the preceding embodiments, wherein the handheld device comprises at least one user-interface element.

14. The system according to any one or more of the preceding embodiments, wherein the at least one user-interface element is at least one motion sensor.

15. The system according to any one or more of the preceding embodiments, wherein the handheld device comprises at least two motion sensors providing sensor fusion.

16. The system according to any one or more of the preceding embodiments, wherein the user interface functionality comprises the use of gestures.

17. The system according to any one or more of the preceding embodiments, wherein the gestures are detected by the at least one motion sensor.

18. The system according to any one or more of the preceding embodiments, wherein the handheld device comprises at least one user-interface element other than the at least one motion sensor.

19. The system according to any one or more of the preceding embodiments, wherein the at least one other user-interface element is a touch-sensitive element.

20. The system according to any one or more of the preceding embodiments, wherein the at least one other user-interface element is a button.

21. The system according to any one or more of the preceding embodiments, wherein the at least one other user-interface element is a scroll wheel.

22. The system according to any one or more of the preceding embodiments, wherein the handheld device is adapted to change a viewing angle with which the 3D environment is represented on the at least one display.

23. The system according to any of the preceding embodiments, wherein the handheld device is adapted to change a magnification factor with which the 3D environment is represented on the at least one display.

24. The system according to any one or more of the preceding embodiments, wherein the handheld device is adapted to change a viewing position with which the 3D environment is represented on the at least one display.

25. The system according to any one or more of the preceding embodiments, wherein the view of the 3D environment comprises a viewing angle, a magnification factor, and/or a viewing position.

26. The system according to any one or more of the preceding embodiments, wherein the view of the 3D environment comprises rendering of texture and/or shading.

27. The system according to any one or more of the preceding embodiments, wherein the at least one display is divided into multiple regions, each showing the 3D environment with a different view.

28. The system according to any one or more of the preceding embodiments, wherein the 3D geometry comprises a 3D surface of the environment.

29. The system according to any one or more of the preceding embodiments, wherein the 3D geometry comprises a 3D volumetric representation of the environment.

30. The system according to any one or more of the preceding embodiments, wherein the handheld device is an intra-oral 3D scanner.

31. The system according to any one or more of the preceding embodiments, wherein the handheld device is a surgical instrument.

32. The system according to any one or more of the preceding embodiments, wherein the handheld device is a mechanical tool.

33. The system according to any one or more of the preceding embodiments, wherein the handheld device is an in-ear 3D scanner.

34. The system according to any one or more of the preceding embodiments, wherein the at least one display is arranged separate from the handheld device.

35. The system according to any one or more of the preceding embodiments, wherein the at least one display is arranged on a cart.

36. The system according to any one or more of the preceding embodiments, wherein the at least one display is defined as a first display, and where the system further comprises a second display.

37. The system according to any one or more of the preceding embodiments, wherein the second display is arranged on the handheld device.

38. The system according to any one or more of the preceding embodiments, wherein the second display is arranged on the handheld device in a position such that the display is adapted to be viewed by the operator, while the operator is operating the handheld device.

39. The system according to any one or more of the preceding embodiments, wherein the second display indicates where the handheld device is positioned relative to the 3D environment.

40. The system according to any one or more of the preceding embodiments, wherein the first display and/or the second display provides instructions for the operator.

41. The system according to any one or more of the preceding embodiments, wherein visual information is provided to the operator on one or more means other than the first display.

42. The system according to any one or more of the preceding embodiments, wherein audible information to the operator is provided to the operator.

43. The system according to any one or more of the preceding embodiments, wherein the scanning is performed by means of LED scanning, laser light scanning, white light scanning, X-ray scanning, and/or CT scanning.

44. A method of interaction between a handheld device and at least one display, where the method comprises the steps of:
- performing at least one action in a physical 3D environment by means of the handheld device;
- visually representing the physical 3D environment by the at least one display; and
- remotely controlling the view of the represented 3D environment on the display by means of the handheld device.

45. A computer program product comprising program code means for causing a data processing system to perform the method of any one or more of the preceding embodiments, when said program code means are executed on the data processing system.

46. A computer program product according to the previous embodiment, comprising a computer-readable medium having stored there on the program code means.

5

Claims

1. A system comprising a handheld device and at least one display, where the handheld device is adapted for switching between
- performing at least one action in a physical 3D environment, where the at least one display is adapted for visually representing the physical 3D environment, and
- remotely controlling the view with which the 3D environment is represented on the display.

2. A system according to any one or more of the preceding claims, wherein the handheld device is adapted to record the 3D geometry of the 3D environment.

3. A system according to any one or more of the preceding claims, wherein means for manually switching between performing the at least one action and remotely controlling the view is provided on the handheld device.

4. A system according to claim 3, wherein the means for manually switching is an actuator, such as a button, a switch or a contact.

5. The system according to any one or more of the preceding claims, wherein the view is defined as viewing angle and/or viewing position.

6. The system according to any one or more of the preceding claims, wherein the handheld device is adapted for remotely controlling the magnification with which the 3D environment is represented on the display.

7. The system according to any one or more of the preceding claims, wherein the handheld device is adapted for changing the rendering of the 3D environment on the display.

8. The system according to any one or more of the preceding claims, wherein the at least one action comprises one or more of:

- measuring,
- recording,
- scanning,
- manipulating, and/or
- modifying.

9. The system according to any one or more of the preceding claims, wherein the 3D environment comprises one or more 3D objects.

10. The system according to any one or more of the preceding claims, wherein the handheld device is adapted to be held in one hand by an operator.

11. The system according to any one or more of the preceding claims, wherein the display is adapted to represent the 3D environment from multiple views.

12. The system according to any one or more of the preceding claims, wherein the handheld device comprises at least one motion sensor.

13. The system according to any one or more of the preceding claims, wherein the view of the 3D environment represented in the at least one display is at least partly determined by the at least one motion sensor.

14. The system according to any one or more of the preceding claims, wherein the magnification represented in the at least one display is at least partly determined by the at least one motion sensor.

15. The system according to any one or more of the preceding claims, wherein the handheld device is adapted to record the 3D geometry of the 3D environment.

16. The system according to any one or more of the preceding claims, wherein the 3D geometry of the 3D environment is known a-priori.

17. The system according to any one or more of the preceding claims, wherein the handheld device comprises at least one user-interface element.

18. The system according to any one or more of the preceding claims, wherein the at least one user-interface element is at least one motion sensor.

19. The system according to any one or more of the preceding claims, wherein the handheld device comprises at least two motion sensors providing sensor fusion.

20. The system according to any one or more of the preceding claims, wherein the user interface functionality comprises the use of gestures.

21. The system according to any one or more of the preceding claims, wherein the gestures are detected by the at least one motion sensor.

22. The system according to any one or more of the preceding claims, wherein the handheld device comprises at least one user-interface element other than the at least one motion sensor.

23. The system according to any one or more of the preceding claims, wherein the at least one other user-interface element is a touch-sensitive element.

24. The system according to any one or more of the preceding claims, wherein the at least one other user-interface element is a button.

25. The system according to any one or more of the preceding claims, wherein the at least one other user-interface element is a scroll wheel.

26. The system according to any one or more of the preceding claims, wherein the handheld device is adapted to change a viewing angle with which the 3D environment is represented on the at least one display.

27. The system according to any of the preceding claims, wherein the handheld device is adapted to change a magnification factor with which the 3D environment is represented on the at least one display.

28. The system according to any one or more of the preceding claims, wherein the handheld device is adapted to change a viewing position with which the 3D environment is represented on the at least one display.

29. The system according to any one or more of the preceding claims, wherein the view of the 3D environment comprises a viewing angle, a magnification factor, and/or a viewing position.

30. The system according to any one or more of the preceding claims, wherein the view of the 3D environment comprises rendering of texture and/or shading.

31. The system according to any one or more of the preceding claims, wherein the at least one display is divided into multiple regions, each showing the 3D environment with a different view.

32. The system according to any one or more of the preceding claims, wherein the 3D geometry comprises a 3D surface of the environment.

33. The system according to any one or more of the preceding claims, wherein the 3D geometry comprises a 3D volumetric representation of the environment.

34. The system according to any one or more of the preceding claims, wherein the handheld device is an intra-oral 3D scanner.

35. The system according to any one or more of the preceding claims, wherein the handheld device is a surgical instrument.

36. The system according to any one or more of the preceding claims, wherein the handheld device is a mechanical tool.

37. The system according to any one or more of the preceding claims, wherein the handheld device is an in-ear 3D scanner.

38. The system according to any one or more of the preceding claims, wherein the at least one display is arranged separate from the handheld device.

39. The system according to any one or more of the preceding claims, wherein the at least one display is arranged on a cart.

40. The system according to any one or more of the preceding claims, wherein the at least one display is defined as a first display, and where the system further comprises a second display.

41. The system according to any one or more of the preceding claims, wherein the second display is arranged on the handheld device.

42. The system according to any one or more of the preceding claims, wherein the second display is arranged on the handheld device in a position such that the display is adapted to be viewed by the operator, while the operator is operating the handheld device.

43. The system according to any one or more of the preceding claims, wherein the second display indicates where the handheld device is positioned relative to the 3D environment.

44. The system according to any one or more of the preceding claims, wherein the first display and/or the second display provides instructions for the operator.

45. The system according to any one or more of the preceding claims, wherein visual information is provided to the operator on one or more means other than the first display.

46. The system according to any one or more of the preceding claims, wherein audible information to the operator is provided to the operator.

47. The system according to any one or more of the preceding claims, wherein the scanning is performed by means of LED scanning, laser light scanning, white light scanning, X-ray scanning, and/or CT scanning.

48. The system according to any one or more of the preceding claims, wherein a graphical pointer is provided on the display for representing the movement of the handheld device when the handheld device is used to

remotely controlling the view with which the 3D environment is represented on the display.

49. The system according to any one or more of the preceding claims, wherein the handheld device is an intra-oral 3D scanner and the at least one action performed in the physical 3D environment is scanning and that the view is remotely controlled by at least one motion sensor arranged in the handheld device, and wherein an actuator provided on the handheld device switches between performing the at least one action and remotely controlling the view.

50. A method of interaction between a handheld device and at least one display, where the method comprises the steps of:

- performing at least one action in a physical 3D environment by means of the handheld device;
- visually representing the physical 3D environment by the at least one display; and
- remotely controlling the view of the represented 3D environment on the display by means of the handheld device.

51. A computer program product comprising program code means for causing a data processing system to perform the method of claim 44, when said program code means are executed on the data processing system.

52. A computer program product according to the previous claim, comprising a computer-readable medium having stored there on the program code means.

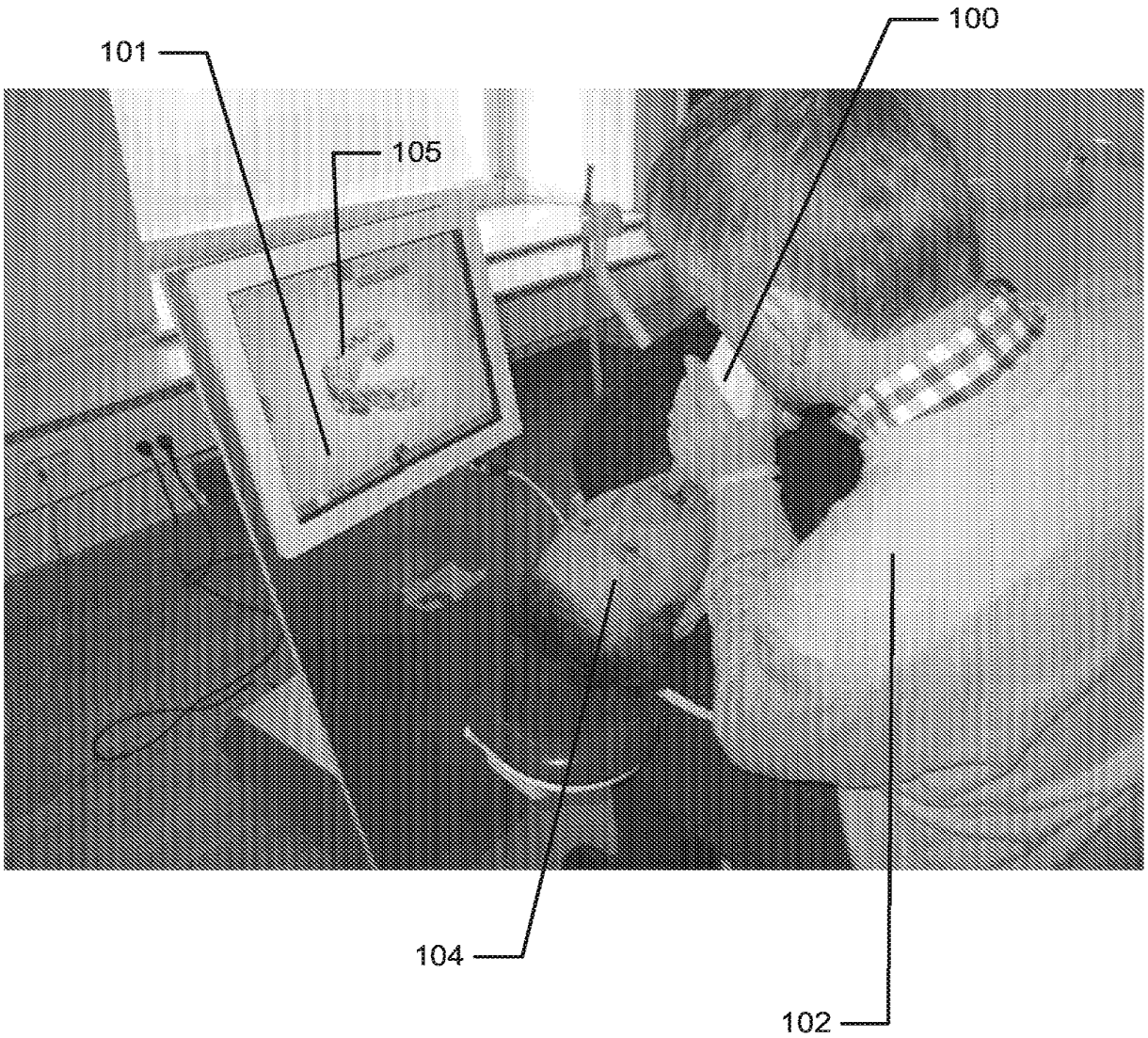


Fig. 1

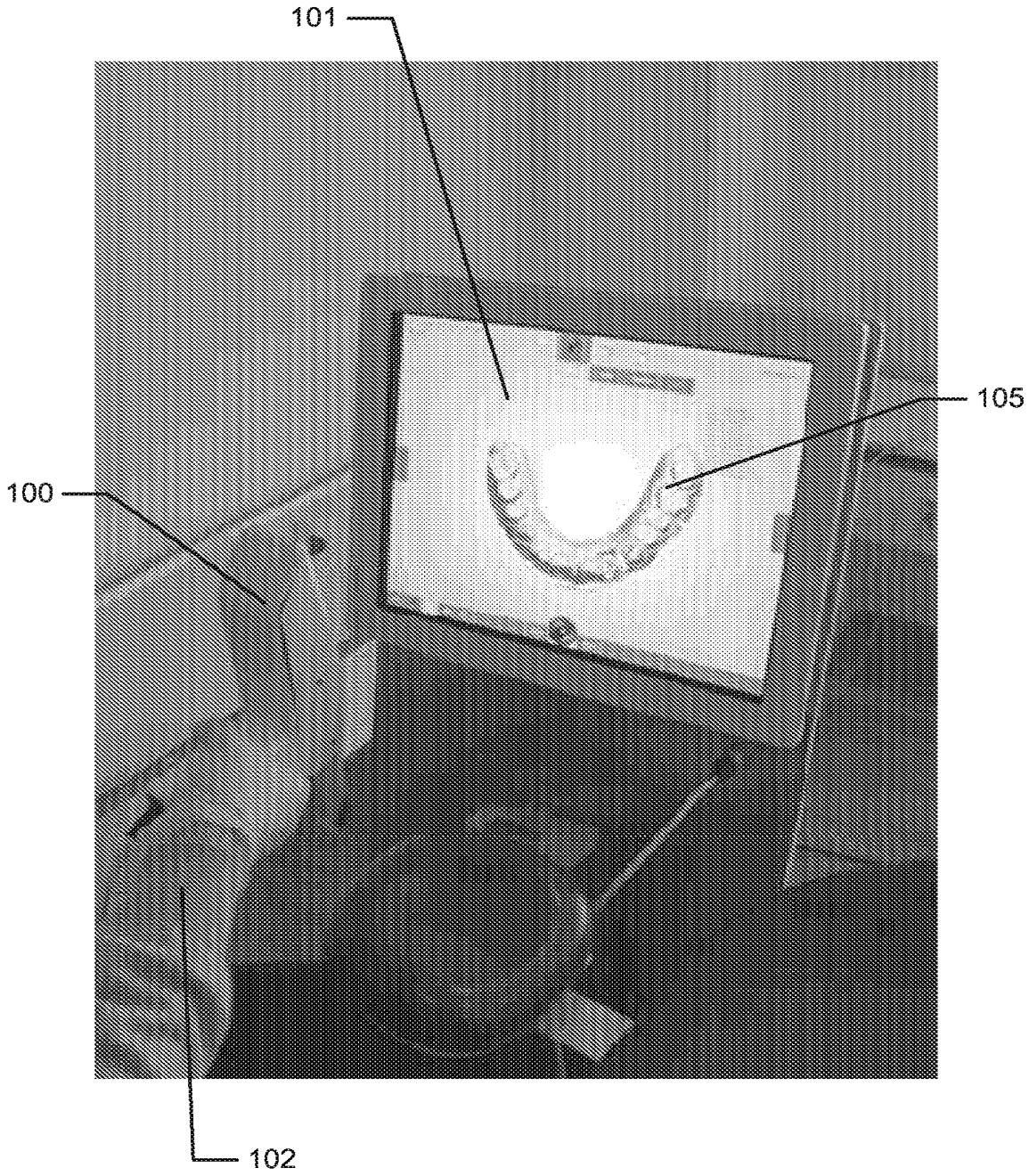


Fig. 2a)

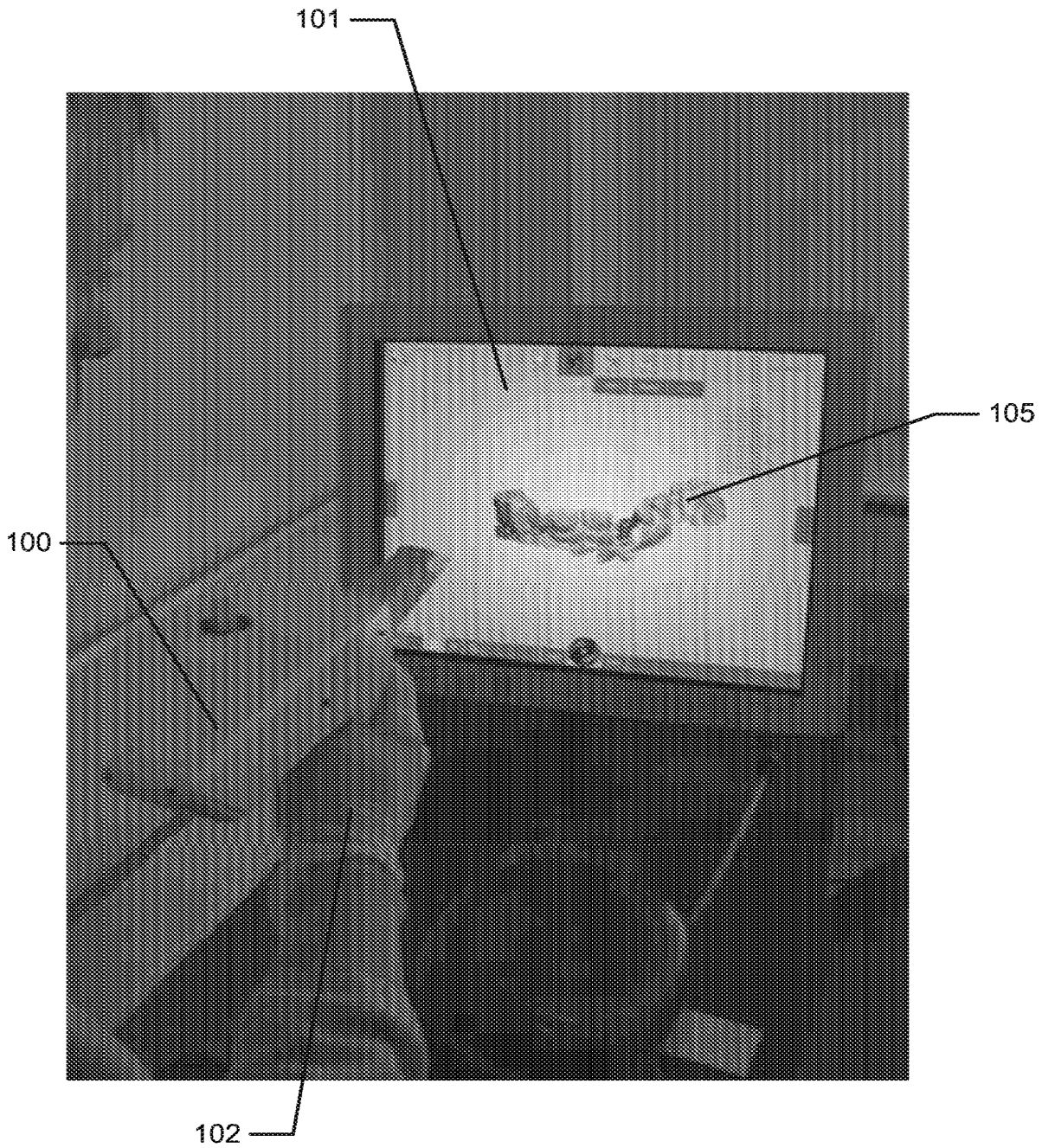


Fig. 2b)

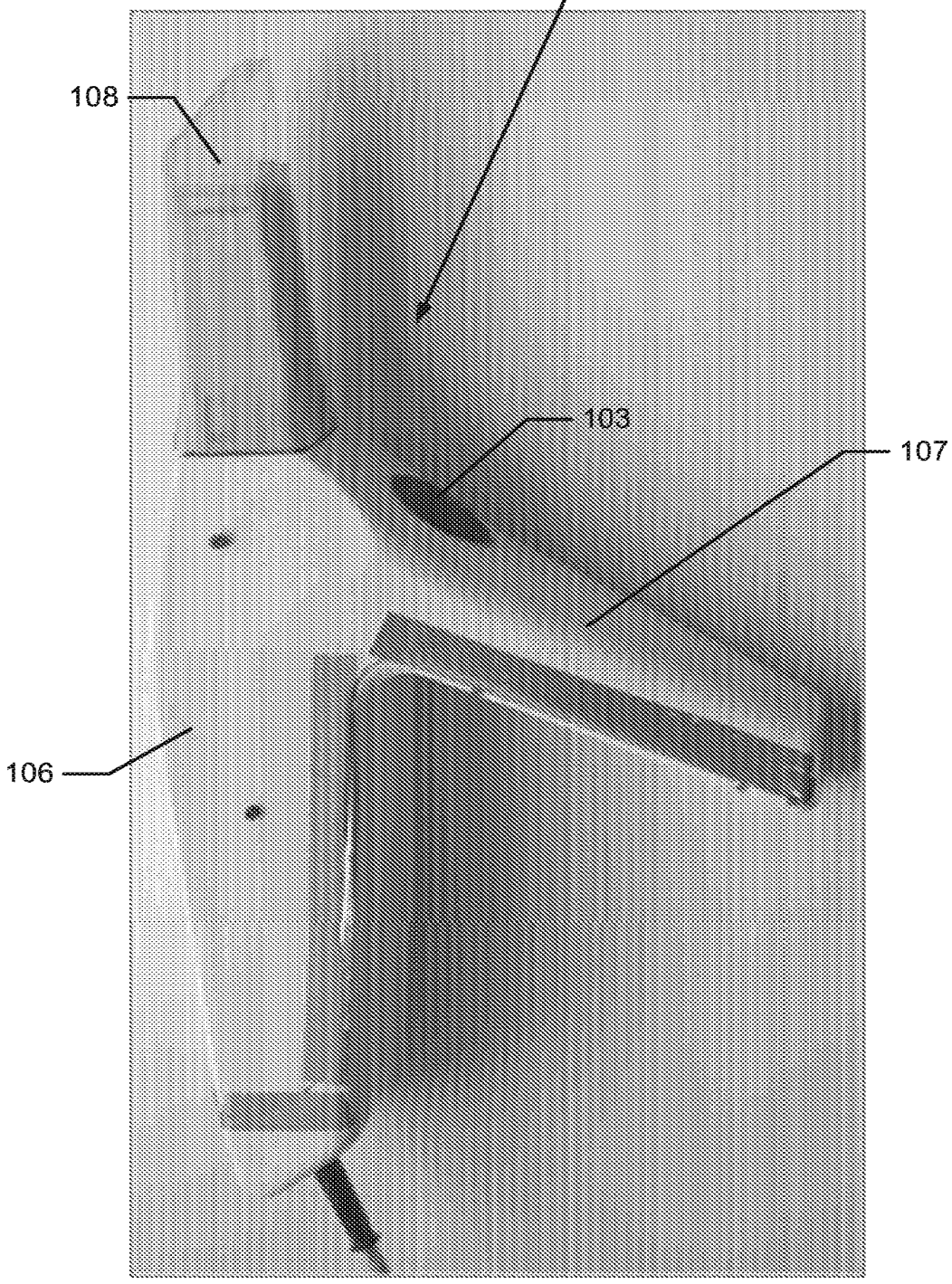


Fig. 3

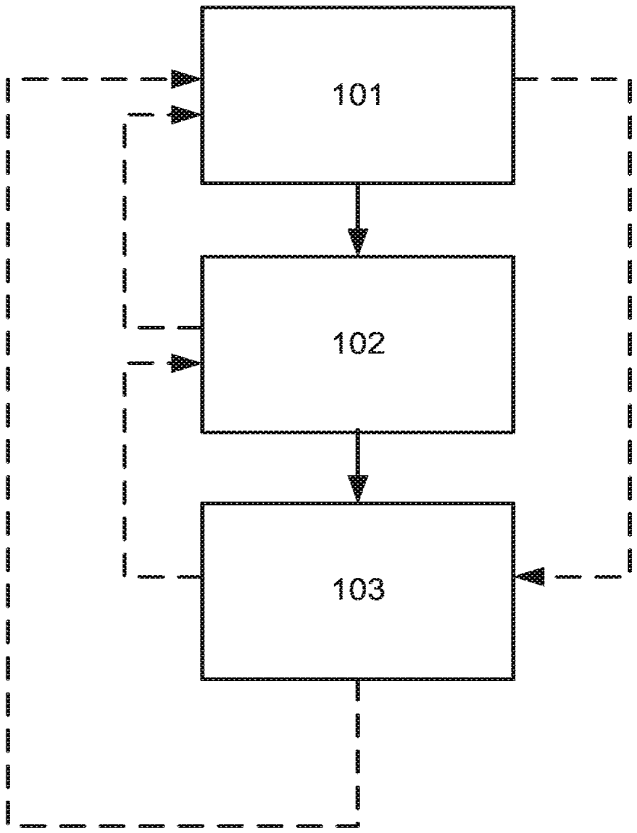


Fig. 4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/DK2011/050461

A. CLASSIFICATION OF SUBJECT MATTER
G01B 11/24 (2006.01), A61C 13/00 (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC/EC: G06F, G01B, A61C; ICO: K63F; FT:4C061/CC

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
DK, SE, FI, NO (IPC classes as above)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPODOC, WPI, TXTE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X; A	US 2009/0217207 A1 (KAGERMEIER et al) 2009.08.27, entire application, in particular sections [0007], [0009], [0012]-[0013], [0019] -[0020], [0023], [0035]-[0039], fig. 1-4	1-33, 38-48, 50-52; 34, 49
X; A	WO 2004/066615 A1 (NOKIA CORPORATION) 2004.08.05, page 3, line 16 to page 4, line 2, page 25, line 12, to page 26, line 5.	1, 3-14, 16-33, 38-48, 50-52; 2, 15, 34, 49
X; A	US 2003/0158482 A1 (POLAND et al) 2003.08.21, sections [0032], [0034], figs 6, 8.	1-11, 15-17, 26-33, 38-39, 46, 48, 50-52; 12-14, 18-25, 34, 40, 41-45, 47
A	US 2009/0061381 A1 (DURBIN et al) 2009.03.05, sections [0018]-[0019], [0024]	1-33, 38-52

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
17/02/2012	22/02/2012
Name and mailing address of the ISA/ Nordic Patent Institute, Helgeshøj Allé 81, DK-2630 Taastrup, Denmark. Facsimile No. +45 43 50 80 08	Authorized officer Lennart Bitsch Telephone No. +45 43 50 8244

Form PCT/ISA/210 (second sheet) (July 2009)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/DK2011/050461

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:
See extra sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1-34, 38-52

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

Exhibit 1004 page 882 of 1621
DENTAL IMAGING

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/DK2011/050461

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US2009217207 A1	20090827	CN101513350 A DE102008010717 A1	20090826 20090827
WO2004066615 A1	20040805	US2006146009 A1 EP1588552 A1 AU2003303787 A1	20060706 20051026 20040813
US2003158482 A1	20030821	JP2005517515 A WO03071306 A1 EP1488253 A1 EP1488253 B1 DE60308495T T2 CN1636151 A CN100340867C C AU2003247479 A1 AT340365T T US7141020 B2	20050616 20030828 20041222 20060920 20070606 20050706 20071003 20030909 20061015 20061128
US2009061381 A1	20090305	WO2009033108 A1 KR20100066538 A JP2010538302 A EP2185891 A1 CA2698525 A1	20090312 20100617 20101209 20100519 20090312

Continuation of Box no. III

This International Searching Authority found multible inventions.

US 2009/0217207 A1 (KAGERMEIER et al) 2009.08.27 describes a system comprising a handheld device (10) and at least one display (3, 22), where the handheld device is adapted for switching between
-performing at least one action in a physical 3D environment, where the at least one display is adapted for visually representing the physical 3D environment ([0013], [0037]), and
-remotely controlling the view with which the 3D environment is represented on the display ([0007], [0036], [0039])

The general concept described in the independent claim 1 is known from US 2009/0217207, and the application does therefore describe 4 inventions

A: Claims 2-34, 38-52 describe modifications of a system, a method, and a computer program product comprising a handheld device for performing at least one action, and for remotely controlling the view, and wherein the handheld device is an intra-oral 3D scanner
B: Claim 35 describes a system wherein the handheld device of claim 1 is a surgical instrument
C: Claim 36 describes a system wherein the handheld device of claim 1 is a mechanical tool
D: Claim 37 describes a system wherein the handheld device of claim 1 is an in-ear 3D scanner

There is no Single General Inventive Concept among the inventions A, B, C and D, and there is, therefore, not a technical relationship to link the invention as defined in Rules 13.1 and 13.2 PCT.

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
24 January 2013 (24.01.2013)

WIPO | PCT

(10) International Publication Number
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PCT/EP2012/063687

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(26) **Publication Language**: English

(30) **Priority Data**:
PA 2011 00547 15 July 2011 (15.07.2011) DK
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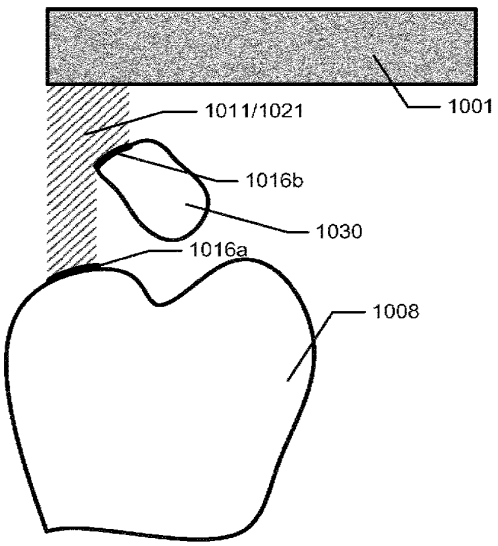
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(54) **Title**: DETECTION OF A MOVABLE OBJECT WHEN 3D SCANNING A RIGID OBJECT

Fig. 10a)



(57) **Abstract**: Disclosed is a method for detecting a movable object in a location, when scanning a rigid object in the location by means of a 3D scanner for generating a virtual 3D model of the rigid object, wherein the method comprises: providing a first 3D representation of at least part of a surface by scanning at least part of the location; providing a second 3D representation of at least part of the surface by scanning at least part of the location; determining for the first 3D representation a first excluded volume in space where no surface can be present; determining for the second 3D representation a second excluded volume in space where no surface can be present; if a portion of the surface in the first 3D representation is located in space in the second excluded volume, the portion of the surface in the first 3D representation is disregarded in the generation of the virtual 3D model, and/or if a portion of the surface in the second 3D representation is located in space in the first excluded volume, the portion of the surface in the second 3D representation is disregarded in the generation of the virtual 3D model.

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Detection of a movable object when 3D scanning a rigid object

Field of the invention

This invention generally relates to a method for detecting a movable object in a location, when scanning a rigid object in the location by means of a 3D scanner for generating a virtual 3D model of the rigid object. More particularly, the invention relates to scanning of a patient's set of teeth in the mouth of the patient by means of a handheld scanner.

Background of the invention

In traditional dentistry, the dentist makes a dental impression of the patient's teeth, when the patient needs a crown, a bridge, a denture, a removable, an orthodontic treatment etc.. An impression is carried out by placing a viscous liquid material into the mouth, usually in a dental impression tray. The material, usually an alginate, then sets to become an elastic solid, and, when removed from the mouth, provides a detailed and stable reproduction of teeth. When the impression is made, cheek retractors are arranged in the patient's mouth to avoid that the soft movable cheeks affect the impression of the teeth.

Today direct 3D scanning of the patient's teeth can be obtained using an intraoral handheld 3D scanner instead of making a physical dental impression.

When scanning a rigid object in a location for obtaining a virtual 3D model of the rigid object, such as scanning teeth in the mouth of a patient by means of a handheld scanner, it may happen that movable objects such as the patient's cheeks, tongue, or the dentist's instruments or fingers are captured

in the sub-scans, because these movable object are located for example between the surface of the teeth and the scanner, whereby the movable object obstruct the view of the teeth for the scanner. As the movable objects are movable they will typically move, and therefore it is likely that the movable object is only captured in one or a few subscans. Since a number of subscans are typically acquired for obtaining a virtual 3D model of, it is likely that there will also be acquired subscans of the same part of the rigid object but without the movable object obstructing the rigid object. Typically the movable objects will move or be moved very fast, since both the patient knows that his tongue should not touch or be near for the teeth when his teeth is scanned and the dentist knows that his instruments should not obstruct the visual access to the teeth. Therefore the movable object will typically only obstruct the visual access of the teeth for a very short time, and this means that the movable object will typically only be captured in one or few subscans. Furthermore, if the dentist notice that a movable object was present when he scanned a part of the teeth, he may return to scan the same part of the teeth where the movable object was before, and thus in most cases, there will also be subscans where the movable object is not present. The problem is then to differentiate between the surface of the movable object and the surface of the rigid object, such that only the surfaces originating from the rigid object are used when generating the virtual 3D model.

In prior art geometry and colour data are used to distinguish between a first and a second tissue, such as hard tissue as teeth and soft tissue as gums, tongue, cheeks, and lips.

EP1607041B discloses a method of providing data useful in procedures associated with the oral cavity characterized by comprising: providing at least two numerical entities (I_1, I_2,...,I_n), each said numerical entity representative of the three-dimensional surface geometry and colour of at least part of the

intra-oral cavity wherein said numerical entity comprises surface geometry and colour data associated with said part of the intra-oral cavity; wherein at least a portion of said entities (I_1, I_2,...I_n) comprise overlapping spatial data, comprising:

- (a) for each entity providing at least one sub entity (IS'_1, IS'_2,...IS'_n) comprising a first tissue data set comprising surface geometry and colour data, wherein said colour data thereof is correlated with a colour representative of a first tissue; and
- (b) stitching said first tissue data sets together based on registering portions of said data set comprising said overlapping spatial data (I_1, I_2,...I_n) and
- manipulating said entity to provide desired data therefrom.

Furthermore, in image processing a method called space carving is used for building up a 3D model.

The article "A Method for Registration of 3-D Shapes" by Besl and McKay, IEEE Transactions of Patten Analysis and Machine Intelligence, vol. 14, no. 2, February 1992 discloses a method for accurate and computationally efficient registration of 3-D shapes.

However, none of the prior art considers the case where some of the objects in the location are movable.

Thus it remains a problem to distinguish between movable objects and rigid objects, when both movable objects and rigid objects are present in a location, when scanning in the location for obtaining a virtual 3D model of the rigid object.

Summary

Disclosed is a method for detecting a movable object in a location, when scanning a rigid object in the location by means of a 3D scanner for generating a virtual 3D model of the rigid object, wherein the method comprises:

- providing a first 3D representation of at least part of a surface by scanning at least part of the location;
- providing a second 3D representation of at least part of the surface by scanning at least part of the location;
- determining for the first 3D representation a first excluded volume in space where no surface can be present;
- determining for the second 3D representation a second excluded volume in space where no surface can be present;
- if a portion of the surface in the first 3D representation is located in space in the second excluded volume, the portion of the surface in the first 3D representation is disregarded in the generation of the virtual 3D model, and/or
- if a portion of the surface in the second 3D representation is located in space in the first excluded volume, the portion of the surface in the second 3D representation is disregarded in the generation of the virtual 3D model.

Consequently, it is an advantage to disregard a surface portion from one representation if the surface portion is located in space in the excluded volume of another representation, because a surface portion detected in an excluded volume represents a movable object which is not part of the rigid object.

Thus it is an advantage that the method provides a determination of whether a detected surface portion is a point in space where there should be no surface, by detecting the space of the surface portion in both a first representation and in the second representation. If the surface portion is only

present in one of the representations and the representations cover the same space of the surface portion, then the surface portion must represent an object which was only present when one of the representations were acquired, and therefore the surface portion must originate from a movable object, which has moved during the acquisitions of the two representations.

When scanning a surface, then all space which is not occupied by the surface, may be defined as empty space, and if in a later scan, a surface is detected in the empty space, then that surface is disregarded. Likewise, if in a later scan, a volume region is seen to be empty, but that volume region was covered by a surface in a previous scan, then the surface is disregarded from the 3D virtual model.

By disregarding is meant not taken into account, such as deleting or not adding, when generating the 3D virtual model. If a surface portion from the first representation has already been added to the virtual 3D model, it may be deleted from it again if it is found that the surface portion is in the second excluded volume. If a surface portion from the second representation is found to be in the first excluded volume, the surface portion is not added to the virtual 3D model.

If a volume region in one representation or subscan is empty then it is excluded from addition of new surfaces even though a later representation or subscan shows that a surface is present in the volume regions. If a later representation or subscan shows that the volume is empty then a surface from a previous subscan in that volume is removed from the 3D model.

A common scan volume can be defined, which is the volume in space where the first scan volume and the second scan volume are overlapping. Thus it may be defined as the volume in space, where all volume units are contained in both the first scan volume and in the second scan volume.

If a portion of the surface in the first 3D representation is not located in space in the second excluded volume, and/or if a portion of the surface in the second 3D representation is not located in space in the first excluded volume, no surface portions are disregarded yet, and the scanning may continue by providing a third representation, a fourth representation etc.

Typically when scanning an object, such as a set of teeth, more representations or subscans may be provided, such as 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 2000, 3000, 4000, 5000, 6000, 7000, 8000, 9000, 10000 etc. during a complete scanning process.

In some embodiments the rigid object is a patient's set of teeth, and the location is the mouth of the patient.

In some embodiments the movable object is a soft tissue part of the patient's mouth, such as the inside of a cheek, the tongue, lips, gums and/or loose gingival.

In some embodiments the movable object is a dentist's instrument or remedy which is temporarily present in the patient's mouth, such as a dental suction device, cotton rolls, and/or cotton pads.

In some embodiments the movable object is a finger, such as the dentist's finger or the dental assistant's finger.

In some embodiments the 3D scanner is a scanner configured for acquiring scans of an object's surface for generating a virtual 3D model of the object.

In some embodiments at least part of the surface captured in the first representation and at least part of the surface captured in the second representation are overlapping the same surface part on the rigid object.

In some embodiments the first representation of at least part of the surface is defined as the first representation of at least a first part of the surface, and the second representation of at least part of the surface is defined as the second representation of at least a second part of the surface.
The first part of the surface and the second part of the surface may be two different parts, or may be the same part, or may be partly the same part.

In some embodiments the first part of the surface and the second part of the surface are at least partially overlapping.

In some embodiments the surface is a surface in the location.

In some embodiments the surface is at least part of the surface of the rigid object and/or at least part of the surface of the movable object.
The purpose of scanning is to acquire a virtual 3D model of the rigid object, e.g. teeth, but if there is a movable object in the location, e.g. the mouth of the patient, when scanning, then the movable object may also be captured in some of the subscans.

In some embodiments the method comprises determining a first scan volume in space related to the first representation of at least part of the surface, and determining a second scan volume in space related to the second representation of at least part of the surface.
The scan volume may be the volume in space which is located in front of the captured surface relative to the scanner.

In some embodiments the scan volume is defined by the focusing optics in the 3D scanner and the distance to the surface which is captured.
The scan volume may be defined as the physical volume which the scanner is adapted to scan relative to the view position and the orientation of the scanner, such as relative to the scan head of the scanner.

Furthermore, the scanner comprises a scan head, and the scan volume may be defined as the distance in space between the surface and the scan head times the area of the opening of the scan head. The scan head may comprise the focusing optics of the scanner.
Instead of the area of the opening of the scan head, the area of the surface projected in the optical direction may be considered.

In some embodiments the first scan volume related to the first representation of at least part of the surface is the volume in space between the focusing optics of the 3D scanner and the surface captured in the first representation; and the second scan volume related to the second representation of at least part of the surface is the volume in space between the focusing optics of the 3D scanner and the surface captured in the second representation.

In some embodiments if no surface is captured in at least part of the first or second representation, then the first or second scan volume is the volume in space between the focusing optics of the 3D scanner and the longitudinally extent of the scan volume.

In some embodiments the first excluded volume and the second excluded volume in space where no surface can be present corresponds to the first scan volume and the second scan volume, respectively.
The space between the focusing optics of the 3D scanner and the captured surface must be an empty space, unless a transparent object, which is not detectable by the 3D scanner, was located in the scan volume.

The scan volume may be defined as the maximum volume which can be scanned, e.g. the maximum volume of light which can be transmitted from the scan head. In that case, the excluded volume would only correspond to the scan volume, if the captured surface is located at the end or edge of the scan volume. But in most cases the excluded volume would be smaller than the scan volume, if the definition of the scan volume was the maximum volume.

In some embodiments the volume of the 3D scanner itself is defined as an excluded volume.

In some embodiments the volume of the 3D scanner itself is comprised in the first excluded volume and in the second excluded volume.

In some embodiments a near threshold distance is defined, which determines a distance from the captured surface in the first representation and the second representation, where a surface portion in the second representation or the first representation, respectively, which is located within the near threshold distance from the captured surface and which is located in space in the first excluded volume or in the second excluded volume, respectively, is not disregarded in the generation of the virtual 3D model.

The near threshold defines how far from the representation or surface in a subscan possibly movable objects are disregarded from the generation of the virtual 3D model. The near threshold distance is defined for avoiding that too much of a representation of a surface is incorrectly disregarded, since there may be noise in the representation and since the registration/alignment between representations or sub-scans may not be completely accurate. Due to different levels of noise in different subscans or due to inaccurate

registration/alignment of subscans, two subscans of the same surface may incorrectly look like two different surfaces.

The near threshold distance may be such as 0.01 mm, 0.05 mm, 0.09 mm, 0.10 mm, 0.15 mm, 0.20 mm etc.

In some embodiments a far threshold distance is defined, which determines a distance from the captured surface, where the volume outside the far threshold distance is not included in the excluded volume of a representation.

Thus the volume outside the far threshold distance is not included in the first excluded volume of the first 3D representation, and the volume outside the far threshold distance is not included in the second excluded volume of the second 3D representation.

According to this embodiment any acquired data or surface or surface points of the first or second representation, which is/are present or located outside the far threshold distance, is not used to determine or define the first or second excluded volume, respectively.

It is an advantage because a surface or surface points from a movable object or from another part of the tooth surface can actually be present outside the far threshold distance without being detected by the scanner, due to the geometry and optical properties of the scanner. The light rays from the scanner head may be transmitted in any directions and with any angle or inclination from a normal plane of the scanner head, and therefore a light ray can be transmitted from the scanner head to a point which is placed behind the movable object or the other part of the tooth surface, when the movable object or the other part of the tooth surface is present partly in front of the scanner head.

Thus the volume outside the far threshold distance is not included in the excluded volume, because in the volume outside the far threshold distance a surface can be present even though no surface is detected by the scanner.

The far threshold distance defines or determines a distance from the captured surface, where the volume or region within the far threshold distance is included in the excluded volume.

Thus if utilizing or applying the far threshold distance, the excluded volume for a representation will be smaller than if not applying the far threshold distance, and therefore less volume can be excluded.
However, the advantage of applying a far threshold distance is that only volumes which can truly be excluded, will be excluded, meaning that the general scan data will have a higher quality.

Thus even though no surface or surface points has/have been detected in a volume or region between the scanner and the tooth surface, the whole region cannot be defined as excluded volume, because the light rays from and to the scanner may travel with inclined angles relative to a normal of the scan head, which means that the scanner can detect a point on the tooth surface even though another part of the tooth is actually placed, at least partly, between the detected tooth surface and the scanner. Therefore a far threshold distance is defined, and no data detected outside this far threshold distance from the tooth surface is used to define the excluded volume of a representation. Only data detected inside the far threshold distance is used to define the excluded volume, because only within this distance can one be certain that the data detected actually corresponds to the real physical situation.

The scanner may detect that no surface is present in the volume or region outside the far threshold distance between the tooth surface and the scanner,

but this data or information cannot be used to define the excluded volume of the representation, because there may actually be a movable object or another part of the tooth surface in this region or volume which the scanner overlooks because of its inclined light rays.

Furthermore, the scanner may overlook a surface part even though the surface part is in the scan volume. This can be caused by that the surface part is outside the focus region of the scanner, for example if the surface part is too close to the opening of the scanner head and/or scanner body, as the focus region may begin some distance from the scanner head and/or scanner body. Alternatively and/or additionally this can be caused by the lightning conditions, which may not be optimal for the given material of the surface, whereby the surface is not properly illuminated and thus can become invisible for the scanner. Thus in any case the scanner may overlook or look through the surface part. Hereby a volume in space may erroneously be excluded, since the scanner detects that no surface is present, and therefore a surface portion captured in this excluded volume in another 3D representation or scan would be disregarded. For avoiding that this happens, which would be unfavorably if the surface part was a true tooth surface, the far threshold distance can be defined, such that the excluded volume becomes smaller, such that only volume which really can be excluded is excluded.

It is an advantage that real surface points of a tooth are not erroneously disregarded, whereby fewer holes, i.e. regions with no scan data, are created in the scans. Thus the excluded volume is reduced by means of the far threshold distance for avoiding that too much surface information is incorrectly disregarded.

The light rays from the scan head of the scanner may spread or scatter or disperse in any directions.

Even if an object, such as a movable object, is arranged between the scan head and the surface of a rigid object, e.g. a tooth, the scanner may still capture a surface point on the tooth surface which is present or hidden "under" the object, because of the angled or inclined light rays. A surface point or area may just have to be visible for one or a small number of light rays from and/or to the scanner in order for that surface point or area to be detected.

Since the far threshold distance determines a distance from the captured surface in a representation, where any acquired data or surface or surface points, which is/are present or located outside the far threshold distance, is not used to define the excluded volume of the representation, any acquired data or surface or surface points in the volume between the far threshold distance and the scan head is not included in the definition of the excluded volume.

The actual distance of the far threshold may depend or be calculated based on the optics of the scanner. The far threshold distance may be a fixed number, such as about 0.5 mm, 1 mm, 2 mm, 3 mm, 4 mm, 5 mm, 6 mm, 7 mm, 8 mm, 9 mm, 10 mm, 20 mm, 30 mm, 40 mm, 50 mm, 60 mm, 70 mm, 80 mm, 90 mm, or 100 mm. Alternatively, the far threshold distance may be a percentage or a fraction of the length of the scan volume, such as about 20%, 25%, 30%, 35%, 40%, 45%, or 50% of the length of the scan volume, or such as ½, 1/3, ¼, 1/5 of the length of the scan volume.

The far threshold distance may be based on a determination of how far a distance from a detected point of the surface it is possible to scan, i.e. how much of the surface around a detected point that is visible for the scanner. If the visible distance in one direction from a surface point is short, then the far threshold distance will be smaller than if the distance in all directions from a surface point is long.

In some embodiments the first representation of at least part of a surface is a first subscan of at least part of the location, and the second representation of

at least part of the surface is a second subscan of at least part of the location.

In some embodiments the first representation of at least part of a surface is a provisional virtual 3D model comprising the subscans of the location acquired already, and the second representation of at least part of the surface is a second subscan of at least part of the location.

In some embodiments acquired subscans of the location are adapted to be added to the provisional virtual 3D model concurrently with the acquisition of the subscans.

In some embodiments the provisional virtual 3D model is termed as the virtual 3D model, when the scanning of the rigid object is finished.

In some embodiments the method comprises:

- providing a third 3D representation of at least part of a surface by scanning at least part of the location;
- determine for the third 3D representation a third excluded volume in space where no surface can be present;
- if a portion of the surface in the first 3D representation is located in space in the third excluded volume, the portion of the surface in the first 3D representation is disregarded in the generation of the virtual 3D model, and/or
- if a portion of the surface in the second 3D representation is located in space in the third excluded volume, the portion of the surface in the second 3D representation is disregarded in the generation of the virtual 3D model, and/or
- if a portion of the surface in the third 3D representation is located in space in the first excluded volume and/or in the second excluded volume, the

portion of the surface in the third 3D representation is disregarded in the generation of the virtual 3D model.

In some embodiments the provisional virtual 3D model comprises the first representation of at least part of the surface and the second representation of at least part of the surface, and where the third representation of at least part of the surface is added to the provisional virtual 3D model.
Thus the timewise first acquired representation, which is not necessarily the first representation, and the timewise second acquired representation, which is not necessarily the second representation, may be combined to create the provisional virtual 3D model, and each time a new representation is acquired or provided, the new representation may be added to the provisional virtual 3D model, whereby the provisional virtual 3D model grows for each added representation.

In some embodiments the virtual 3D model is used for virtually designing a restoration for one or more of the patient's teeth.

Thus the purpose of scanning is to obtain a virtual 3D model of the patient's teeth. If the patient should have a restoration, e.g. a crown, a bridge, a denture, a partial removable etc., the restoration can be digitally or virtually designed on or relative to the 3D virtual model.

In some embodiments the virtual 3D model is used for virtually planning and designing an orthodontic treatment for the patient.

In some embodiments the relative motion of the scanner and the rigid object is determined.

In some embodiments the relative motion of the scanner and the rigid object is determined by means of motion sensors.

If the scanner used for acquiring the sub-scans is a handheld scanner, then the relative position, orientation or motion of scanner and the object which is scanned must be known. The relative position, orientation and motion of the scanner can be determined by means of position, orientation and/or motion sensors. However, if these sensors are not accurate enough for the purpose, the precise relative position of scanner and object can be determined by comparing the obtained 3D surfaces in the sub-scans, such as by means of alignment/registration.

A motion sensor is a device that can perform motion measurement, such as an accelerometer. Furthermore the motion sensor may be defined as a device which works as a position and orientation sensor as well.

A position sensor is a device that permits position measurement. It can be an absolute position sensor or a relative position sensor, also denoted displacement sensor. Position sensors can be linear or angular.

An orientation sensor is a device that can perform orientation measurement, such as a gyrosscope.

In some embodiments the relative motion of the scanner and the rigid object is determined by registering/aligning the first representation and the second representation.

In some embodiments the first representation and the second representation are aligned/registered before the first excluded volume and the second excluded volume are determined.

Thus after the first and the second representation are provided, they may be aligned/registered, and after this, the first and second excluded volume may be determined, and then it is detected whether a portion of the surface in the first 3D representation or in the second 3D representation is located in space in the second excluded volume or in the first excluded volume, respectively, such that such portion of the surface in the representation is disregarded in the generation of the virtual 3D model.

Alignment or registration may comprise bringing the 3D representations or subscans together in a common reference system, and then merging them to create the virtual 3D model or a provisional virtual 3D model. For each representation or subscan which is aligned/registered to the provisional virtual 3D model, the model grows and finally it becomes the virtual 3D model of the object.

In some embodiments the relative motion of the scanner and the rigid object determined by means of the motions sensors is verified and potentially adjusted by registering/aligning the first representation and the second representation.

In some embodiments motion sensors are used for an initial determination of the relative motion of the scanner and the rigid object, and where registering/aligning is used for the final determination of the relative motion of the scanner and the rigid object.
Thus in practice the motion sensors may be used as a first guess for the motion, and based on this the alignment/registration may be used for testing the determined motion and/or determining the precise motion or adjusting the determined motion.

In some embodiments the optical system of the scanner is telecentric.
A telecentric system is an optical system that provides imaging in such a way that the chief rays are parallel to the optical axis of said optical system. In a telecentric system out-of-focus points have substantially same magnification as in-focus points. This may provide an advantage in the data processing. A perfectly telecentric optical system may be difficult to achieve, however an optical system which is substantially telecentric or near telecentric may be provided by careful optical design. Thus, when referring to a telecentric optical system it is to be understood that it may be only near telecentric.

As the chief rays in a telecentric optical system are parallel to the optical axis, the scan volume becomes rectangular or cylindrical.

In some embodiments the optical system of the scanner is perspective.
If the optical system is a perspective system, the chief rays are angled relative to the optical axis, and the scan volume thus becomes cone shaped. Note that the scan volume is typically a 3D shape.

In some embodiments a mirror in a scan head of the scanner provides that the light rays from the light source in the scanner are transmitted with an angle relative to the opening of the scan head.

The scan volume may be defined not as rectangular but rather as resembling a parallelogram.
The light reflected back from a point on the surface may be projected as rays forming a cone or as parallel rays.

In some embodiments the 3D scanner is a hand-held scanner.
The 3D scanner may for example be a hand-held intraoral scanner.

In some embodiments the scanner is a pinhole scanner.
A pinhole scanner comprises a pinhole camera having a single small aperture. The size of the aperture may be such as 1/100 or less of the distance between it and the projected image. Furthermore, the pinhole size may be determined by the formula $d=2\sqrt{(2f\lambda)}$, where d is pinhole diameter, f is focal length, i.e. the distance from pinhole to image plane, and λ is the wavelength of light.
It is an advantage to use the present method for detecting a movable object in a location in a pinhole scanner, since determining the first excluded volume and the second excluded volume is very fast, easy and accurate due to the pinhole setup, where the camera and the light source/projected

pattern, respectively, of the scanner are well-defined points in space relative to the captured surface.

Furthermore, if the scanner is a pinhole scanner, the excluded volume may be bigger, compared to if the scanner is not a pinhole scanner. The reason for this is because no far threshold distance can or should be defined when using a pinhole scanner, since no volume between the scanner and the captured tooth surface may not be included in the excluded volume due to the geometry and optical properties of the scanner. The pinhole scanner cannot overlook a surface or surface points from e.g. a movable object due to its geometry and optical properties.

In some embodiments the scanner comprises an aperture, and the size of the aperture is less than 1/100 of the distance between it and the projected image.
This size of aperture corresponds to a pinhole scanner.

In some embodiments the scanner comprises an aperture, and the size of the aperture is more than 1/100 of the distance between it and the projected image.
This size of aperture corresponds to a scanner which is not a pinhole scanner.

Further aspects

According to another aspect of the invention, disclosed is a method for detecting movable objects in the mouth of a patient, when scanning the patient's set of teeth in the mouth by means of a 3D scanner for generating a virtual 3D model of the set of teeth, wherein the method comprises:

- providing a first 3D representation of at least part of a surface by scanning at least part of the teeth;
- providing a second 3D representation of at least part of the surface by scanning at least part of the teeth;
- determining for the first 3D representation a first excluded volume in space where no surface can be present;
- determining for the second 3D representation a second excluded volume in space where no surface can be present;
- if a portion of the surface in the first 3D representation is located in space in the second excluded volume, the portion of the surface in the first 3D representation is disregarded in the generation of the virtual 3D model, and/or
- if a portion of the surface in the second 3D representation is located in space in the first excluded volume, the portion of the surface in the second 3D representation is disregarded in the generation of the virtual 3D model.

According to another aspect of the invention, disclosed is a method for detecting a movable object in a location, when scanning a rigid object in the location by means of a 3D scanner for generating a virtual 3D model of the rigid object, wherein the method comprises:

- providing a first representation of at least part of a surface by scanning the rigid object;
- determining a first scan volume in space related to the first representation of at least part of the surface;
- providing a second representation of at least part of the surface by scanning the rigid object;
- determining a second scan volume in space related to the second representation of at least part of the surface;
- if there is a common scan volume, where the first scan volume and the second scan volume are overlapping, then:

- determine whether there is a volume region in the common scan volume which in at least one of the first representation or the second representation is empty and comprises no surface; and
- if there is a volume region in the common scan volume which in at least one of the first representation or the second representation is empty and comprises no surface, then exclude the volume region by disregarding in the generation of the virtual 3D model any surface portion in the second representation or in the first representation, respectively, which is detected in the excluded volume region, since a surface portion detected in the excluded volume region represents a movable object which is not part of the rigid object.

According to another aspect of the invention, disclosed is a method for detecting a movable object in a location, when scanning a rigid object in the location by means of a 3D scanner for generating a virtual 3D model of the rigid object, wherein the method comprises:

- providing a first surface by scanning the rigid object;
- determining a first scan volume related to the first surface;
- providing a second surface by scanning the rigid object;
- determining a second scan volume related to the second surface;

where the first scan volume and the second scan volume are overlapping in an overlapping/common scan volume;

- if at least a portion of the first surface and a portion of the second surface are not coincident in the overlapping/common scan volume, then disregard the portion of either the first surface or the second surface in the overlapping/common scan volume which is closest to the focusing optics of the 3D scanner, as this portion of the first surface or second surface represents a movable object which is not part of the rigid object.

According to another aspect of the invention, disclosed is a method for detecting a movable object in the mouth of the patient, when scanning the patient's set of teeth by means of a 3D scanner for generating a virtual 3D model of the set of teeth, wherein the method comprises:

- providing a first surface by scanning the set of teeth;
- determining a first scan volume related to the first surface;
- providing a second surface by scanning the set of teeth;
- determining a second scan volume related to the second surface;
where the first scan volume and the second scan volume are overlapping in an overlapping/common scan volume;
- if at least a portion of the first surface and a portion of the second surface are not coincident in the overlapping/common scan volume, then disregard the portion of either the first surface or the second surface in the overlapping/common scan volume which is closest to the focusing optics of the 3D scanner, as this portion of the first surface or second surface represents a movable object which is not part of the set of teeth.

According to another aspect of the invention, disclosed is a method for detecting movable objects recorded in subscans, when scanning a set of teeth by means of a scanner for generating a virtual 3D model of the set of teeth, where the virtual 3D model is made up of the already acquired subscans of the surface of the set of teeth, and where new subscans are adapted to be added to the 3D virtual model, when they are acquired, wherein the method comprises:

- acquiring at least a first subscan of at least a first surface of part of the set of teeth, where the at least first subscan is defined as the 3D virtual model;
- acquiring a first subscan of a first surface of part of the set of teeth;
- determining a first scan volume of the first subscan;

- determining a scan volume of the virtual 3D model;
- if the first scan volume of the first subscan and the scan volume of the virtual 3D model are at least partly overlapping in a common scan volume; then:
    - calculate whether at least a portion of the first surface lies within the common scan volume;
    - calculate whether at least a portion of the surface of the virtual 3D model lies within the common scan volume, and
    - determine whether at least a portion of a surface is present in the overlapping volume only in one subscan and not the other subscan/3D virtual model;
    - if at least a portion of a surface is present in only one subscan, then disregard the portion of the surface in the overlapping volume which is closest to the focusing optics of the scanner, since the portion of the surface represents a movable object which is not part of the set of teeth, and the portion of the surface is disregarded in the creation of the virtual 3D model of the set of teeth.

According to another aspect of the invention, disclosed is s method for detecting movable objects recorded in subscans, when scanning a set of teeth by means of a scanner for generating a virtual 3D model of the set of teeth, wherein the method comprises:

a) providing a first subscan of a first surface of part of the set of teeth;
b) calculating a first scan volume of the first subscan;
c) providing a second subscan of a second surface of part of the set of teeth;
d) calculating a second scan volume of the second subscan; and
e) if the first scan volume and the second scan volume are at least partly overlapping in a common scan volume; then:

f) calculate whether at least a portion of the first surface lies within the common scan volume;

g) calculate whether at least a portion of the second surface lies within the common scan volume, and

h) if at least a portion of the first surface or at least a portion of the second surface lie within the common scan volume, and the portion of the first surface or the portion of the second surface is located in space between the scanner and at least a portion of the second surface or at least a portion of the first surface, respectively;

then the portion of the surface represents a movable object which is not part of the set of teeth, and the portion of the surface is disregarded in the creation of the virtual 3D model of the set of teeth.

In some embodiments the method above further comprises:

- providing a third subscan of a third surface of part of the set of teeth;
- calculating a third scan volume of the third subscan;
- if the third scan volume is at least partly overlapping with the first scan volume and/or with the second scan volume in a common scan volume; then repeat steps f) - h) for the third subscan with respect to the first subscan and/or the second subscan.

Further embodiments are disclosed in the following sections:

Focus scanning and motion determination

In some embodiments the 3D scanning comprises the steps of:

- generating a probe light,
- transmitting the probe light towards the object thereby illuminating at least a part of the object,

- transmitting light returned from the object to a camera comprising an array of sensor elements,
- imaging on the camera at least part of the transmitted light returned from the object to the camera by means of an optical system,
- varying the position of the focus plane on the object by means of focusing optics,
- obtaining at least one image from said array of sensor elements,
- determining the in-focus position(s) of:
  - each of a plurality of the sensor elements for a sequence of focus plane positions, or
  - each of a plurality of groups of the sensor elements for a sequence of focus plane positions.

There may be for example more than 200 focus plane images, such as 225 focus plane images, in a sequence of focus plane images used in generating a 3D surface. The focus plane images are 2D images.

Image sensor(s), photo sensor and the like can be used for acquiring images in the scanner. By scanning is generally meant optical scanning or imaging using laser light, white light etc.

In some embodiments a sequence of focus plane images are depth images captured along the direction of the optical axis.

In some embodiments at least a part of the object is in focus in at least one of the focus plane images in a sequence of focus plane images.

In some embodiments the time period between acquisition of each focus plane image is fixed/predetermined/known.

Each focus plane image may be acquired a certain time period after the previous focus plane image was acquired. The focus optics may move between the acquisition of each image, and thus each focus plane image may be acquired in a different distance from the object than the previous focus plane images.

One cycle of focus plane image capture may be from when the focus optics is in position P until the focus optics is again in position P. This cycle may be denoted a sweep. There may such as 15 sweeps per second.

A number of 3D surfaces or sub-scans may then be combined to create a full scan of the object for generating a 3D model of the object.

In some embodiments determining the relative motion of the scanner during the acquisition of the sequence of focus plane images is performed by analysis of the sequence in itself.

Motion detection by means of hardware

In some embodiments determining the relative motion of the scanner during the acquisition of the sequence of focus plane images is performed by sensors in and/or on the scanner and/or by sensors on the object and/or by sensors in the room where the scanner and the object are located.

The motion sensors may be small sensor such as microelectromechanical systems (MEMS) motion sensors. The motion sensors may measure all motion in 3D, i.e., both translations and rotations for the three principal coordinate axes. The benefits are:

- Motion sensors can detect motion, also vibrations and/or shaking. Scans such affected can e.g. be corrected by use of the compensation techniques described.

- Motion sensors can help with stitching and/or registering partial scans to each other. This advantage is relevant when the field of view of the scanner is smaller than the object to be scanned. In this situation, the scanner is applied for small regions of the object (one at a time) that then are combined to obtain the full scan. In the ideal case, motion sensors can provide the required relative rigid-motion transformation between partial scans' local coordinates, because they measure the relative position of the scanning device in each partial scan. Motion sensors with limited accuracy can still provide a first guess for a software-based stitching/ registration of partial scans based on, e.g., the Iterative Closest Point class of algorithms, resulting in reduced computation time.
Even if it is too inaccurate to sense translational motion, a 3-axis accelerometer can provide the direction of gravity relative to the scanning device. Also a magnetometer can provide directional information relative to the scanning device, in this case from the earth's magnetic field. Therefore, such devices can help with stitching/registration.

In some embodiments the motion is determined by means of a texture image sensor having a depth of focus which is larger than the depth of focus of the focusing optics.

In some embodiments the motion is determined by determining the position and orientation of one or more of the sensors.

In some embodiments the motion is determined by means of one or more physical components arranged in the handheld scanner.

In some embodiments the motion is determined by means of 3D position sensors.

In some embodiments the motion is determined by means of optical tracking. The optical tracking may comprise LED(s) and camera(s), where the LED(s) may flash and the flashing can be detected by the camera(s).

In some embodiments the motion is determined by means of one or more gyroscopes.

A gyroscope is a device for measuring or maintaining orientation, based on the principles of conservation of angular momentum. A mechanical gyroscope is essentially a spinning wheel or disk whose axle is free to take any orientation. The gyroscopes used to determine the orientation of the sensor may be mechanical gyroscopes, electronic, microchip-packaged MEMS gyroscope devices, solid state ring lasers, fibre optic gyroscopes, quantum gyroscope and/or the like.

In some embodiments the motion is determined by means of one or more accelerometers.

In some embodiments the motion is determined by means of one or more magnetometers.

In some embodiments the motion is determined by means of one or more electromagnetic coils.

In some embodiments the motion is determined by means of a computerized measurement arm.

The measurement arm may for instance be from FARO Technologies. There may be goniometers in the measurement arm for measuring the movements of the arm.

In some embodiments the motion is determined by means of one or more axes on which the sensor is configured to move.

An example of an axes based system is a coordinate measuring machine (CMM), which is a device for measuring the physical geometrical characteristics of an object. This machine may be computer controlled. A typical CMM is composed of three axes, X, Y and Z, and these axes are orthogonal to each other in a typical three dimensional coordinate system. Each axis has a scale system that indicates the location of that axis. Measurements may be defined by a probe attached to the third moving axis of this machine, and the machine will read the input from the touch probe. Probes may be mechanical, optical, laser, or white light, among others.

In some embodiments the axes on which the sensor is configured to move are translational and / or rotational axes.

For each focus plane image that is acquired there is six degrees of freedom of the sensor, e.g. the handheld scanner, since the scanner is a rigid body which can perform motion in a three dimensional space, where the motion can be translation in three perpendicular axes, x, y, z, which is movement forward/backward, up/down, left/right, and this is combined with rotation about the three perpendicular axes. Thus the motion has six degrees of freedom as the movement along each of the three axes is independent of each other and independent of the rotation about any of these axes.

3D modeling

3D modeling is the process of developing a mathematical, wireframe representation of any three-dimensional object, called a 3D model, via specialized software. Models may be created automatically, e.g. 3D models may be created using multiple approaches, such as use of NURBS curves to generate accurate and smooth surface patches, polygonal mesh modeling

which is a manipulation of faceted geometry, or polygonal mesh subdivision which is advanced tessellation of polygons, resulting in smooth surfaces similar to NURBS models.

Obtaining a three dimensional representation of the surface of an object by scanning the object in a 3D scanner can be denoted 3D modeling, which is the process of developing a mathematical representation of the three-dimensional surface of the object via specialized software. The product is called a 3D model. A 3D model represents the 3D object using a collection of points in 3D space, connected by various geometric entities such as triangles, lines, curved surfaces, etc. The purpose of a 3D scanner is usually to create a point cloud of geometric samples on the surface of the object.
3D scanners collect distance information about surfaces within its field of view. The "picture" produced by a 3D scanner may describe the distance to a surface at each point in the picture.
For most situations, a single a scan or sub-scan will not produce a complete model of the object. Multiple sub-scans, such as 5, 10, 12, 15, 20, 30, 40, 50, 60, 70, 80, 90 or in some cases even hundreds, from many different directions may be required to obtain information about all sides of the object. These sub-scans are brought in a common reference system, a process that may be called alignment or registration, and then merged to create a complete model.

3D scanners may be fixed or stationary desktop scanners into which for example a dental impression, an ear canal impression or a casted gypsum model of teeth can be placed for scanning. 3D scanners may also be handheld intraoral scanners for scanning a patient directly in the mouth or handheld or fixed ear scanners for scanning a patient directly in the ear.

Thus a 3D scanner may be a handheld scanner where scanner and object are not arranged stationary relative to each other and where the relative motion may be unlimited, a desktop scanner where the object and the

scanning means, e.g. light source and camera, are arranged stationary relative to each other, a stationary scanner where the object for example can move relative to the stationary scanner etc.

A triangulation 3D laser scanner uses laser light to probe the environment or object. A triangulation laser shines a laser on the object and exploits a camera to look for the location of the laser dot. Depending on how far away the laser strikes a surface, the laser dot appears at different places in the camera's field of view. This technique is called triangulation because the laser dot, the camera and the laser emitter form a triangle. A laser stripe, instead of a single laser dot, may be used and is then swept across the object to speed up the acquisition process.

Structured-light 3D scanners project a pattern of light on the object and look at the deformation of the pattern on the object. The pattern may be one dimensional or two dimensional. An example of a one dimensional pattern is a line. The line is projected onto the object using e.g. an LCD projector or a sweeping laser. A camera, offset slightly from the pattern projector, looks at the shape of the line and uses a technique similar to triangulation to calculate the distance of every point on the line. In the case of a single-line pattern, the line is swept across the field of view to gather distance information one strip at a time.

An example of a two-dimensional pattern is a grid or a line stripe pattern. A camera is used to look at the deformation of the pattern, and an algorithm is used to calculate the distance at each point in the pattern. Algorithms for multistripe laser triangulation may be used.

Confocal scanning or focus scanning may also be used, where in-focus images are acquired at different depth to reconstruct the 3D model.

Iterative Closest Point (ICP) is an algorithm employed to minimize the difference between two clouds of points. ICP can be used to reconstruct 2D or 3D surfaces from different scans or sub-scans. The algorithm is

conceptually simple and is commonly used in real-time. It iteratively revises the transformation, i.e. translation and rotation, needed to minimize the distance between the points of two raw scans or sub-scans. The inputs are: points from two raw scans or sub-scans, initial estimation of the transformation, criteria for stopping the iteration. The output is: refined transformation. Essentially the algorithm steps are:

1. Associate points by the nearest neighbor criteria.
2. Estimate transformation parameters using a mean square cost function.
3. Transform the points using the estimated parameters.
4. Iterate, i.e. re-associate the points and so on.

Aligning/registration

In some embodiments the motion between at least two subsequent 3D surfaces are determined by aligning/registering the at least two subsequent 3D surfaces.

This may be performed by means of the method of iterative closest point (ICP) or similar methods. The method of Iterative Closest Point (ICP) can be used for aligning, and it is employed to minimize the difference between two clouds of points. ICP can be used to reconstruct 2D or 3D surfaces from different scan. ICP iteratively revises the transformation, i.e. translation or rotation, needed to minimize the distance between the points of two raw scans or subscans. The input for ICP may be points from two raw scans or subscans, initial estimation of the transformation, and criteria for stopping the iteration. The output will thus be a refined transformation.

The alignment may be performed in two steps, where the first step is a subscan to subscan alignment, and the second step is a subscan to provisional virtual 3D model (combined model) alignment. The start guess for

the alignment may be determined by using the gyroscopes, estimated speed of the scanner etc.

Additionally and/or alternatively, the method of least squares fit can be used in alignment.

In some embodiments aligning/registering is performed by selecting corresponding points on the at least two 3D surfaces, and minimizing the distance between the at least two 3D surfaces.
Corresponding points may the closest points on two surfaces, or point determined by a normal vector from a point on the other surface etc
The distance may be minimized with regards to translation and rotation.

In some embodiments aligning/registration is continued in an iterative process to obtain an improved motion estimation.

In some embodiments the sensor position of each sequence is determined based on the alignment.

In some embodiments aligning comprises aligning the coordinate systems of at least two 3D surfaces.

In some embodiments aligning comprises aligning by means of matching / comparing one or more specific features, such as one or more specific features common to the at least two 3D surfaces, such as the margin line.

In some embodiments aligning comprises aligning by means of matching / comparing one or more peripheral features of the at least two 3D surfaces.

In some embodiments aligning comprises registration of the at least two 3D surfaces.

In some embodiments aligning comprises applying a predefined criterion for maximum allowed error in the registration.

In some embodiments the motion compensation comprises reconstructing a self-consistent surface model and motion and/or rotation of the scanner relative to the object from two or more scans of the object where two successive scans overlap at least partially.

Focus scanning

The 3D scanner may be used for providing a 3D surface registration of objects using light as a non-contact probing agent. The light may be provided in the form of an illumination pattern to provide a light oscillation on the object. The variation / oscillation in the pattern may be spatial, e.g. a static checkerboard pattern, and/or it may be time varying, for example by moving a pattern across the object being scanned. The invention provides for a variation of the focus plane of the pattern over a range of focus plane positions while maintaining a fixed spatial relation of the scanner and the object. It does not mean that the scan must be provided with a fixed spatial relation of the scanner and the object, but merely that the focus plane can be varied (scanned) with a fixed spatial relation of the scanner and the object. This provides for a hand held scanner solution based on the present invention.

In some embodiments the signals from the array of sensor elements are light intensity.

One embodiment of the invention comprises a first optical system, such as an arrangement of lenses, for transmitting the probe light towards the object and a second optical system for imaging light returned from the object to the camera. In the preferred embodiment of the invention only one optical system

images the pattern onto the object and images the object, or at least a part of the object, onto the camera, preferably along the same optical axis, however along opposite optical paths.

In the preferred embodiment of the invention an optical system provides an imaging of the pattern onto the object being probed and from the object being probed to the camera. Preferably, the focus plane is adjusted in such a way that the image of the pattern on the probed object is shifted along the optical axis, preferably in equal steps from one end of the scanning region to the other. The probe light incorporating the pattern provides a pattern of light and darkness on the object. Specifically, when the pattern is varied in time for a fixed focus plane then the in-focus regions on the object will display an oscillating pattern of light and darkness. The out-of-focus regions will display smaller or no contrast in the light oscillations.

Generally we consider the case where the light incident on the object is reflected diffusively and/or specularly from the object's surface. But it is understood that the scanning apparatus and method are not limited to this situation. They are also applicable to e.g. the situation where the incident light penetrates the surface and is reflected and/or scattered and/or gives rise to fluorescence and/or phosphorescence in the object. Inner surfaces in a sufficiently translucent object may also be illuminated by the illumination pattern and be imaged onto the camera. In this case a volumetric scanning is possible. Some planktic organisms are examples of such objects.

When a time varying pattern is applied a single sub-scan can be obtained by collecting a number of 2D images at different positions of the focus plane and at different instances of the pattern. As the focus plane coincides with the scan surface at a single pixel position, the pattern will be projected onto the surface point in-focus and with high contrast, thereby giving rise to a large variation, or amplitude, of the pixel value over time. For each pixel it is thus

possible to identify individual settings of the focusing plane for which each pixel will be in focus. By using knowledge of the optical system used, it is possible to transform the contrast information vs. position of the focus plane into 3D surface information, on an individual pixel basis.

Thus, in one embodiment of the invention the focus position is calculated by determining the light oscillation amplitude for each of a plurality of sensor elements for a range of focus planes.

For a static pattern a single sub-scan can be obtained by collecting a number of 2D images at different positions of the focus plane. As the focus plane coincides with the scan surface, the pattern will be projected onto the surface point in-focus and with high contrast. The high contrast gives rise to a large spatial variation of the static pattern on the surface of the object, thereby providing a large variation, or amplitude, of the pixel values over a group of adjacent pixels. For each group of pixels it is thus possible to identify individual settings of the focusing plane for which each group of pixels will be in focus. By using knowledge of the optical system used, it is possible to transform the contrast information vs. position of the focus plane into 3D surface information, on an individual pixel group basis.

Thus, in one embodiment of the invention the focus position is calculated by determining the light oscillation amplitude for each of a plurality of groups of the sensor elements for a range of focus planes.

The 2D to 3D conversion of the image data can be performed in a number of ways known in the art. I.e. the 3D surface structure of the probed object can be determined by finding the plane corresponding to the maximum light oscillation amplitude for each sensor element, or for each group of sensor elements, in the camera's sensor array when recording the light amplitude for a range of different focus planes. Preferably, the focus plane is adjusted in

equal steps from one end of the scanning region to the other. Preferably the focus plane can be moved in a range large enough to at least coincide with the surface of the object being scanned.

The scanner preferably comprises at least one beam splitter located in the optical path. For example, an image of the object may be formed in the camera by means of a beam splitter. Exemplary uses of beam splitters are illustrated in the figures.

In a preferred embodiment of the invention light is transmitted in an optical system comprising a lens system. This lens system may transmit the pattern towards the object and images light reflected from the object to the camera.

In a telecentric optical system, out-of-focus points have the same magnification as in-focus points. Telecentric projection can therefore significantly ease the data mapping of acquired 2D images to 3D images. Thus, in a preferred embodiment of the invention the optical system is substantially telecentric in the space of the probed object. The optical system may also be telecentric in the space of the pattern and camera.

The present invention relates to different aspects including the method described above and in the following, and corresponding methods, devices, apparatuses, systems, uses and/or product means, each yielding one or more of the benefits and advantages described in connection with the first mentioned aspect, and each having one or more embodiments corresponding to the embodiments described in connection with the first mentioned aspect and/or disclosed in the appended claims.

In particular, disclosed herein is a system for detecting a movable object in a location, when scanning a rigid object in the location by means of a 3D

scanner for generating a virtual 3D model of the rigid object, wherein the system comprises:

- means for providing a first 3D representation of at least part of a surface by scanning at least part of the location;
- means for providing a second 3D representation of at least part of the surface by scanning at least part of the location;
- means for determining for the first 3D representation a first excluded volume in space where no surface can be present;
- means for determining for the second 3D representation a second excluded volume in space where no surface can be present;
- means for disregarding the portion of the surface in the first 3D representation in the generation of the virtual 3D model, if a portion of the surface in the first 3D representation is located in space in the second excluded volume, and/or
- means for disregarding the portion of the surface in the second 3D representation in the generation of the virtual 3D model, if a portion of the surface in the second 3D representation is located in space in the first excluded volume.

Furthermore, the invention relates to a computer program product comprising program code means for causing a data processing system to perform the method according to any of the embodiments, when said program code means are executed on the data processing system, and a computer program product, comprising a computer-readable medium having stored there on the program code means.

Brief description of the drawings

The above and/or additional objects, features and advantages of the present invention, will be further elucidated by the following illustrative and non-limiting detailed description of embodiments of the present invention, with reference to the appended drawings, wherein:

Fig. 1 shows an example of a flowchart of the method for detecting a movable object in a location, when scanning a rigid object in the location by means of a 3D scanner for generating a virtual 3D model of the rigid object.

Fig. 2 shows an example of a scan head of an intraoral 3D scanner scanning a set of teeth.

Fig. 3 shows an example of a handheld 3D scanner.

Fig. 4 shows an example of a section of teeth in the mouth which can be covered in a sub-scan.

Fig. 5 shows an example of how the different sub-scans generating 3D surfaces are distributed across a set of teeth.

Fig. 6 shows an example of registering/aligning representations of 3D surfaces and compensating for motion in a 3D surface.

Fig. 7 shows an example of a 3D surface where overlapping sub-scans are indicated.

Fig. 8 shows an example of excluded volume.

Fig. 9 shows an example of scanning a tooth and acquiring a first and a second representation of the surface of the tooth, where no movable object is present.

Fig. 10 shows an example of scanning a tooth and acquiring a first and a second representation of the surface of the tooth, where a movable object is captured in part of the first representation.

Fig. 11 shows an example of scanning a tooth and acquiring a first and a second representation of the surface of the tooth, where a movable object is captured in the second representation.

Fig. 12 shows an example of acquiring a first and a second representation of the surface of an object, e.g. a tooth, where a movable object is captured in the first representation.

Fig. 13 shows an example of acquiring a first and a second representation of a surface of an object, where no movable object is present.

Fig. 14 shows an example of acquiring a first and a second representation of a surface of an object, where a movable object of the second representation is present in the excluded volume of the first representation.

Fig. 15 shows an example of acquiring a first and a second representation of a surface of an object, where a possible movable object is present in the second representation, but not in the excluded volume of the first representation.

Fig. 16 shows an example of a near threshold distance defining how far from the representation possible movable objects are disregarded in the generation of the virtual 3D model.

Fig. 17 shows an example of how the excluded volume is determined.

Fig. 18 shows examples of how movable objects can look in subscans.

Fig. 19 shows an example of a pinhole scanner.

Fig. 20 shows examples of the principle of a far threshold distance from the captured surface defining a volume which is not included in the excluded volume of a representation.

Detailed description

In the following description, reference is made to the accompanying figures, which show by way of illustration how the invention may be practiced.

Figure 1 shows an example of a flowchart of the method for detecting a movable object in a location, when scanning a rigid object in the location by means of a 3D scanner for generating a virtual 3D model of the rigid object.
In step 101 a first 3D representation of at least part of a surface is provided by scanning at least part of the location.
In step 102 a second 3D representation of at least part of the surface is provided by scanning at least part of the location.
In step 103 a first excluded volume in space where no surface can be present is determined for the first 3D representation.
In step 104 a second excluded volume in space where no surface can be present is determined for the second 3D representation.
In step 105 a portion of the surface in the first 3D representation is disregarded in the generation of the virtual 3D model, if the portion of the surface in the first 3D representation is located in space in the second excluded volume, and/or a portion of the surface in the second 3D representation is disregarded in the generation of the virtual 3D model, if the

portion of the surface in the second 3D representation is located in space in the first excluded volume.

Fig. 2 shows an example of a scan head of an intraoral 3D scanner scanning a set of teeth.

An intraoral handheld 3D scanner (not shown) comprising a scan head 207 is scanning a tooth 208. The scanning is performed by transmitting light rays on the tooth 208. The light rays forms a scan volume 211, which is cone shaped in this example.

The length 203 of the scan volume 211, i.e. the distance from the opening 202 of the scan head to the end of the scan volume may be for example about 5 mm, 10 mm, 15 mm, 16 mm, 17 mm, 18 mm, 19 mm, 20 mm, 25 mm, 30 mm.

The scan volume may be about 20 mm x 20 mm.

Fig. 3 shows an example of a handheld 3D scanner.

The handheld scanner 301 comprises a light source 302 for emitting light, a beam splitter 304, movable focus optic 305, such as lenses, an image sensor 306, and a tip or probe 307 for scanning an object 308. In this example the object 308 is teeth in an intra oral cavity.

The scanner comprises a scan head or tip or probe 307 which can be entered into a cavity for scanning an object 308. The light from the light source 302 travels back and forth through the optical system. During this passage the optical system images the object 308 being scanned onto the image sensor 306. The movable focus optics comprises a focusing element which can be adjusted to shift the focal imaging plane on the probed object 308. One way to embody the focusing element is to physically move a single lens element back and forth along the optical axis. The device may include polarization optics and/or folding optics which directs the light out of the device in a direction different to the optical axis of the lens system, e.g. in a

direction perpendicular to the optical axis of the lens system. As a whole, the optical system provides an imaging onto the object being probed and from the object being probed to the image sensor, e.g. camera. One application of the device could be for determining the 3D structure of teeth in the oral cavity. Another application could be for determining the 3D shape of the ear canal and the external part of the ear.

The optical axis in fig. 3 is the axis defined by a straight line through the light source, optics and the lenses in the optical system. This also corresponds to the longitudinal axis of the scanner illustrated in fig. 3. The optical path is the path of the light from the light source to the object and back to the camera. The optical path may change direction, e.g. by means of beam splitter and folding optic.

The focus element is adjusted in such a way that the image on the scanned object is shifted along the optical axis, for example in equal steps from one end of the scanning region to the other. A pattern may be imaged on the object, and when the pattern is varied in time in a periodic fashion for a fixed focus position then the in-focus regions on the object will display a spatially varying pattern. The out-of-focus regions will display smaller or no contrast in the light variation. The 3D surface structure of the probed object may be determined by finding the plane corresponding to an extremum in the correlation measure for each sensor in the image sensor array or each group of sensor in the image sensor array when recording the correlation measure for a range of different focus positions. Preferably one would move the focus position in equal steps from one end of the scanning region to the other. The distance from one end of the scanning region to the other may be such as 5 mm, 10 mm, 15 mm, 16 mm, 20 mm, 25 mm, 30 mm etc.

Fig. 4 shows an example of a section of teeth in the mouth which can be covered in a sub-scan.

In fig. 4a) the teeth 408 are seen in a top view, and in fig. 4b) the teeth 408 are seen in a perspective view.

An example of the scan volume 411 for one sequence of focus plane images is indicated by the transparent box. The scan volume may be such as 17x15x20 mm, where the 15 mm may be the "height" of the scan volume corresponding to the distance the focus optics can move.

Fig. 5 shows an example of how the different sub-scans generating 3D surfaces is distributed across a set of teeth.

Four sub-scans 512 are indicated on the figure. Each sub-scan provides a 3D surface of the scanned teeth. The 3D surfaces may be partly overlapping, whereby a motion of the scanner performed during the acquisition of the sub-scans can be determined by comparing the overlapping parts of two or more 3D surfaces.

Fig. 6 shows an example of registering/aligning representations of 3D surfaces and compensating for motion in a 3D surface.

Fig. 6a) shows a 3D surface 616, which for example may be generated from a number of focus plane images.

Fig. 6b) shows another 3D surface 617, which may have been generated in a subsequent sequence of focus plane images.

Fig. 6c) shows the two 3D surface 616, 617 are attempted to be aligned/registered. Since the two 3D surfaces 616, 617 have 3D points which correspond to the same area of a tooth, it is possible to perform the registration/alignment by ICP, by comparing the corresponding points in the two 3D surfaces etc.

Fig. 6d) shows the resulting 3D surface 618 when the two 3D surfaces 616, 617 have been merged together.

Fig 6e) shows that based on the resulting 3D surface 618 the relative motion performed by the scanner during the acquisition of the sub-scans or focus plane images generating 3D surface 616 and 617 can be determined, and

based on this determined motion the resulting 3D surface 618 can be corrected to a final "correct" 3D surface 619.

Fig. 7 shows an example of a 3D surface where overlapping sub-scans are indicated.

A number of 3D representations or sub-scans are indicated by the numbers 1-11 and the subdivision markers 712 on a 3D surface 713. The subdivision markers 712 for sub-scans 1, 3, 5, 7, 9, and 11 are with dotted lines, and the subdivision markers for sub-scan 2, 4, 6, 8, 10 are marked with full lines. The sub-scans are all overlapping with the same distance, but the overlapping distance may be different for each pair of subscans. As typically a dentist will hold the scanner and move it across the teeth of the patient, the overlapping distance depends on how fast the dentist moves the scanner and the time frame between the acquisition of each scan, so if the time frame is constant, and the dentist does not move the scanner exactly with a constant speed, the overlapping distance will not be the same for all subscans.

Fig. 8 shows an example of excluded volume.

The excluded volume 821 is the volume in space where no surface can be present. At least a part of the excluded volume 821 may correspond to the scan volume 811 of a 3D representation, since the space between the scan head 807 or the focusing optics of the 3D scanner and the captured surface 816 must be an empty space, unless a transparent object, which is not detectable by the 3D scanner, was located in the scan volume. Furthermore the volume of the scan head 807 and the 3D scanner 801 may be defined as an excluded volume 823, since the scanner and scan head occupies their own volume in space, whereby no surface can be present there. Furthermore, the tooth 808 which is being scanned also occupies a volume in space, but since the surface 816 of the tooth 808 is being captured by the scanner, it is not considered what is "behind" the surface 816.

Fig. 9 shows an example of scanning a tooth and acquiring a first and a second representation of the surface of the tooth, where no movable object is present.

Fig. 9a) shows an example of scanning the tooth 908 using a 3D scanner 901 for acquiring a first 3D representation 916 of the surface of the tooth 908. A first scan volume 911 in space is related to the first representation, and a first excluded volume 921 corresponds to the first scan volume 911.

Fig. 9b) shows an example of scanning the tooth 908 using a 3D scanner 901 for acquiring a second 3D representation 917 of the surface of the tooth 908. A second scan volume 912 in space is related to the second representation, and a second excluded volume 922 corresponds to the second scan volume 912. The second representation is acquired with a different angle between scanner and tooth than the first representation.

No surface portion of the first representation 916 lies in the second excluded volume 922, and no surface portion of the second representation 917 lies in the first excluded volume 921, so no surface portion(s) are disregarded in the generation of the virtual 3D model in this case.

Fig. 10 shows an example of scanning a tooth and acquiring a first and a second representation of the surface of the tooth, where a movable object is captured in part of the first representation.

Fig. 10a) shows an example of scanning the tooth 1008 using a 3D scanner 1001 for acquiring a first 3D representation 1016 of the surface of the tooth 1008. A movable object 1030 is present, and a part 1016b of the first representation 1016 comprises the surface of the movable object 1030. The part 1016a of the first representation 1016 comprises the surface of the tooth. A first scan volume 1011 in space is related to the first representation, and a first excluded volume 1021 corresponds to the first scan volume 1011.

Fig. 10b) shows an example of scanning the tooth 1008 using a 3D scanner 1001 for acquiring a second 3D representation 1017 of the surface of the tooth 1008. A second scan volume 1012 in space is related to the second

representation, and a second excluded volume 1022 corresponds to the second scan volume 1012. The second representation is acquired with a different angle between scanner and tooth than the first representation.
Since the surface portion 1016b of the first representation 1016 lies in the second excluded volume 1022, this surface portion 1016b is disregarded in the generation of the virtual 3D model.

Fig. 11 shows an example of scanning a tooth and acquiring a first and a second representation of the surface of the tooth, where a movable object is captured in the second representation.
Fig. 11a) shows an example of scanning the tooth 1108 using a 3D scanner 1101 for acquiring a first 3D representation 1116 of the surface of the tooth 1108. A first scan volume 1111 in space is related to the first representation, and a first excluded volume 1121 corresponds to the first scan volume 1111.
Fig. 11b) shows an example of scanning the tooth 1108 using a 3D scanner 1101 for acquiring a second 3D representation 1117 of the surface of the tooth 1108. A movable object 1130 is present, and the second representation 1117 comprises the surface of the movable object 1130. A second scan volume 1112 in space is related to the second representation, and a second excluded volume 1122 corresponds to the second scan volume 1112. The second representation is acquired with a different angle between scanner and tooth than the first representation.
Since the surface of the second representation 1117 lies in the first excluded volume 1121, the surface of the second representation 1117 is disregarded in the generation of the virtual 3D model.
The figures in fig. 11 are shown in 2D, but it is understood that the figures represent 3D figures.

Fig. 12 shows an example of acquiring a first and a second representation of the surface of an object, e.g. a tooth, where a movable object is captured in the first representation.

Fig. 12a) shows a first 3D representation 1216 comprising two parts, part 1216a and part 1216b. The first scan volume 1211 is indicated by the vertical lines. The first excluded volume 1221 corresponds to the first scan volume.

Fig. 12b) shows a second 3D representation 1217. The second scan volume 1212 is indicated by the vetical lines. The second excluded volume 1222 corresponds to the second scan volume.

The part 1216a of the first representation 1216 corresponds to the first part of the second representation 1217, whereas the part 1216b of the second representation 1216 does not correspond to the second part of the second representation 1217.

The part 1216b of the first representation 1216 lies in the second excluded volume 1222, and the part 1216b is therefore disregarded in the generation of the virtual 3D model

Fig. 12c) shows the resulting 3D representation 1219, which corresponds to the second representation.

The figures in fig. 12 are shown in 2D, but it is understood that the figures represent 3D figures.

Fig. 13 shows an example of acquiring a first and a second representation of a surface of an object, where no movable object is present.

Fig. 13a) shows an example of acquiring a first 3D representation 1316 of a surface of an object (not shown). A first scan volume 1311 in space is related to the first representation. The first scan volume 1311 is indicated by dotted vertical lines. A first excluded volume 1321 corresponds to the first scan volume 1311.

Fig. 13b) shows an example of acquiring a second 3D representation 1317 of a surface of an object (not shown). A second scan volume 1312 in space is related to the second representation. The second scan volume 1312 is indicated by dotted vertical lines. A second excluded volume 1322 corresponds to the second scan volume 1312.

The second representation is acquired with a different angle between scanner and tooth than the first representation. Furthermore, the second representation is displaced in space relative to the first representation, so the first and second representation does not represent the same entire surface part of the object, but parts of the representations are overlapping.

Fig. 13c) shows an example where the first representation 1316 and the second representation 1317 are aligned/registered, such that the corresponding parts of the representations are arranged in the same location.

Fig. 13d) shows an example where the overlapping common scan volume 1340 of the first representation 1316 and the second representation 1317 is indicated as a shaded area. If a surface portion of one of the representations is located in the overlapping common scan volume 1340, then this corresponds to that the surface portion is located in the excluded volume of the other representation. However, in this case, no surface portion of the first representation 1316 or of the second representation 1317 lies in the overlapping common scan volume 1340, so no surface portion(s) are disregarded in the generation of the virtual 3D model in this case.

In order to be able to distinguish between the surface of the first and the surface of the second representation, these two surfaces are slightly displaced, but in a real case the surface of the first and the surface of the second representation may be exactly overlapping each other, so that the surface part from the first representation and the surface part from the second representation cannot be distinguished.

Fig. 13e) shows an example of the resulting virtual 3D surface 1319.

The figures in fig. 13 are shown in 2D, but it is understood that the figures represent 3D figures.

Fig. 14 shows an example of acquiring a first and a second representation of a surface of an object, where a movable object of the second representation is present in the excluded volume of the first representation.

Fig. 14a) shows an example of acquiring a first 3D representation 1416 of a surface of an object (not shown). A first scan volume 1411 in space is related to the first representation. The first scan volume 1411 is indicated by dotted vertical lines. A first excluded volume 1421 corresponds to the first scan volume 1411.

Fig. 14b) shows an example of acquiring a second 3D representation 1417 of a surface of an object (not shown). A second scan volume 1412 in space is related to the second representation. The second scan volume 1412 is indicated by dotted vertical lines. A second excluded volume 1422 corresponds to the second scan volume 1412. The second 3D representation 1417 comprises two parts 1417a and 1417b. The part 1417b is located between the part 1417a and the scanner (not shown), which is arranged somewhere at the end of the scan volume.

The second representation is acquired with a different angle between scanner and tooth than the first representation. Furthermore, the second representation is displaced in space relative to the first representation, so the first and second representation does not represent the same entire surface part of the object, but parts of the representations are overlapping.

Fig. 14c) shows an example where the first representation 1416 and the second representation 1417 are aligned/registered, such that the corresponding parts of the representations are arranged in the same location. Some of the part 1417a of the second representation is aligned/registered with the first representation. The part 1417b cannot be aligned/registered with the first representation 1416, since there is no corresponding surface portions between the surface 1416 and the surface 1417b.

Fig. 14d) shows an example where the overlapping common scan volume 1440 of the first representation 1416 and the second representation 1417 is indicated as a shaded area. The surface portion 1417b of the second representation is located in the overlapping common scan volume 1440, and the surface portion 1417b of the second representation 1417 is therefore located in the excluded volume 1421 of the first representation 1416, and

part 1417b must therefore be a movable object, which is only present in the second representation.

In order to be able to distinguish between the surface of the first and the surface of the second representation, these two surfaces are slightly displaced, but in a real case the surface of the first and the surface of the second representation may be exactly overlapping each other, so that the surface part from the first representation and the surface part from the second representation cannot be distinguished.

Fig. 14e) shows an example of the resulting virtual 3D surface 1419, where the surface portion 1417b is disregarded in the generation of the virtual 3D model, so the virtual 3D model comprises the first representation 1416 and the part 1417a of the second representation 1417.

The figures in fig. 14 are shown in 2D, but it is understood that the figures represent 3D figures.

Fig. 15 shows an example of acquiring a first and a second representation of a surface of an object, where a possible movable object is present in the second representation, but not in the excluded volume of the first representation.

Fig. 15a) shows an example of acquiring a first 3D representation 1516 of a surface of an object (not shown). A first scan volume 1511 in space is related to the first representation. The first scan volume 1511 is indicated by dotted vertical lines. A first excluded volume 1521 corresponds to the first scan volume 1511.

Fig. 15b) shows an example of acquiring a second 3D representation 1517 of a surface of an object (not shown). A second scan volume 1512 in space is related to the second representation. The second scan volume 1512 is indicated by dotted vertical lines. A second excluded volume 1522 corresponds to the second scan volume 1512. The second 3D representation 1517 comprises two parts 1517a and 1517b. The part 1517b is located

between the part 1517a and the scanner (not shown), which is arranged somewhere at the end of the scan volume.

The second representation 1517 is acquired with a different angle between scanner and tooth than the first representation 1516. Furthermore, the second representation is displaced in space relative to the first representation, so the first and second representation does not represent the same entire surface part of the object, but parts of the representations are overlapping.

Fig. 15c) shows an example where the first representation 1516 and the second representation 1517 are aligned/registered, such that the corresponding parts of the representations are arranged in the same location. Some of the part 1517a of the second representation is aligned/registered with the first representation 1516. The part 1517b cannot be aligned/registered with the first representation 1516, since there is no corresponding surface portions between the surface 1516 and the surface 1517b.

Fig. 15d) shows an example where the overlapping common scan volume 1540 of the first representation 1516 and the second representation 1517 is indicated as a shaded area. The surface portion 1517b of the second representation is not located in the overlapping common scan volume 1540, and the surface portion 1517b of the second representation 1517 is therefore not located in the excluded volume 1521 of the first representation 1516.

In order to be able to distinguish between the surface of the first and the surface of the second representation, these two surfaces are slightly displaced, but in a real case the surface of the first and the surface of the second representation may be exactly overlapping each other, so that the surface part from the first representation and the surface part from the second representation cannot be distinguished.

Fig. 15e) shows an example of the resulting virtual 3D surface 1519, where the surface portion 1517b is not disregarded in the generation of the virtual

3D model, so the virtual 3D model comprises the first representation 1516 and both parts, 1517a and 1517b, of the second representation 1517.

Even though the surface portion 1517b probably is the representation of a movable object, at least this would be assumed if the object in this case is a tooth, since a tooth is unlikely to have a protrusion like the part 1517b of the representation shows, the surface portion 1517b cannot be disregarded yet, because the surface portion 1517b is not found to be located in any excluded volume from any representation yet. But when the scanning of the object's surface continues, there will probably be acquired a third representation which has an overlapping common scan volume with the second representation, and if the surface portion 1517b is located in the excluded volume of the third representation, then the surface portion 1517b can be disregarded from the virtual 3D model.

The figures in fig. 15 are shown in 2D, but it is understood that the figures represent 3D figures.

Fig. 16 shows an example of a threshold distance defining how far from the representation or captured surface possible movable objects are disregarded in the generation of the virtual 3D model.

A near threshold distance 1650 is defined, which determines a distance from the captured surface 1616 in a first representation, where a surface portion in the second representation (not shown) which is located within the near threshold distance 1650 from the captured surface 1616 and which is located in space in the first excluded volume 1611 is not disregarded in the generation of the virtual 3D model.

The near threshold distance is defined for avoiding that too much of a representation of a surface is incorrectly disregarded, since there may be noise in the representation and since the registration/alignment between representations or sub-scans may not be completely accurate.

Reference numeral 1607 is the scan head of the scanner 1601, and reference numeral 1608 is the volume of the tooth.

The fig. 20 is shown in 2D, but it is understood that the figure represents 3D figures.

Fig. 17 shows an example of how the excluded volume is determined.

The space may be quantized in a 3D volume grid 1760. The distance 1762 between the corners 1761 in the 3D grid 1760 may be equidistant. The single cells 1763 in the grid each comprises eight corners 1761, and when each of the eight corners 1761 has been covered by a representation, then this cell 1763 is marked as seen. Thus if all eight corners 1761 of a cell 1763 is in the scan volume of a representation, then this cell 1763 may be marked as excluded volume. There may be such as ten, hundred, thousands or millions of cells in the space of a representation.

Fig. 18 shows examples of how movable objects can look in subscans.

Fig. 18a) shows a subscan where the tip of a finger 1870 has been captured in the subscan.

Fig. 18b) shows an example where a dental instrument 1871 has been captured in the subscan.

Fig. 19 shows an example of a pinhole scanner.

The pinhole scanner 1980 comprises a camera 1982 and a light source 1981, e.g. comprising a pattern (not shown). The light source 1981 transmits light rays 1983 to the surface 1916 from a small aperture, i.e. all the light rays 1983 transmitted to the surface 1961 are transmitted from a point. Light rays 1984 are reflected back from the surface 1961 and received by the camera 1982 through a small aperture.

Due to the pinhole setup, the point of light transmitted to the surface from the light source is well defined and the point of received light from the surface is also well defined.

Thus the excluded volume for a representation of the surface is defined by the volume in space that the light rays 1983 and 1984 span, and this volume is well defined due to the pinhole setup.

Fig. 20 shows examples of the principle of a far threshold distance from the captured surface defining a volume which is not included in the excluded volume of a representation.

The light rays 2052 (shown in dotted lines) from the scan head 2007 of the scanner 2001 may spread or scatter or disperse in any directions as seen in fig. 20a), where a number of the light rays are illustrated. It is understood that only some of all the light rays are shown here. The surface area on the tooth surface where the light rays impinge has reference numeral 2016.

In fig. 20b) it is shown that even if an object 2072, such as a movable object, is arranged between the scan head 2007 and the surface 2016 of a tooth, the scanner 2001 may still capture a surface point 2053 on the tooth surface 2016 which is present or hidden "under" the object 2072, because of the angled or inclined light rays 2052. A surface point 2053 needs just be visible for one light ray from the scanner in order for that surface point to be detected.

Fig. 20c) shows an example of the far threshold distance 2051, which determines a distance from the captured surface 2016 in a representation, where any acquired data or surface or surface points, which is/are present or located outside the far threshold distance 2051, is not included in the excluded volume for the representation. Thus any acquired data or surface or surface points in the volume 2054 between the far threshold distance 2051 and the scan head 2007 is not used in defining the excluded volume of the representation.

Fig. 20d) shows an example where defining the far threshold distance is an advantage for avoiding that real tooth surface parts are erroneously disregarded.

The scanner 2001 should in principle capture all surface parts, 2016 and 2017, present in the scan volume, but in some cases the scanner cannot capture all surface parts in the scan volume. This may happen for example because the surface part is present outside the focus region of the scanner 2001 or of the scan head 2007 or because of poor lightning conditions for the surface part. In such cases the surface part 2017 may not be captured and registered, and an excluded volume would be determined in the space region where the surface part 2017 of the tooth surface is actually present. By defining the far threshold distance 2051 less of the scan volume is excluded, and thereby it can be avoided that a real surface part 2017 is erroneously disregarded.

The actual distance of the threshold may depend or be calculated based on the optics of the scanner. The far threshold distance may be a fixed number, such as about 0.5 mm, 1 mm, 2 mm, 3 mm, 4 mm, 5 mm, 6 mm, 7 mm, 8 mm, 9 mm, 10 mm, 20 mm, 30 mm, 40 mm, 50 mm, 60 mm, 70 mm, 80 mm, 90 mm, or 100 mm. Alternatively, the far threshold distance may be a percentage or a fraction of the length of the scan volume, such as about 20%, 25%, 30%, 35%, 40%, 45%, or 50% of the length of the scan volume, or such as ½, 1/3, ¼, 1/5 of the length of the scan volume.

The far threshold distance may be based on a determination of how far a distance from a detected point of the surface it is possible to scan, i.e. how much of the surface around a detected point that is visible for the scanner. If the visible distance in one direction from a surface point is short, then the far threshold distance will be smaller than if the distance in all directions from a surface point is long.

The figures in fig. 20 are shown in 2D, but it is understood that the figures represent 3D figures.

Although some embodiments have been described and shown in detail, the invention is not restricted to them, but may also be embodied in other ways within the scope of the subject matter defined in the following claims. In

particular, it is to be understood that other embodiments may be utilised and structural and functional modifications may be made without departing from the scope of the present invention.

In device claims enumerating several means, several of these means can be embodied by one and the same item of hardware. The mere fact that certain measures are recited in mutually different dependent claims or described in different embodiments does not indicate that a combination of these measures cannot be used to advantage.

A claim may refer to any of the preceding claims, and "any" is understood to mean "any one or more" of the preceding claims.

It should be emphasized that the term "comprises/comprising" when used in this specification is taken to specify the presence of stated features, integers, steps or components but does not preclude the presence or addition of one or more other features, integers, steps, components or groups thereof.

The features of the method described above and in the following may be implemented in software and carried out on a data processing system or other processing means caused by the execution of computer-executable instructions. The instructions may be program code means loaded in a memory, such as a RAM, from a storage medium or from another computer via a computer network. Alternatively, the described features may be implemented by hardwired circuitry instead of software or in combination with software.

Claims:

1. A method for detecting a movable object in a location, when scanning a rigid object in the location by means of a 3D scanner for generating a virtual 3D model of the rigid object, wherein the method comprises:

- providing a first 3D representation of at least part of a surface by scanning at least part of the location;
- providing a second 3D representation of at least part of the surface by scanning at least part of the location;
- determining for the first 3D representation a first excluded volume in space where no surface can be present;
- determining for the second 3D representation a second excluded volume in space where no surface can be present;
- if a portion of the surface in the first 3D representation is located in space in the second excluded volume, the portion of the surface in the first 3D representation is disregarded in the generation of the virtual 3D model, and/or
- if a portion of the surface in the second 3D representation is located in space in the first excluded volume, the portion of the surface in the second 3D representation is disregarded in the generation of the virtual 3D model.

2. The method according to any one or more of the preceding claims, wherein the rigid object is a patient's set of teeth, and the location is the mouth of the patient.

3. The method according to any one or more of the preceding claims, wherein the movable object is a soft tissue part of the patient's mouth, such as the inside of a cheek, the tongue, lips, gums and/or loose gingival.

4. The method according to any one or more of the preceding claims, wherein the movable object is a dentist's instrument or remedy which is temporarily present in the patient's mouth, such as a dental suction device, cotton rolls, and/or cotton pads.

5. The method according to any one or more of the preceding claims, wherein the movable object is a finger, such as the dentist's finger or the dental assistant's finger.

6. The method according to any one or more of the preceding claims, wherein the 3D scanner is a scanner configured for acquiring scans of an object's surface for generating a virtual 3D model of the object.

7. The method according to any one or more of the preceding claims, wherein at least part of the surface captured in the first representation and at least part of the surface captured in the second representation are overlapping the same surface part on the rigid object.

8. The method according to any one or more of the preceding claims, wherein the first representation of at least part of the surface is defined as the first representation of at least a first part of the surface, and the second representation of at least part of the surface is defined as the second representation of at least a second part of the surface.

9. The method according to any one or more of the preceding claims, wherein the first part of the surface and the second part of the surface are at least partially overlapping.

10. The method according to any one or more of the preceding claims, wherein the surface is a surface in the location.

11. The method according to any one or more of the preceding claims, wherein the surface is at least part of the surface of the rigid object and/or at least part of the surface of the movable object.

12. The method according to any one or more of the preceding claims, wherein the method comprises determining a first scan volume in space related to the first representation of at least part of the surface, and determining a second scan volume in space related to the second representation of at least part of the surface.

13. The method according to any one or more of the preceding claims, wherein the scan volume is defined by the focusing optics in the 3D scanner and the distance to the surface which is captured.

14. The method according to any one or more of the preceding claims, wherein the first scan volume related to the first representation of at least part of the surface is the volume in space between the focusing optics of the 3D scanner and the surface captured in the first representation; and the second scan volume related to the second representation of at least part of the surface is the volume in space between the focusing optics of the 3D scanner and the surface captured in the second representation.

15. The method according to any one or more of the preceding claims, wherein if no surface is captured in at least part of the first or second representation, then the first or second scan volume is the volume in space between the focusing optics of the 3D scanner and the longitudinally extent of the scan volume.

16. The method according to any one or more of the preceding claims, wherein the first excluded volume and second excluded volume in space

where no surface can be present corresponds to the first scan volume and the second scan volume, respectively.

17. The method according to any one or more of the preceding claims, wherein the volume of the 3D scanner itself is defined as an excluded volume.

18. The method according to any one or more of the preceding claims, wherein the volume of the 3D scanner itself is comprised in the first excluded volume and in the second excluded volume.

19. The method according to any one or more of the preceding claims, wherein a near threshold distance is defined, which determines a distance from the captured surface in the first representation and the second representation, where a surface portion in the second representation or the first representation, respectively, which is located within the near threshold distance from the captured surface and which is located in space in the first excluded volume or in the second excluded volume, respectively, is not disregarded in the generation of the virtual 3D model.

20. The method according to any one or more of the preceding claims, wherein a far threshold distance is defined, which determines a distance from the captured surface, where the volume outside the far threshold distance is not included in the excluded volume of a representation.

21. The method according to any one or more of the preceding claims, wherein the first representation of at least part of a surface is a first subscan of at least part of the location, and the second representation of at least part of the surface is a second subscan of at least part of the location.

22. The method according to any one or more of the preceding claims, wherein the first representation of at least part of a surface is a provisional virtual 3D model comprising the subscans of the location acquired already, and the second representation of at least part of the surface is a second subscan of at least part of the location.

23. The method according to any one or more of the preceding claims, wherein acquired subscans of the location are adapted to be added to the provisional virtual 3D model concurrently with the acquisition of the subscans.

24. The method according to any one or more of the preceding claims, wherein the provisional virtual 3D model is termed as the virtual 3D model, when the scanning of the rigid object is finished.

25. The method according to any one or more of the preceding claims, wherein the method comprises:

- providing a third 3D representation of at least part of a surface by scanning at least part of the location;
- determine for the third 3D representation a third excluded volume in space where no surface can be present;
- if a portion of the surface in the first 3D representation is located in space in the third excluded volume, the portion of the surface in the first 3D representation is disregarded in the generation of the virtual 3D model, and/or
- if a portion of the surface in the second 3D representation is located in space in the third excluded volume, the portion of the surface in the second 3D representation is disregarded in the generation of the virtual 3D model, and/or
- if a portion of the surface in the third 3D representation is located in space in the first excluded volume and/or in the second excluded volume, the

portion of the surface in the third 3D representation is disregarded in the generation of the virtual 3D model.

26. The method according to any one or more of the preceding claims, wherein the provisional virtual 3D model comprises the first representation of at least part of the surface and the second representation of at least part of the surface, and where the third representation of at least part of the surface is added to the provisional virtual 3D model.

27. The method according to any one or more of the preceding claims, wherein the virtual 3D model is used for virtually designing a restoration for one or more of the patient's teeth.

28. The method according to any one or more of the preceding claims, wherein the virtual 3D model is used for virtually planning and designing an orthodontic treatment for the patient.

29. The method according to any one or more of the preceding claims, wherein the relative motion of the scanner and the rigid object is determined.

30. The method according to any one or more of the preceding claims, wherein the relative motion of the scanner and the rigid object is determined by means of motion sensors.

31. The method according to any one or more of the preceding claims, wherein the relative motion of the scanner and the rigid object is determined by registering/aligning the first representation and the second representation.

32. The method according to any one or more of the preceding claims, wherein the first representation and the second representation are

aligned/registered before the first excluded volume and the second excluded volume are determined.

33. The method according to any one or more of the preceding claims, wherein the relative motion of the scanner and the rigid object determined by means of the motions sensors is verified and potentially adjusted by registering/aligning the first representation and the second representation.

34. The method according to any one or more of the preceding claims, wherein motion sensors are used for an initial determination of the relative motion of the scanner and the rigid object, and where registering/aligning is used for the final determination of the relative motion of the scanner and the rigid object.

35. The method according to any one or more of the preceding claims, wherein the optical system of the scanner is telecentric.

36. The method according to any one or more of the preceding claims, wherein the optical system of the scanner is perspective.

37. The method according to any one or more of the preceding claims, wherein a mirror in a scan head of the scanner provides that the light rays from the light source in the scanner are transmitted with an angle relative to the opening of the scan head.

38. The method according to any one or more of the preceding claims, wherein the 3D scanner is a hand-held scanner.

39. The method according to any one or more of the preceding claims, wherein the scanner is a pinhole scanner.

40. The method according to any one or more of the preceding claims, wherein the scanner comprises an aperture, and where the size of the aperture is less than 1/100 of the distance between it and the projected image.

41. The method according to any one or more of the preceding claims, wherein the scanner comprises an aperture, and where the size of the aperture is more than 1/100 of the distance between it and the projected image.

42. A method for detecting movable objects in the mouth of a patient, when scanning the patient's set of teeth in the mouth by means of a 3D scanner for generating a virtual 3D model of the set of teeth, wherein the method comprises:

- providing a first 3D representation of at least part of a surface by scanning at least part of the teeth;
- providing a second 3D representation of at least part of the surface by scanning at least part of the teeth;
- determining for the first 3D representation a first excluded volume in space where no surface can be present;
- determining for the second 3D representation a second excluded volume in space where no surface can be present;
- if a portion of the surface in the first 3D representation is located in space in the second excluded volume, the portion of the surface in the first 3D representation is disregarded in the generation of the virtual 3D model, and/or
- if a portion of the surface in the second 3D representation is located in space in the first excluded volume, the portion of the surface in the second 3D representation is disregarded in the generation of the virtual 3D model.

43. A method for detecting a movable object in a location, when scanning a rigid object in the location by means of a 3D scanner for generating a virtual 3D model of the rigid object, wherein the method comprises:

- providing a first representation of at least part of a surface by scanning the rigid object;
- determining a first scan volume in space related to the first representation of at least part of the surface;
- providing a second representation of at least part of the surface by scanning the rigid object;
- determining a second scan volume in space related to the second representation of at least part of the surface;
- if there is a common scan volume, where the first scan volume and the second scan volume are overlapping, then:
    - determine whether there is a volume region in the common scan volume which in at least one of the first representation or the second representation is empty and comprises no surface; and
    - if there is a volume region in the common scan volume which in at least one of the first representation or the second representation is empty and comprises no surface, then exclude the volume region by disregarding in the generation of the virtual 3D model any surface portion in the second representation or in the first representation, respectively, which is detected in the excluded volume region, since a surface portion detected in the excluded volume region represents a movable object which is not part of the rigid object.

44. A method for detecting a movable object in a location, when scanning a rigid object in the location by means of a 3D scanner for generating a virtual 3D model of the rigid object, wherein the method comprises:

- providing a first surface by scanning the rigid object;
- determining a first scan volume related to the first surface;
- providing a second surface by scanning the rigid object;
- determining a second scan volume related to the second surface;

where the first scan volume and the second scan volume are overlapping in an overlapping/common scan volume;

- if at least a portion of the first surface and a portion of the second surface are not coincident in the overlapping/common scan volume, then disregard the portion of either the first surface or the second surface in the overlapping/common scan volume which is closest to the focusing optics of the 3D scanner, as this portion of the first surface or second surface represents a movable object which is not part of the rigid object.

45. A method for detecting a movable object in the mouth of the patient, when scanning the patient's set of teeth by means of a 3D scanner for generating a virtual 3D model of the set of teeth, wherein the method comprises:

- providing a first surface by scanning the set of teeth;
- determining a first scan volume related to the first surface;
- providing a second surface by scanning the set of teeth;
- determining a second scan volume related to the second surface;

where the first scan volume and the second scan volume are overlapping in an overlapping/common scan volume;

- if at least a portion of the first surface and a portion of the second surface are not coincident in the overlapping/common scan volume, then disregard the portion of either the first surface or the second surface in the overlapping/common scan volume which is closest to the focusing optics of the 3D scanner, as this portion of the first surface or second surface represents a movable object which is not part of the set of teeth.

46. A method for detecting movable objects recorded in subscans, when scanning a set of teeth by means of a scanner for generating a virtual 3D model of the set of teeth, where the virtual 3D model is made up of the already acquired subscans of the surface of the set of teeth, and where new subscans are adapted to be added to the 3D virtual model, when they are acquired, wherein the method comprises:

- acquiring at least a first subscan of at least a first surface of part of the set of teeth, where the at least first subscan is defined as the 3D virtual model;
- acquiring a first subscan of a first surface of part of the set of teeth;
- determining a first scan volume of the first subscan;
- determining a scan volume of the virtual 3D model;
- if the first scan volume of the first subscan and the scan volume of the virtual 3D model are at least partly overlapping in a common scan volume; then:
    - calculate whether at least a portion of the first surface lies within the common scan volume;
    - calculate whether at least a portion of the surface of the virtual 3D model lies within the common scan volume, and
    - determine whether at least a portion of a surface is present in the overlapping volume only in one subscan and not the other subscan/3D virtual model;
    - if at least a portion of a surface is present in only one subscan, then disregard the portion of the surface in the overlapping volume which is closest to the focusing optics of the scanner, since the portion of the surface represents a movable object which is not part of the set of teeth, and the portion of the surface is disregarded in the creation of the virtual 3D model of the set of teeth.

47. A method for detecting movable objects recorded in subscans, when scanning a set of teeth by means of a scanner for generating a virtual 3D model of the set of teeth, wherein the method comprises:

a) providing a first subscan of a first surface of part of the set of teeth;
b) calculating a first scan volume of the first subscan;
c) providing a second subscan of a second surface of part of the set of teeth;
d) calculating a second scan volume of the second subscan; and
e) if the first scan volume and the second scan volume are at least partly overlapping in a common scan volume; then:
f) calculate whether at least a portion of the first surface lies within the common scan volume;
g) calculate whether at least a portion of the second surface lies within the common scan volume, and
h) if at least a portion of the first surface or at least a portion of the second surface lie within the common scan volume, and the portion of the first surface or the portion of the second surface is located in space between the scanner and at least a portion of the second surface or at least a portion of the first surface, respectively;
then the portion of the surface represents a movable object which is not part of the set of teeth, and the portion of the surface is disregarded in the creation of the virtual 3D model of the set of teeth.

48. The method according to the previous claims, wherein the method further comprises:
- providing a third subscan of a third surface of part of the set of teeth;
- calculating a third scan volume of the third subscan;
- if the third scan volume is at least partly overlapping with the first scan volume and/or with the second scan volume in a common scan volume; then

repeat steps f) - h) for the third subscan with respect to the first subscan and/or the second subscan.

49. A computer program product comprising program code means for causing a data processing system to perform the method of any one or more of the preceding claims, when said program code means are executed on the data processing system.

50. A computer program product according to the previous claim, comprising a computer-readable medium having stored there on the program code means.

51. A system for detecting a movable object in a location, when scanning a rigid object in the location by means of a 3D scanner for generating a virtual 3D model of the rigid object, wherein the system comprises:

- means for providing a first 3D representation of at least part of a surface by scanning at least part of the location;
- means for providing a second 3D representation of at least part of the surface by scanning at least part of the location;
- means for determining for the first 3D representation a first excluded volume in space where no surface can be present;
- means for determining for the second 3D representation a second excluded volume in space where no surface can be present;
- means for disregarding the portion of the surface in the first 3D representation in the generation of the virtual 3D model, if a portion of the surface in the first 3D representation is located in space in the second excluded volume, and/or
- means for disregarding the portion of the surface in the second 3D representation in the generation of the virtual 3D model, if a portion of the

surface in the second 3D representation is located in space in the first excluded volume.

5

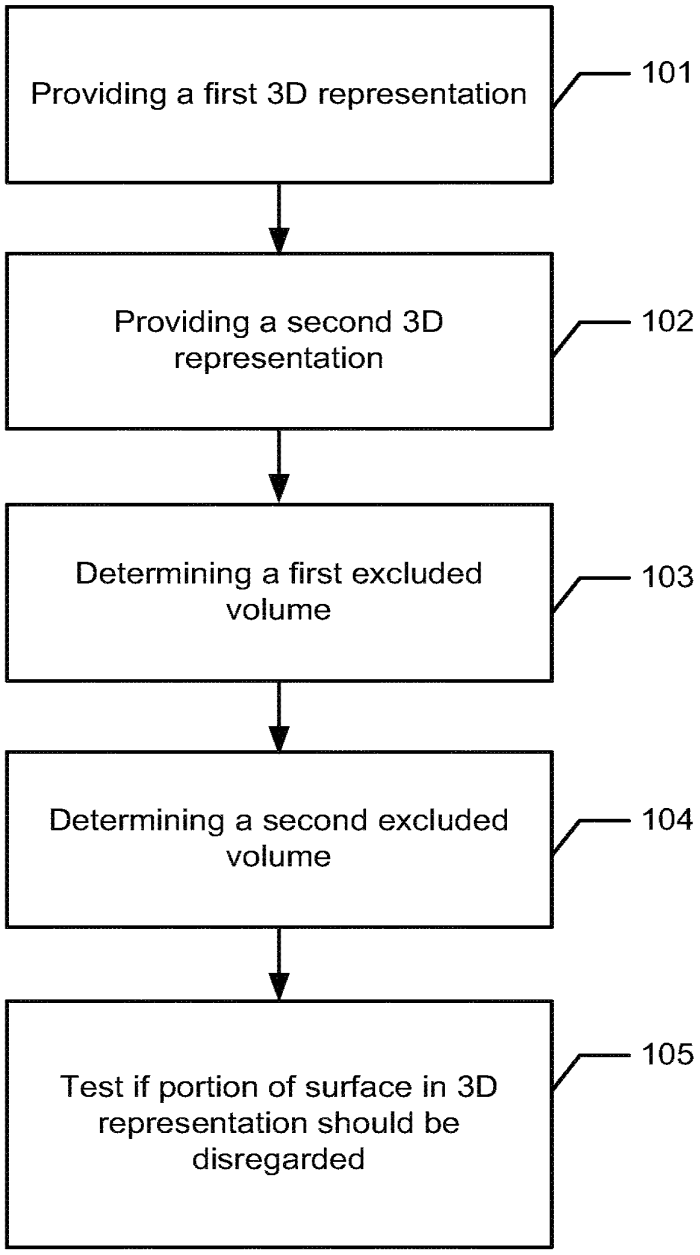

Providing a first 3D representation
101
Providing a second 3D representation
102
Determining a first excluded volume
103
Determining a second excluded volume
104
Test if portion of surface in 3D representation should be disregarded
105

Fig. 1

Fig. 2

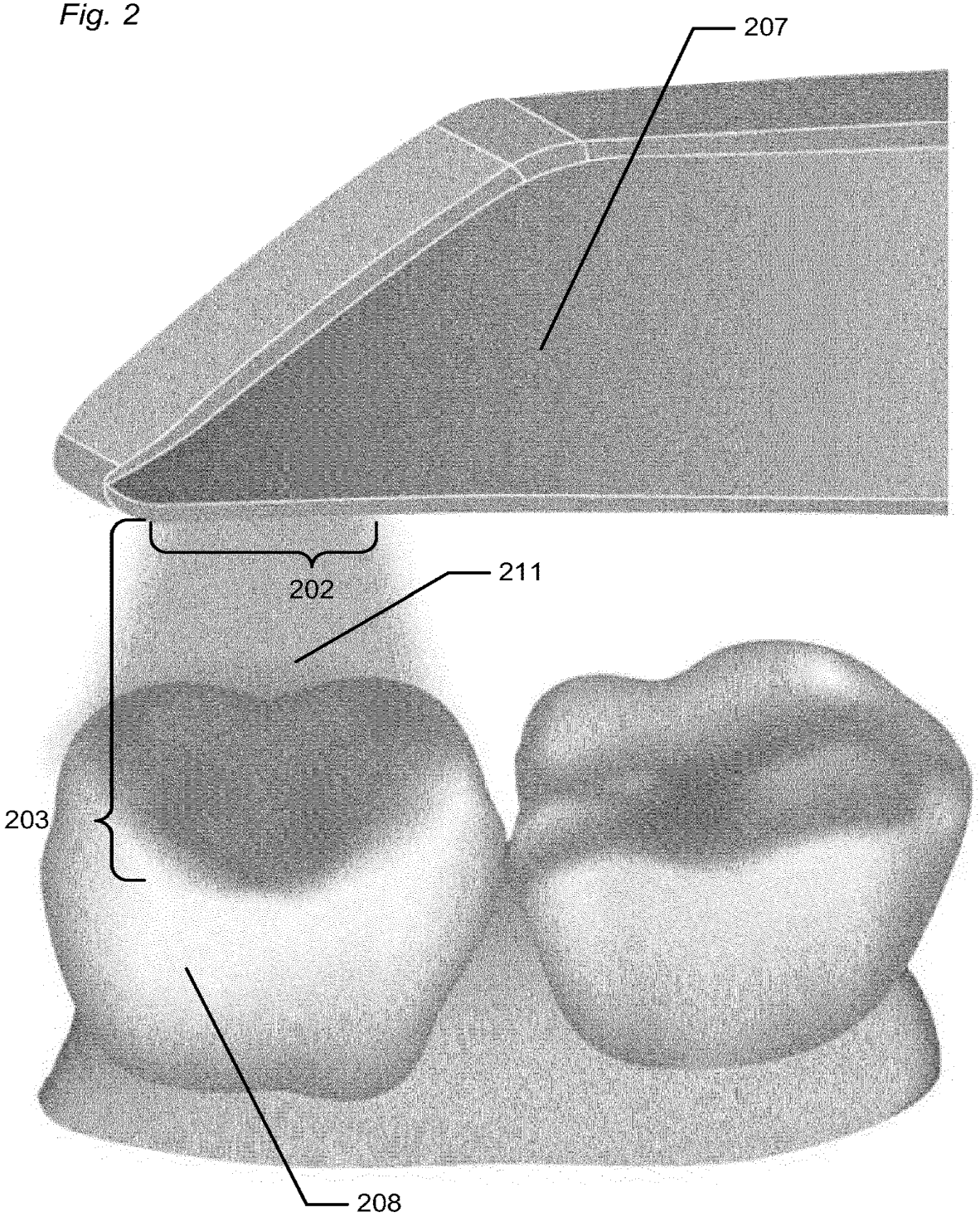


Fig. 3

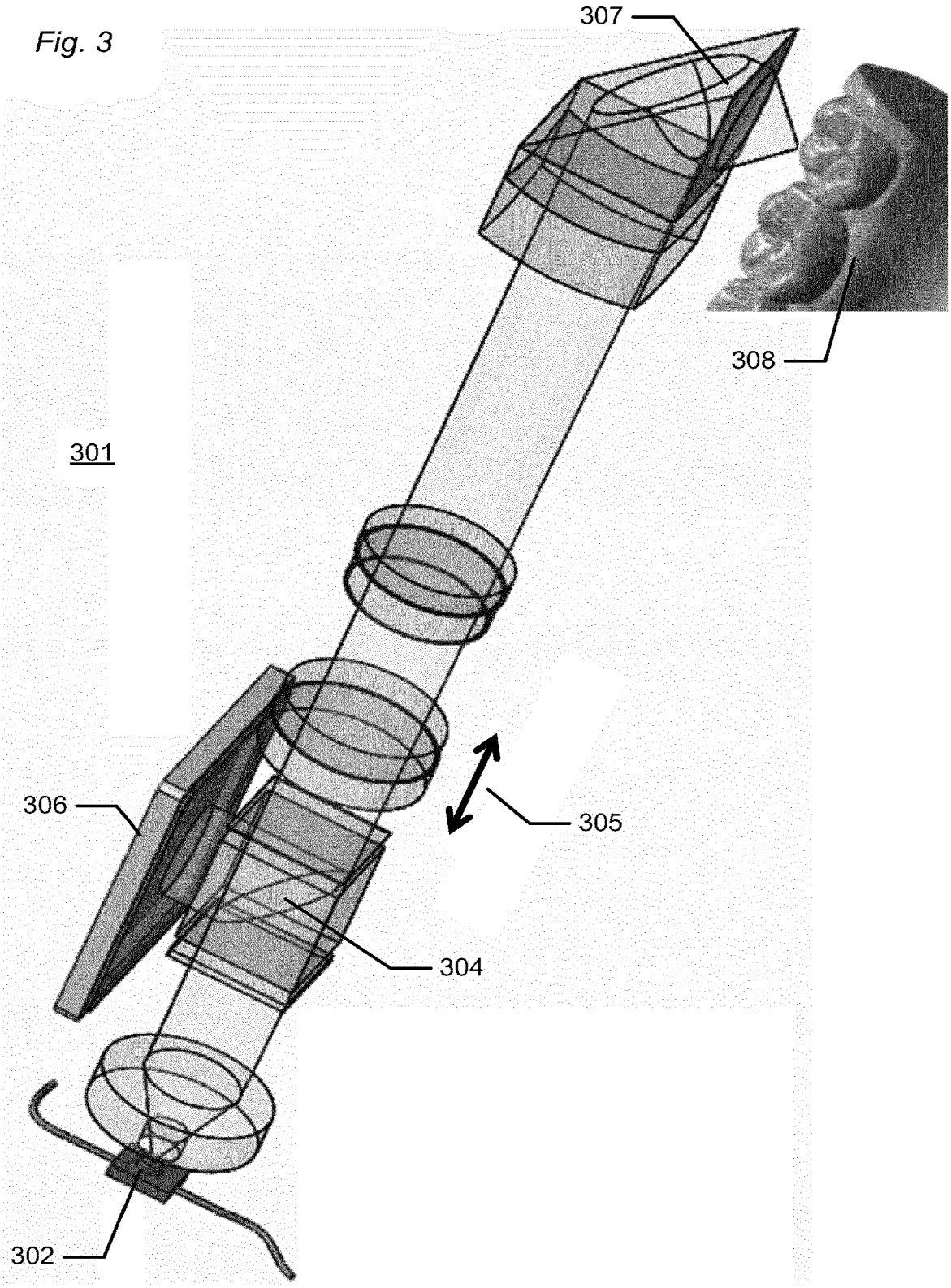


Fig. 4

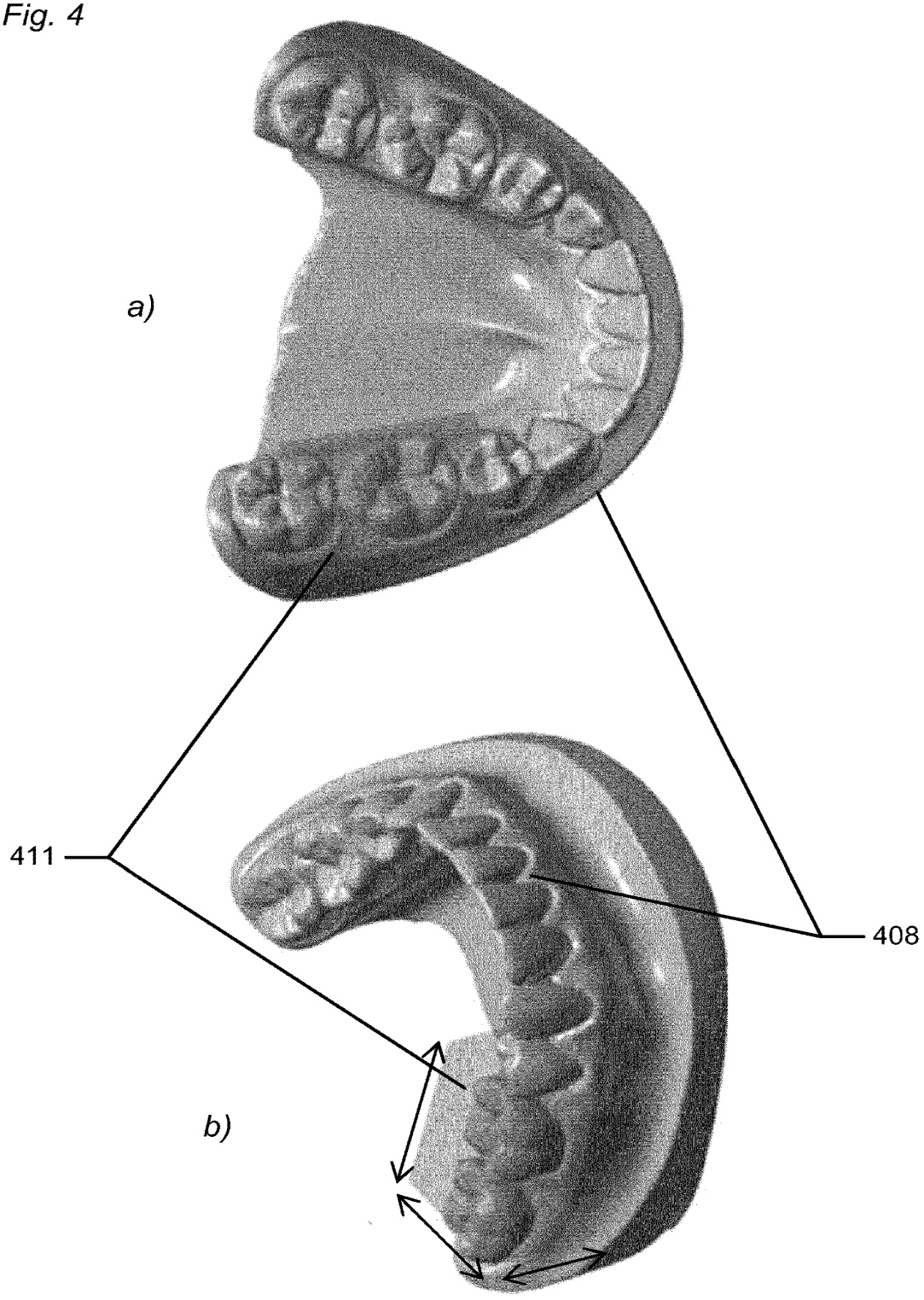


Fig. 5

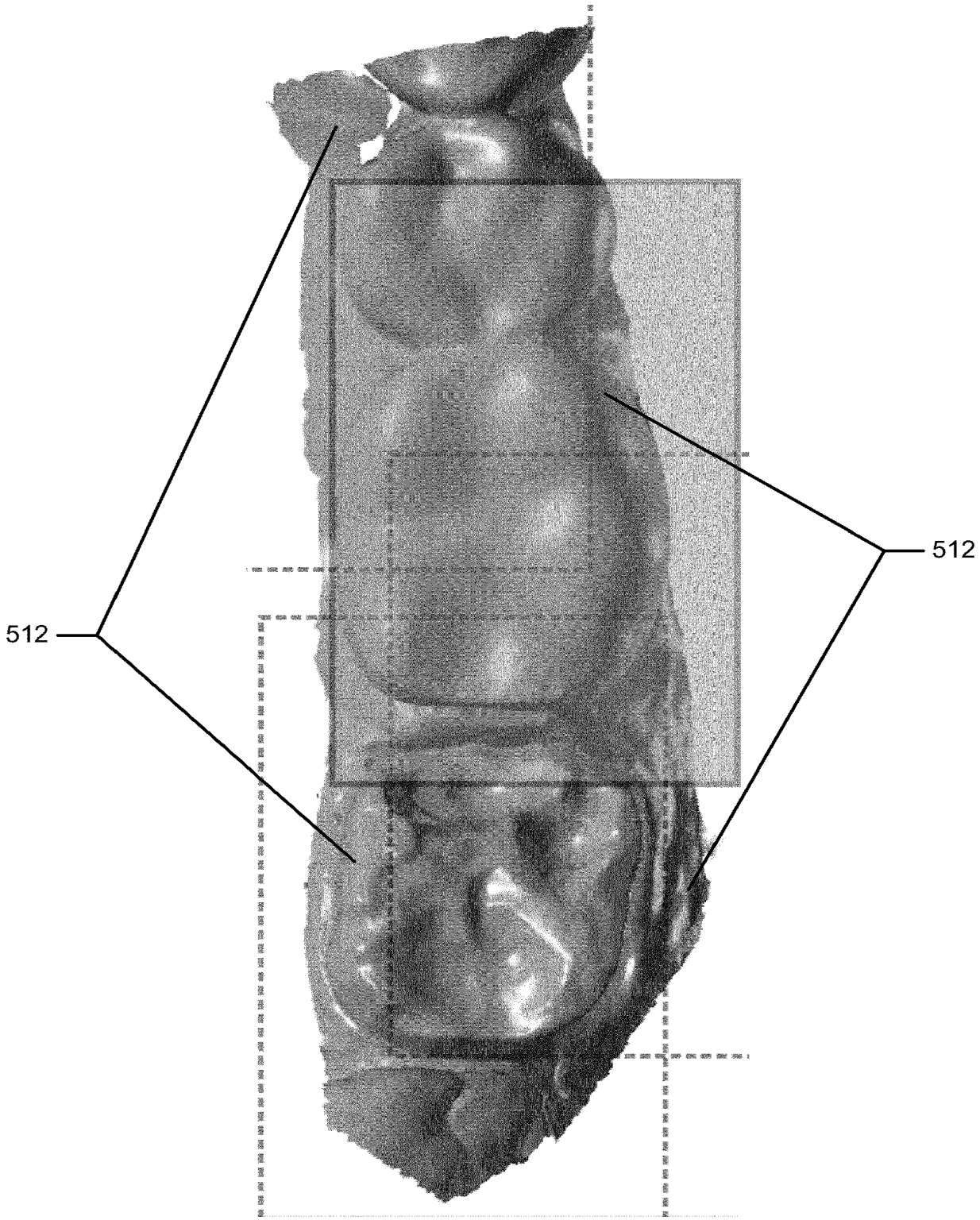


Fig. 6

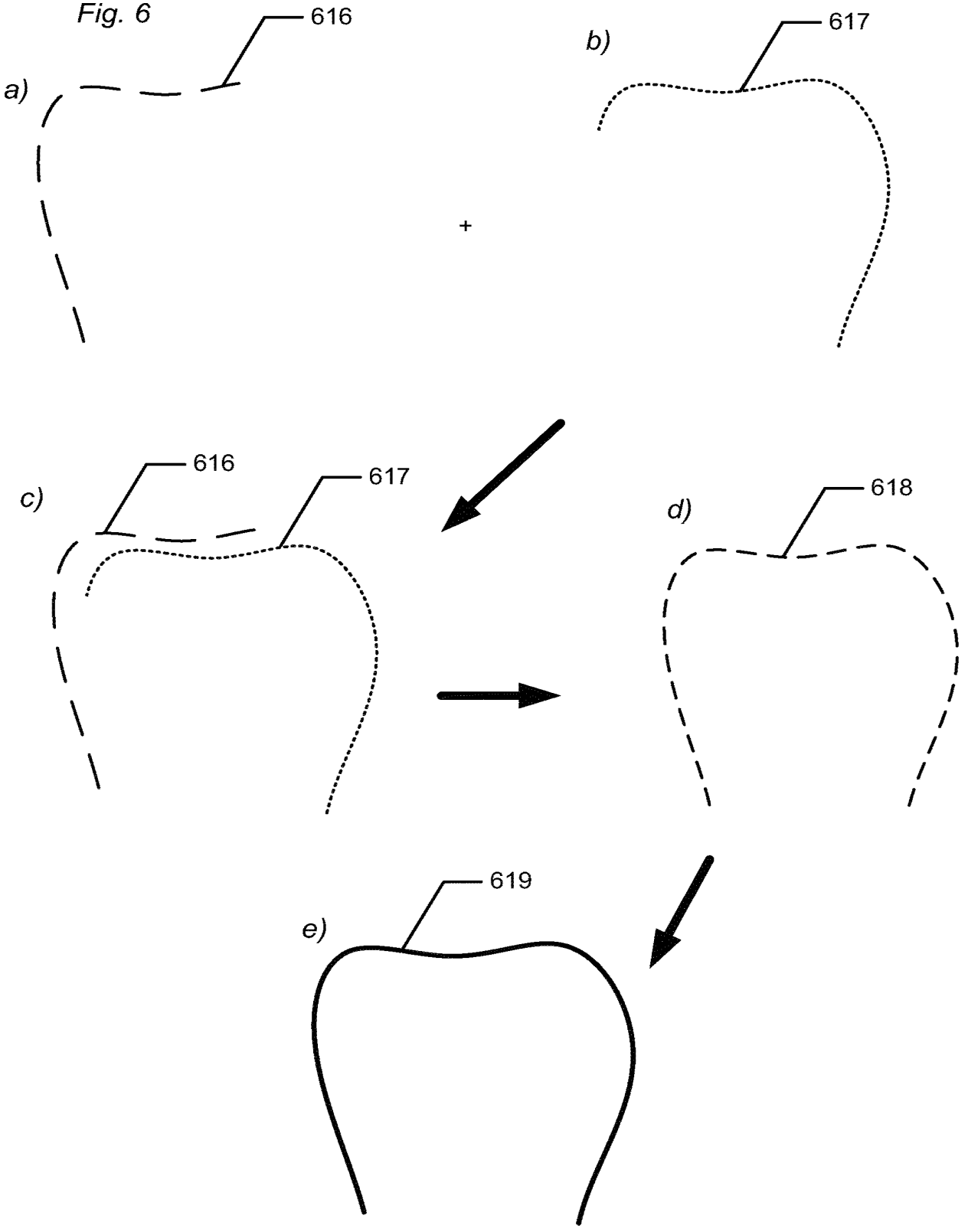


Fig. 7

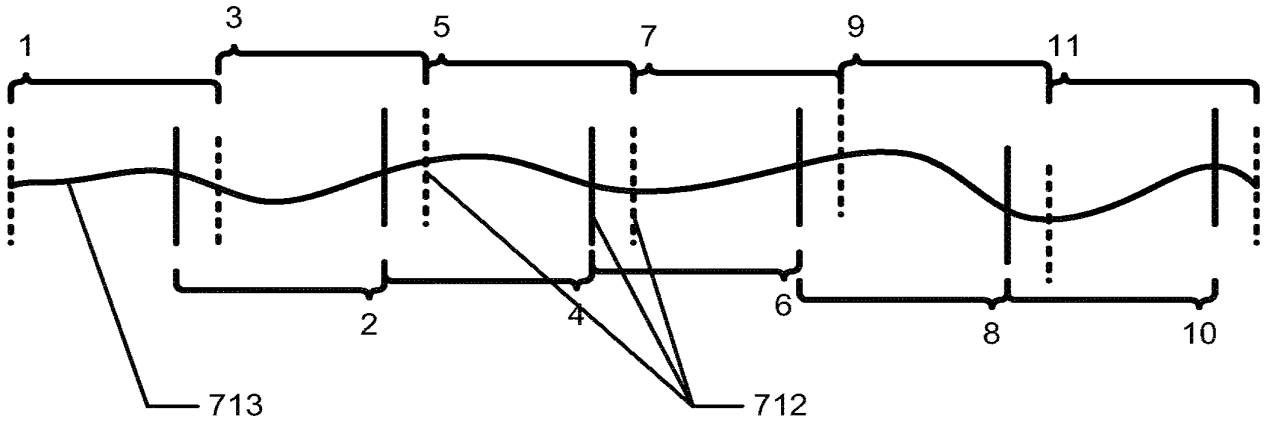
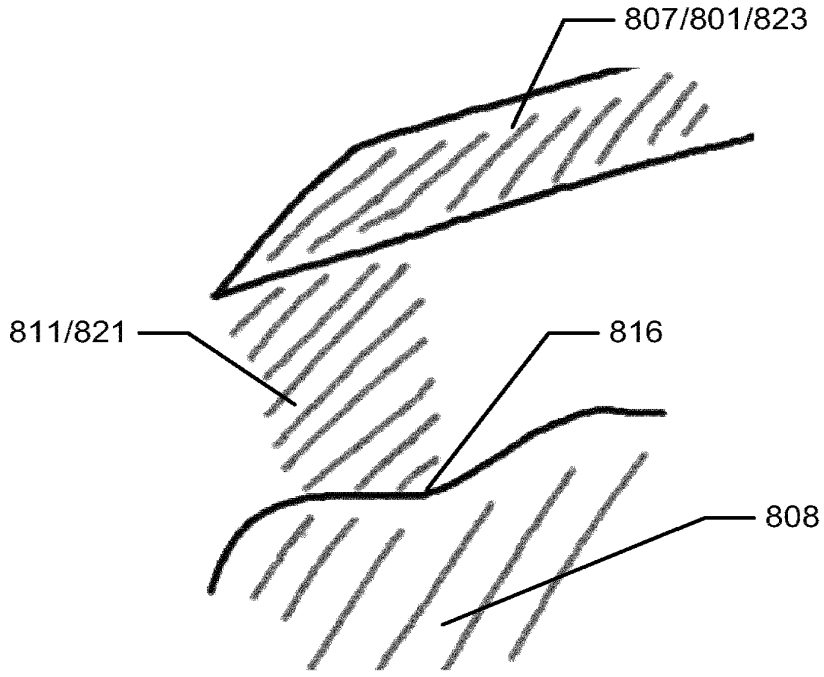


Fig. 8



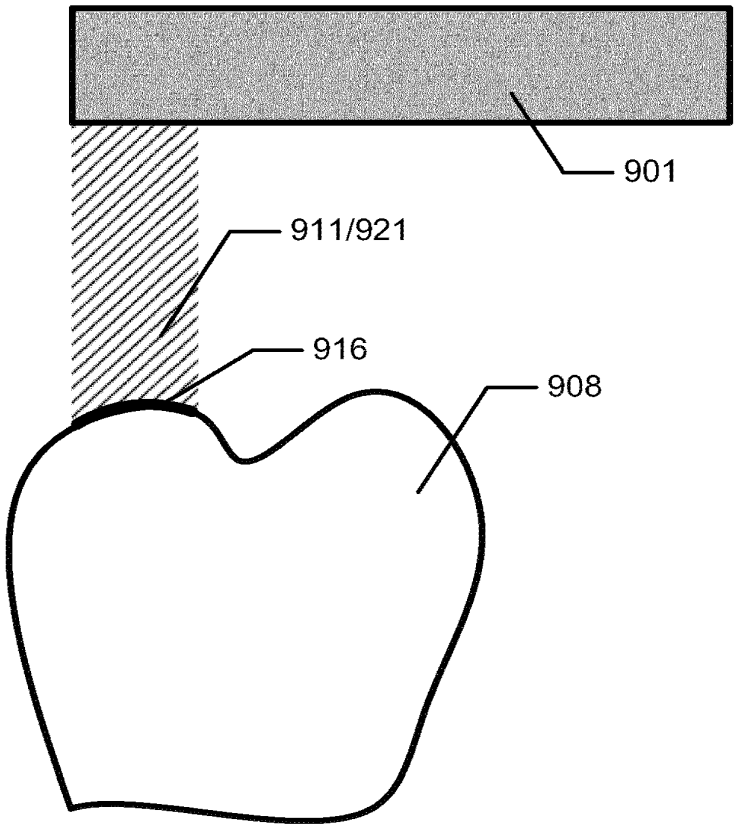


Fig. 9a)

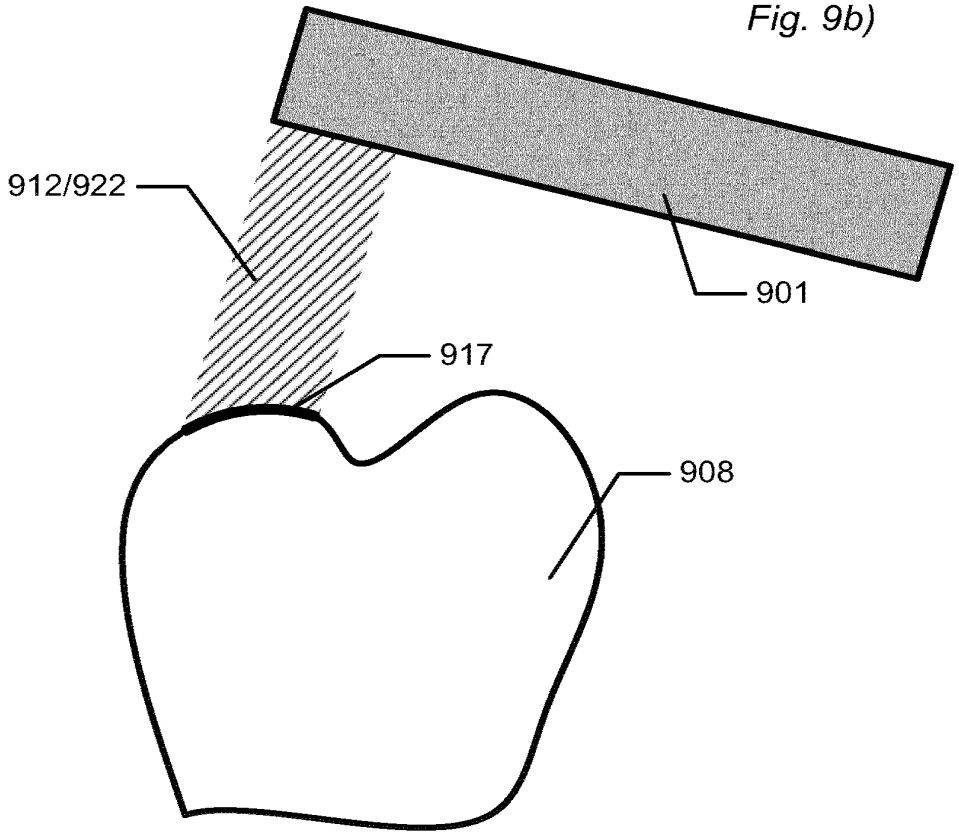


Fig. 9b)

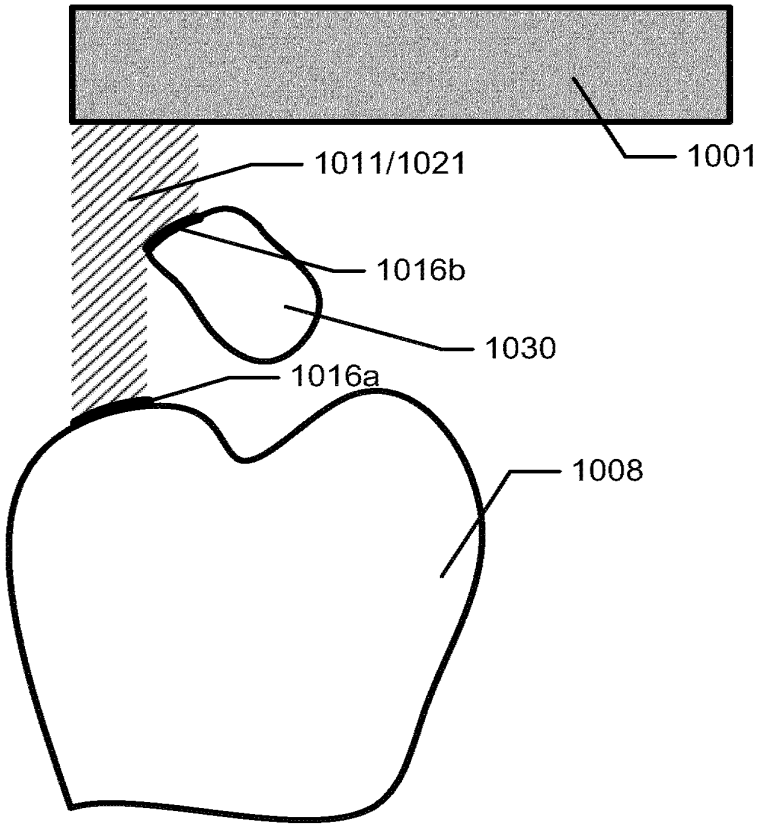


Fig. 10a)

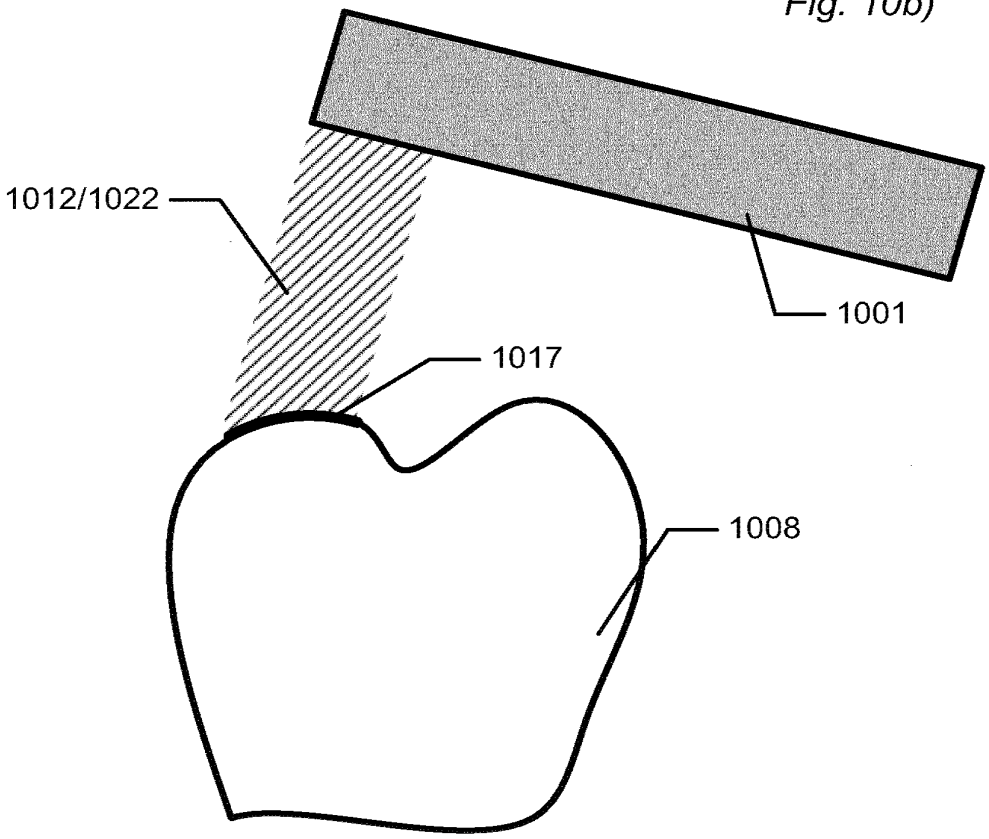


Fig. 10b)

Fig. 11a)

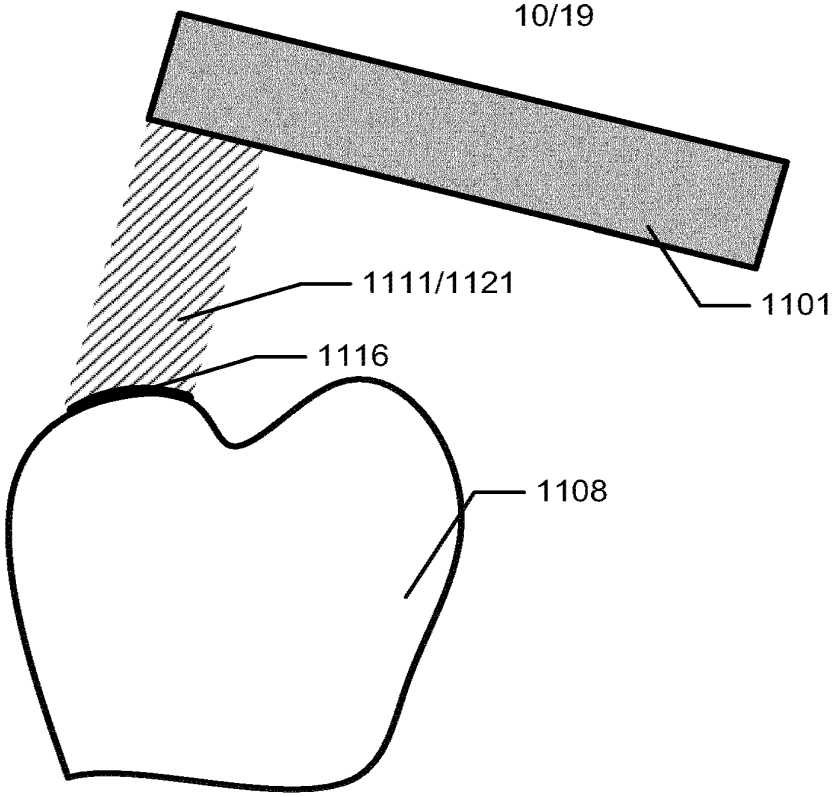


Fig. 11b)

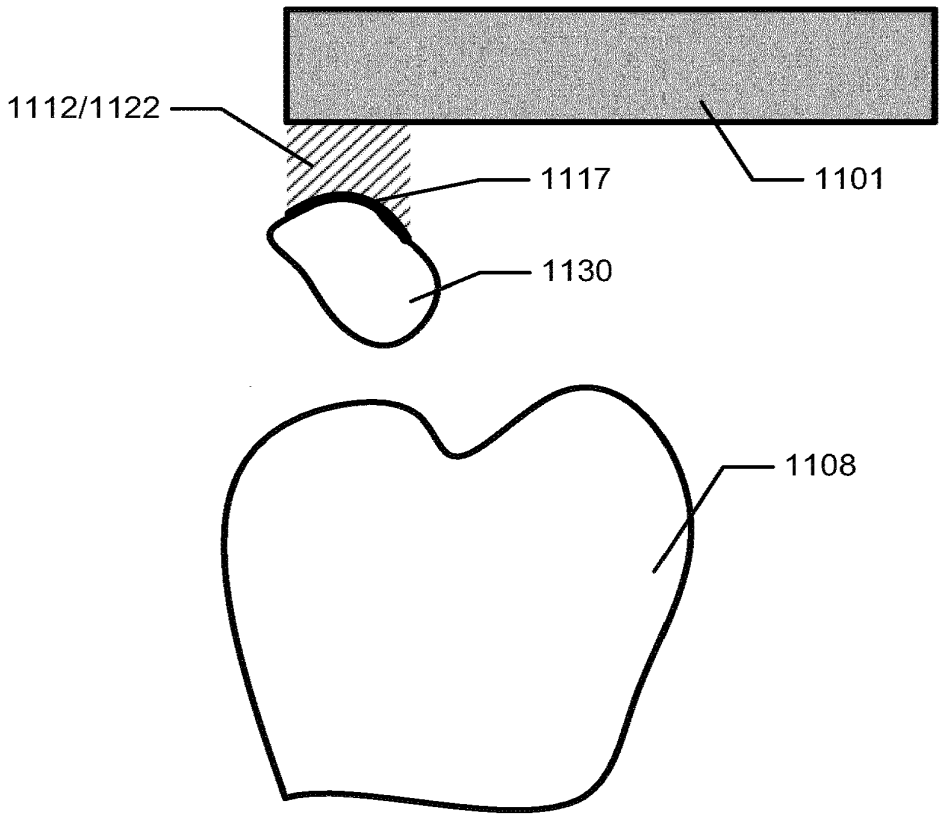


Fig. 12

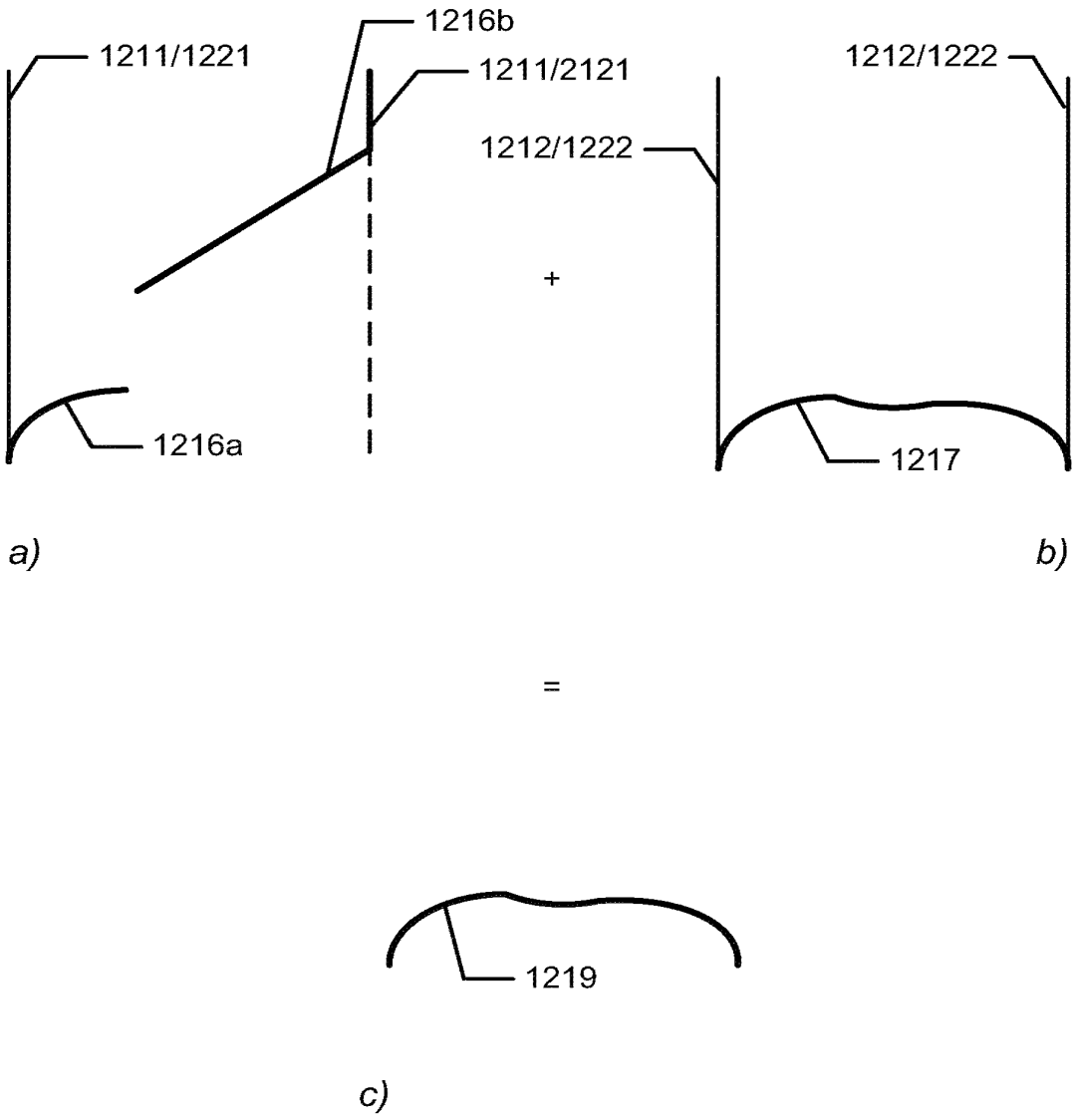
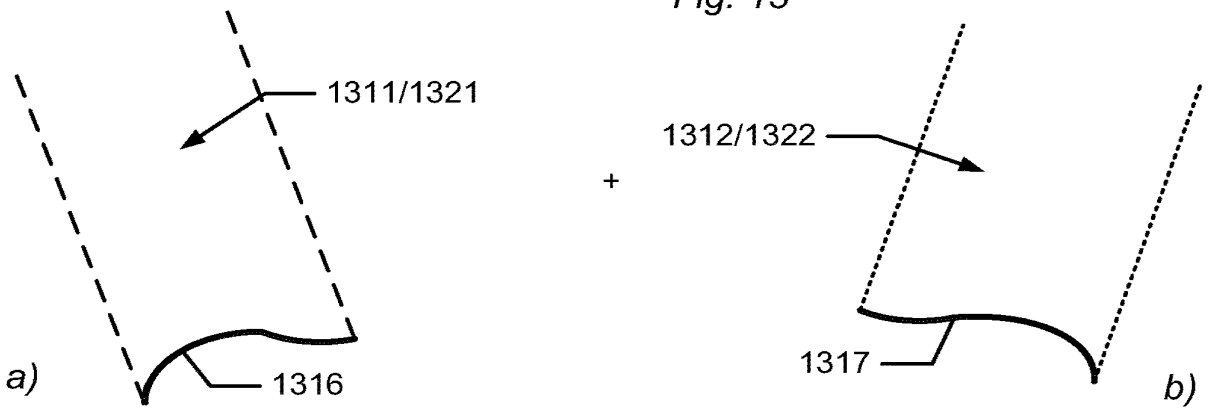
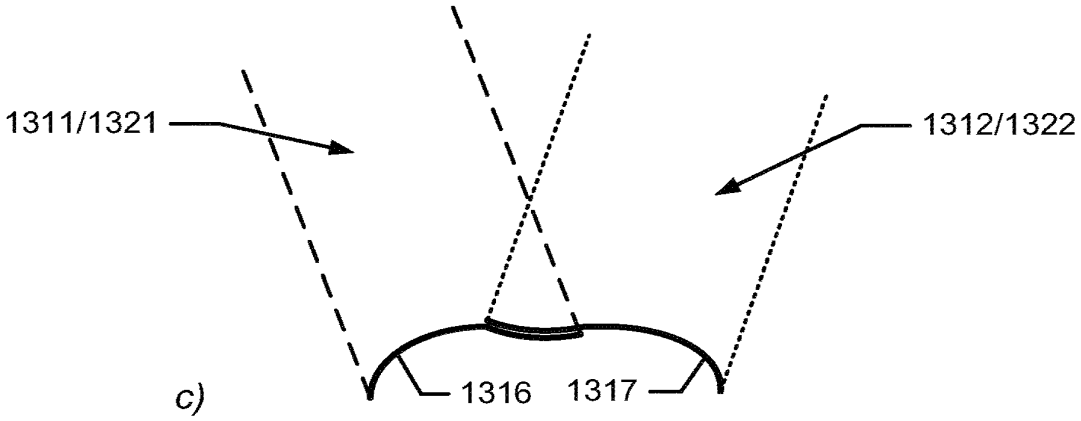
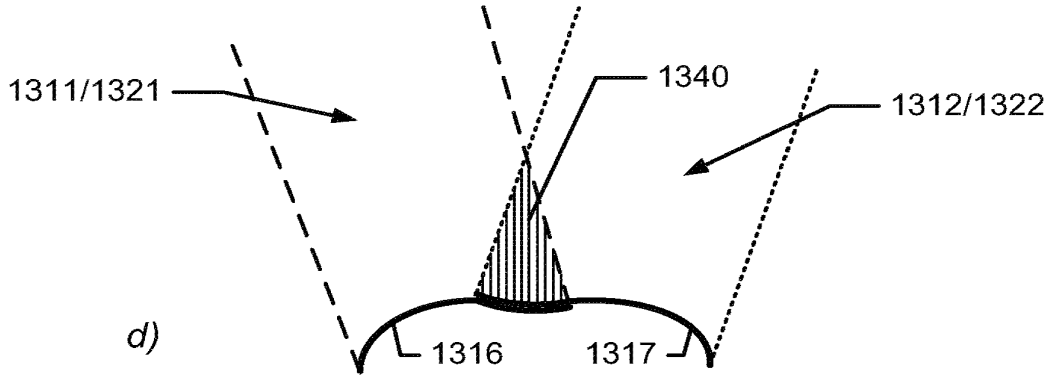

1216b
1211/1221
1211/2121
1212/1222
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+
1216a
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a)
b)
=
1219
c)

Fig. 13

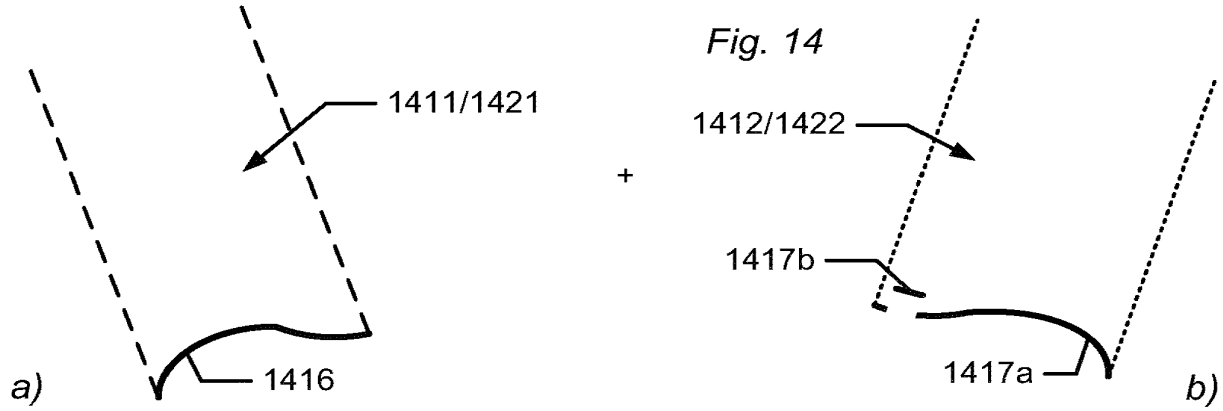

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a)
1316
+
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b)

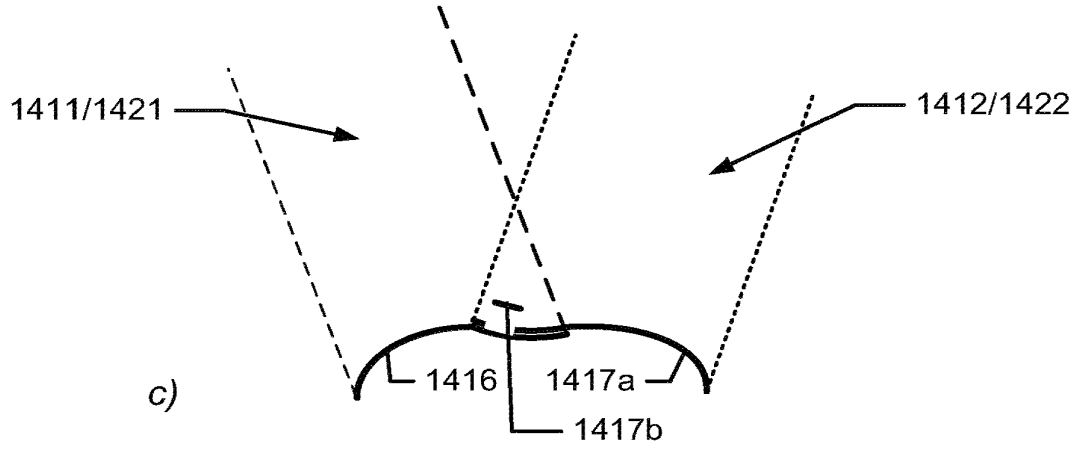

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c)
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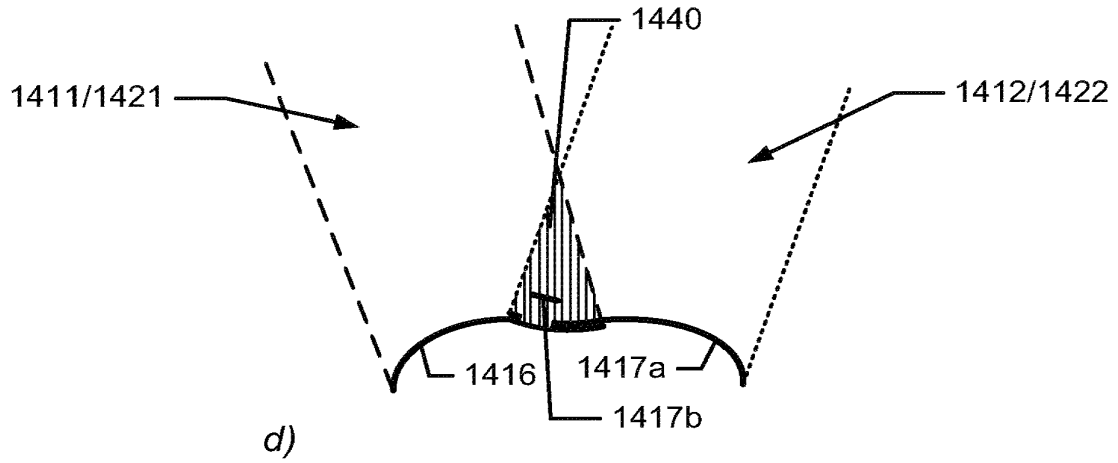

1311/1321
1340
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d)
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e)
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Fig. 14

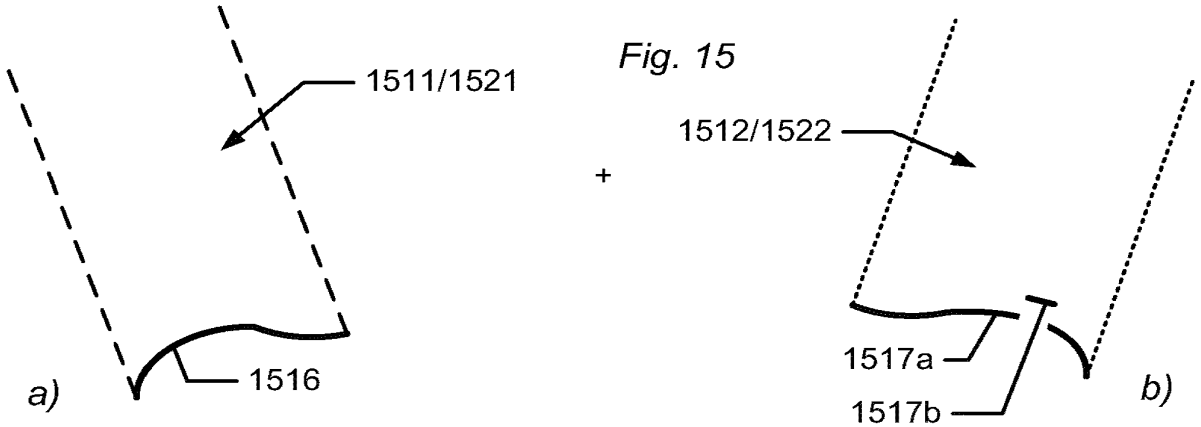

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a)
+
1412/1422
1417b
1417a
b)

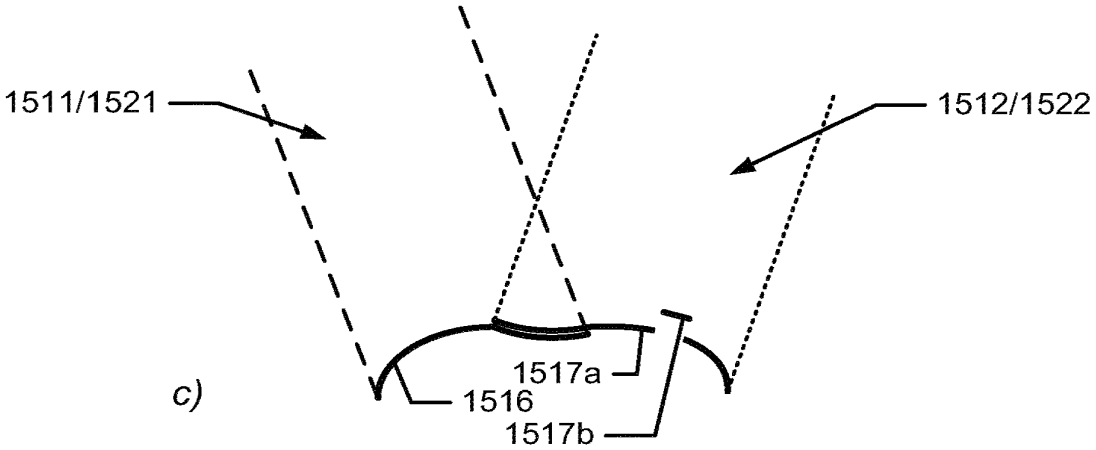

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1417a
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c)

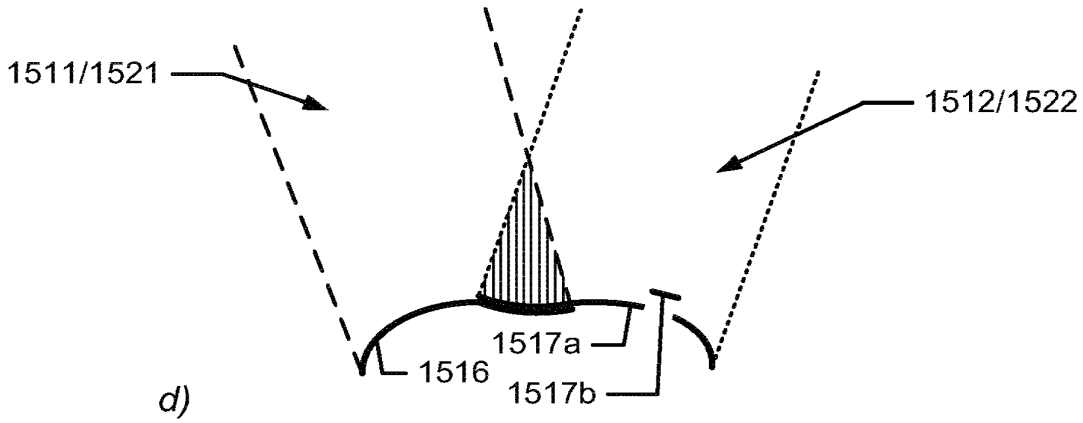

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1411/1421
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1417a
1417b
d)


e)
1419

Fig. 15


1511/1521
1516
a)
+
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1517a
1517b
b)


1511/1521
1512/1522
1517a
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1517b
c)


1511/1521
1512/1522
1517a
1516
1517b
d)

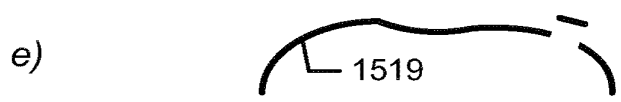

e)
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Fig. 16

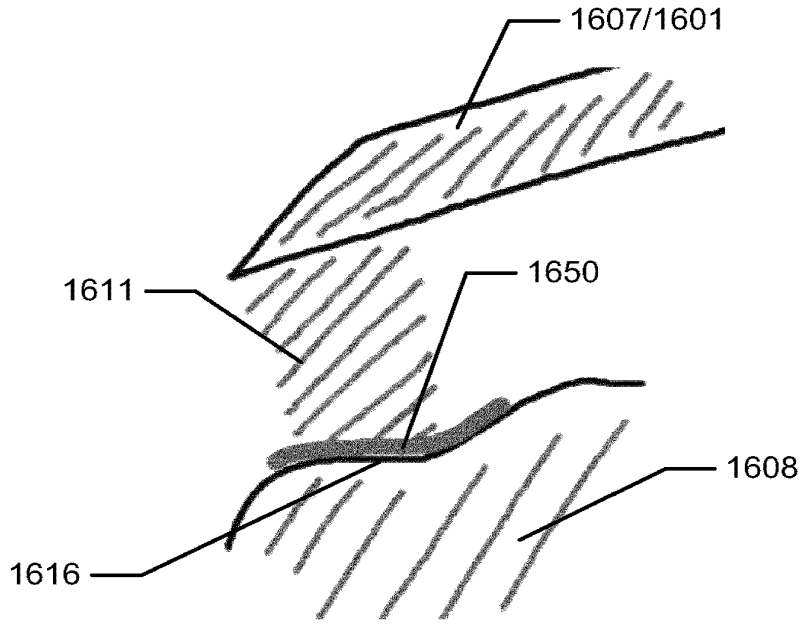

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Fig. 17

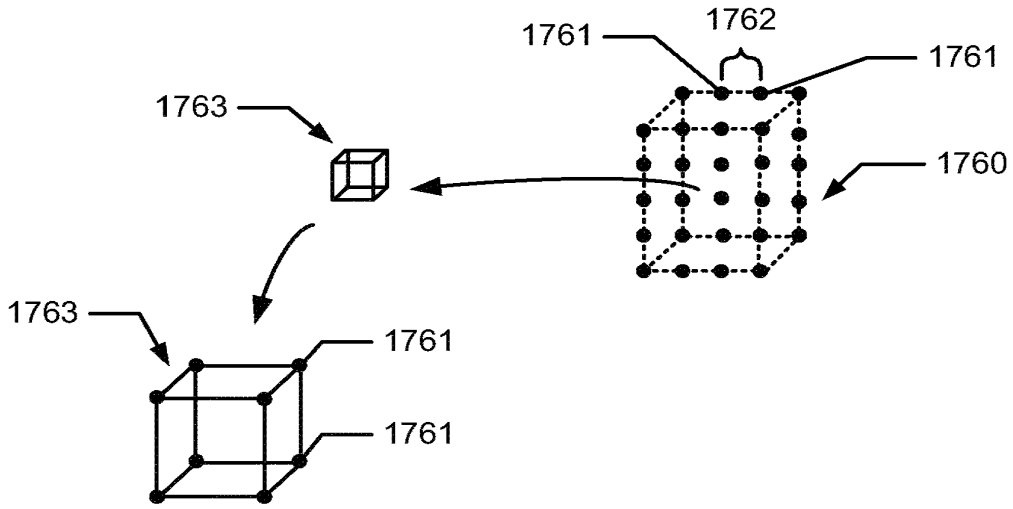

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1760
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Fig. 18a)

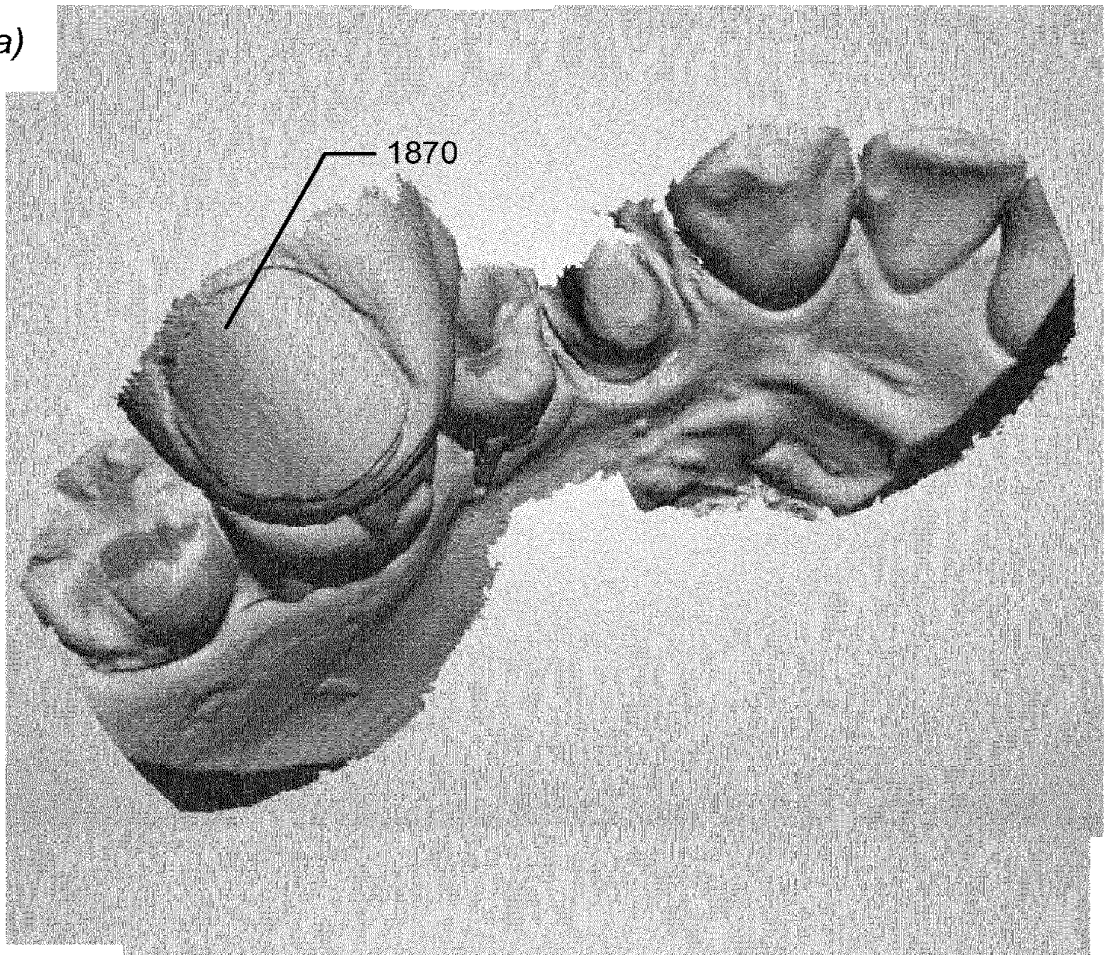
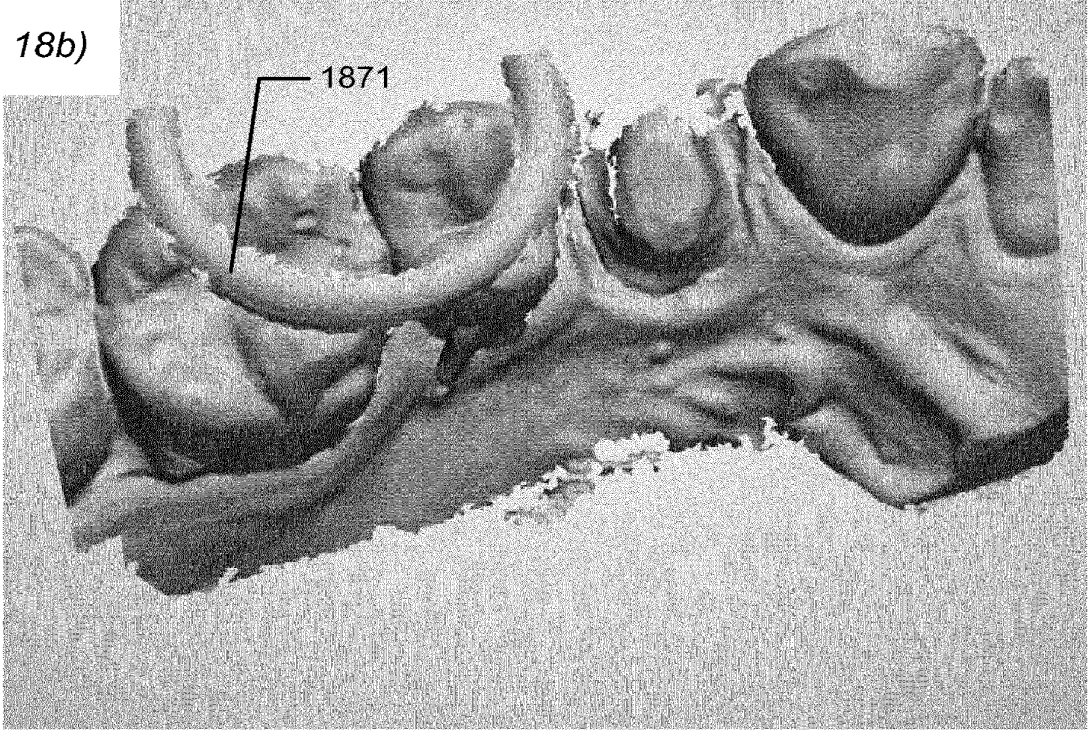


Fig. 18b)



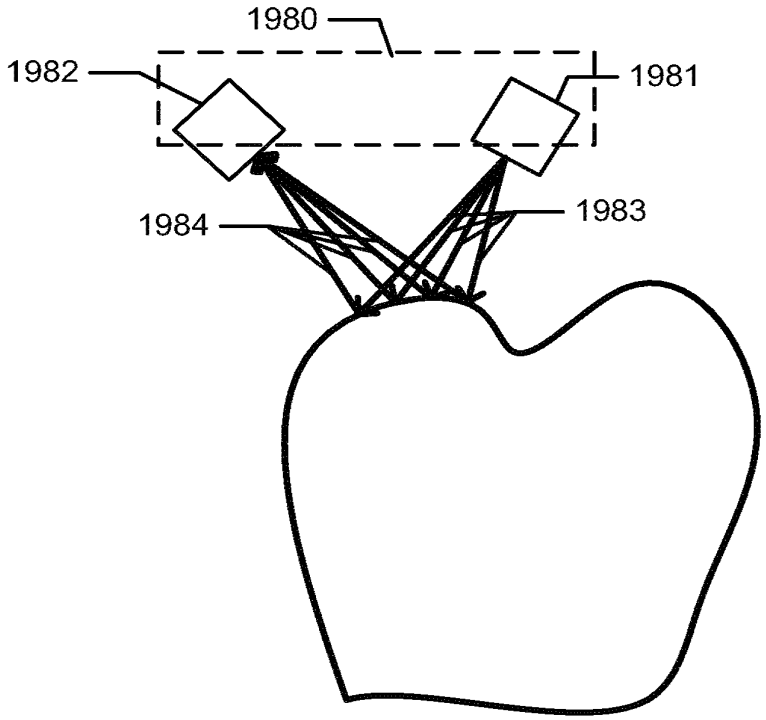


Fig. 19

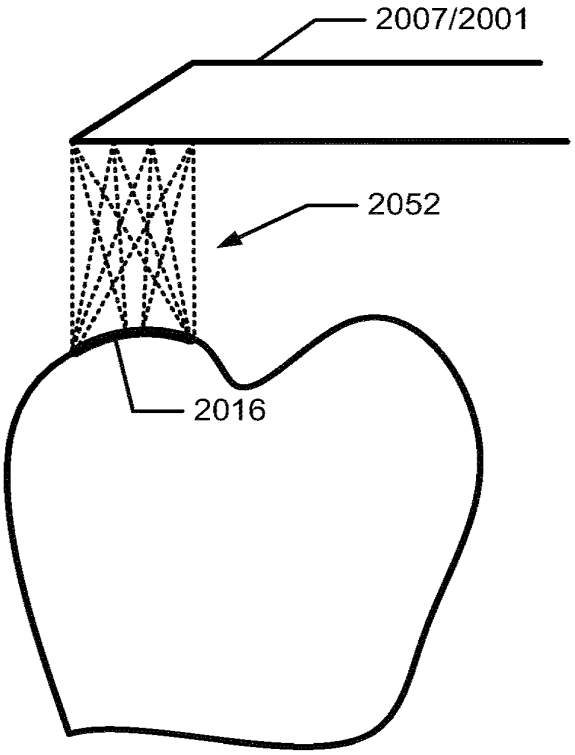


Fig. 20a)

Fig. 20b)

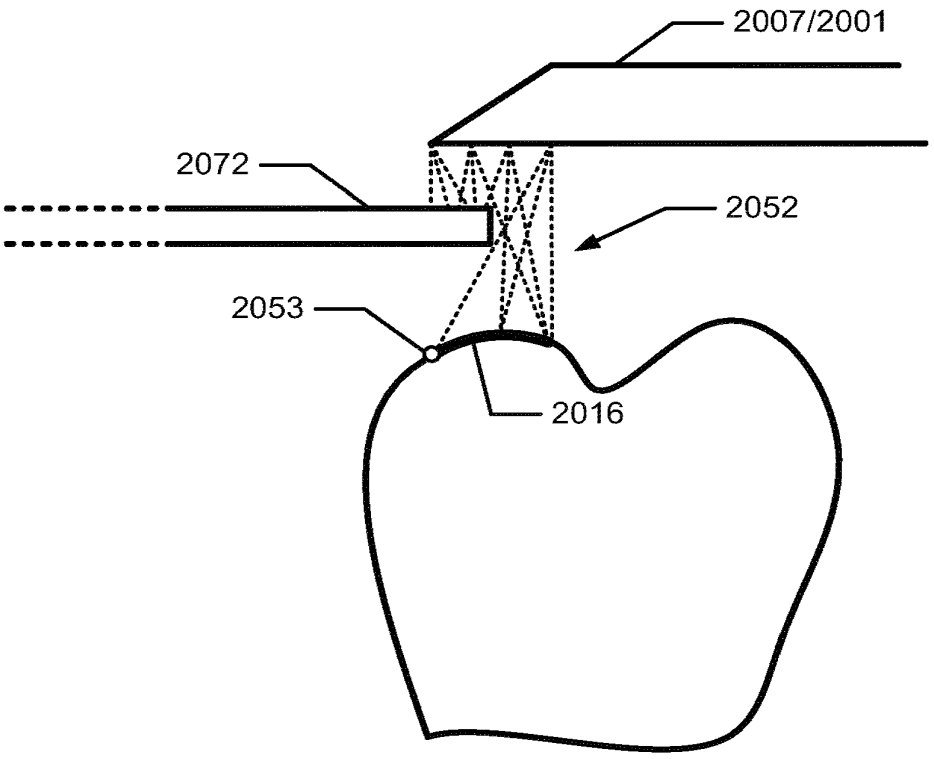


Fig. 20c)

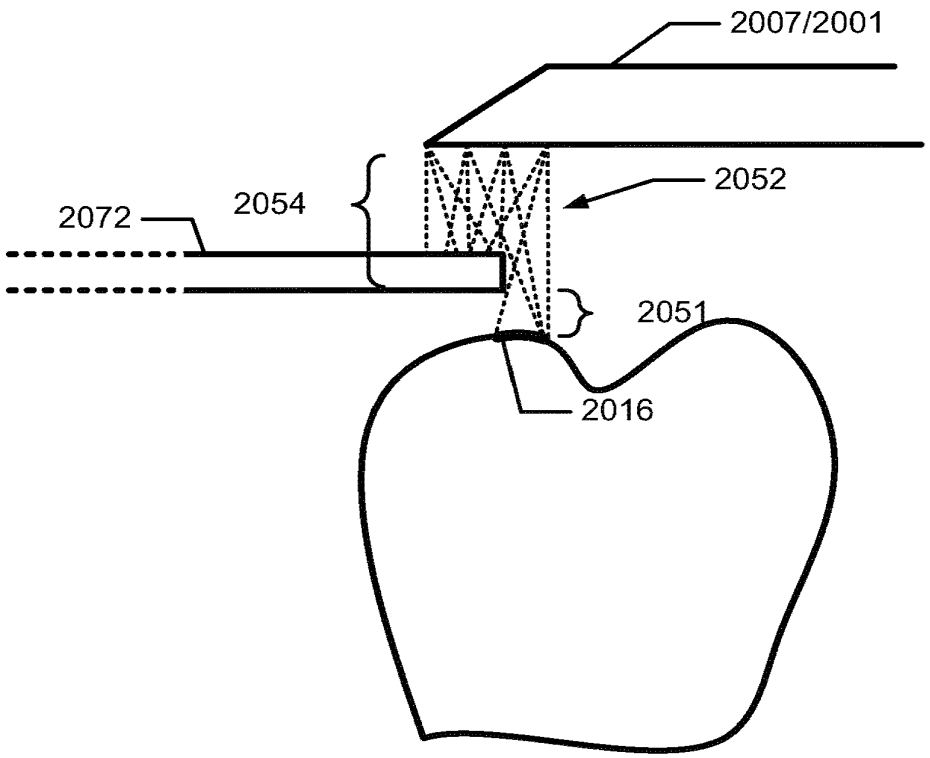
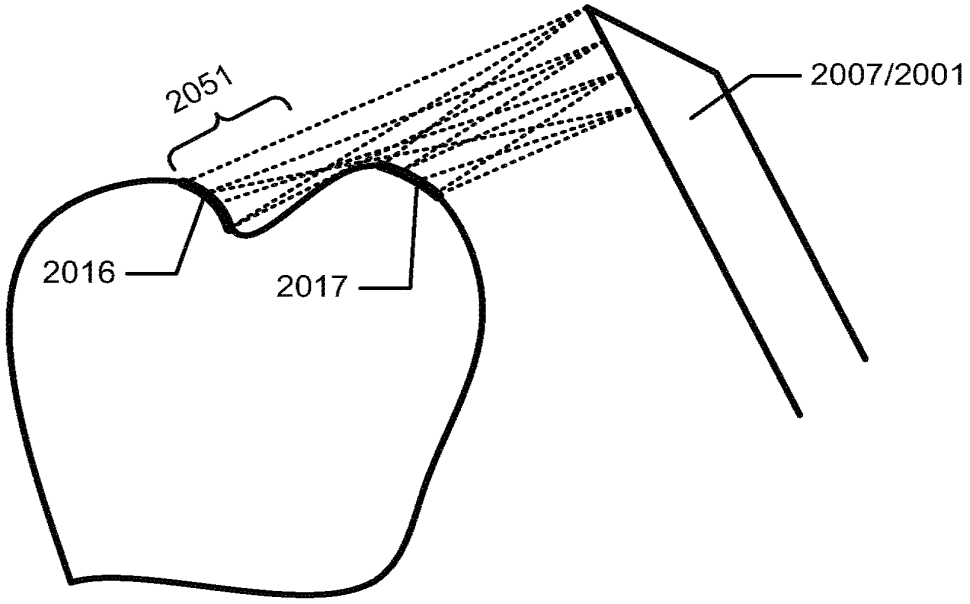


Fig. 20d)



INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2012/063687

A. CLASSIFICATION OF SUBJECT MATTER
INV. G06T7/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G06T G06K A61B A61C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	MEHL A ET AL: "Accuracy testing of a new intraoral 3D camera", INTERNATIONAL JOURNAL OF COMPUTERIZED DENTISTRY, QUINTESSENCE, NEW MALDEN, GB, vol. 12, no. 1, 1 January 2009 (2009-01-01), pages 11-28, XP009162619, ISSN: 1463-4201 the whole document	1-51

-/--

[X] Further documents are listed in the continuation of Box C.

[ ] See patent family annex.

* Special categories of cited documents :

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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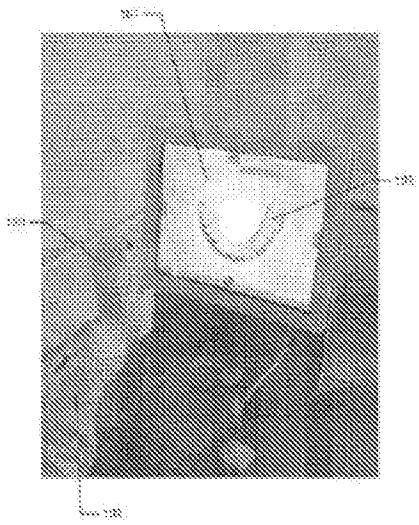
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[Continued on next page]

(54) Title: SYSTEM WITH 3D USER INTERFACE INTEGRATION



(57) Abstract: Disclosed is a system comprising a handheld device (100) and at least one display (101), where the handheld device (100) is adapted for performing at least one action in a physical 3D environment. The actions include measuring, modifying, manipulating, recording, touching, sensing, scanning, moving, transforming, cutting, welding, chemically treating, cleaning. The display (101) is adapted for visually representing the physical 3D environment, and where the handheld device (100) is adapted for remotely controlling the view with which the 3D environment is represented on the display (101).

Fig. 1a

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System with 3D user interface integration

Field of the invention

This invention generally relates to a method and a system comprising a handheld device and at least one display.

Background of the invention

3D visualization is important in many fields of industry and medicine, where 3D information is becoming more and more predominant.

Displaying and inspecting 3D information is inherently difficult. To fully understand a 3D object or entire environment on a screen, the user should generally be able to rotate the object or scene, such that many or preferentially all surfaces are displayed. This is true even for 3D displays, e.g. stereoscopic or holographic, where from a given viewing position and with a given viewing angle, the user will only see some surfaces of an arbitrary 3D environment. Often, the user will also want to zoom into details or zoom out for an overview.

Various user interaction devices are in use for software that displays 3D data; these devices are: 3D mice, space balls, and touch screens. The operation of these current interaction devices requires physically touching them.

Physically touching a user-interaction device can be a disadvantage in medical applications due to risks of cross-contamination between patients or between patient and operator, or in industrial applications in dirty environments.

Several non-touch user interfaces for 3D data viewing in medical applications have been described in the literature. Vogt et al (2004) describe a touchless interactive system for in-situ visualization of 3D medical imaging data. The user interface is based on tracking of reflective markers, where a camera is mounted on the physician's head. Graetzel et al (2004) describe a touchless system that interprets hand gestures as mouse actions. It is based on stereo vision and intended for use in minimally invasive surgery.

It remains a problem to improve systems that require user interfaces for view control, which for example can be used for clinical purposes.

Summary

Disclosed is a system comprising a handheld device and at least one display, where the handheld device is adapted for performing at least one action in a physical 3D environment, where the at least one display is adapted for visually representing the physical 3D environment, and where the handheld device is adapted for remotely controlling the view with which said 3D environment is represented on the display.

The system may be adapted for switching between performing the at least one action in the physical 3D environment, and remotely controlling the view with which the 3D environment is represented on the display.

The system disclosed here performs the integration of 3D user interface functionality with any other handheld device with other operating functionality, such that the operator ideally only touches this latter device that is intended to be touched. A particular example of such a handheld device is one that records some 3D geometry, for example a handheld 3D scanner.

The handheld device is a multi-purpose device, such as a dual-purpose or two-purpose device, i.e. a device both for performing actions in the physical 3D environment, such as measuring and manipulating, and for remotely controlling the view of the 3D environment on the display.

Geometrically, a view is determined by the virtual observer's/camera's position and orientation relative to the 3D environment or its visual representation. If the display is two-dimensional, the view is also determined by the type of projection. A view may also be determined by a magnification factor.

The virtual observer's and the 3D environment's position and orientation are always relative to each other. In terms of user experience in software systems with 3D input devices, the user may feel that for example, he/she is moving the 3D environment while remaining stationary himself/herself, but there is always an equivalent movement of the virtual observer/camera that gives the same results on the display. Often, descriptions of 3D software systems use the expression "pan" to indicate an apparent translational movement of the 3D environment, "rotate" to indicate a rotational movement of the 3D environment, and "zoom" to indicate a change in magnification factor.

Graphically, a view can represent a 3D environment by means of photographs or as some kind of virtual representation such as a computer graphic, or similar. A computer graphic can be rendered for example with texture and/or shading and/or virtual light sources and/or light models for surface properties. A computer graphic can also be a simplified representation of the 3D environment, for example a mesh, an outline, or an otherwise simplified representation. All or parts of the 3D environment can also be rendered with some degree of transparency. A view may represent the 3D environment in total or only parts thereof.

All of the touch-less prior art systems are 3D user interface devices only. In many prior art applications, the operator using such user interface device will also hold and work with another device that really is the central device in the overall application, e.g. a medical instrument.

It is thus an advantage of the present system that the 3D user-interface functionality is integrated in the central device, which is used for performing some kind of action.

In some embodiments the handheld device is adapted for remotely controlling the magnification with which the 3D environment is represented on the display.

In some embodiments the handheld device is adapted for changing the rendering of the 3D environment on the display.

In some embodiments the view is defined as viewing angle and/or viewing position.

In some embodiments the at least one action comprises one or more of the actions of:

- measuring,
- recording,
- scanning,
- manipulating,
- modifying.

In some embodiments the 3D environment comprises one or more 3D objects.

In some embodiments the handheld device is adapted to be held in one hand by an operator.

In some embodiments the display is adapted to represent the 3D environment from multiple views.

In some embodiments the display is adapted to represent the 3D environment from different viewing angles and/or viewing positions.

In some embodiments the view of the 3D environment in the at least one display is at least partly determined by the motion of the operator's hand holding said device.

In some embodiments the magnification represented in the at least one display is at least partly determined by the motion of the operator's hand holding said device.

In some embodiments the handheld device is adapted to record the 3D geometry of the 3D environment.

Thus the handheld device may be an intraoral dental scanner, which records the 3D geometry of a patient's teeth. The operator may move the scanner along the teeth of the patient for capturing the 3D geometry of the relevant teeth, e.g. all teeth. The scanner may comprise motion sensors for taking the movement of the scanner into account while creating the 3D model of the scanned teeth.

The 3D model of the teeth may be shown on a display, and the display may for example be a PC screen and/or the like.

The user interface functionality may comprise incorporating motion sensors in the scanner to provide that the user can determine the view on the screen by moving the scanner. Pointing the scanner down can provide that the scanned teeth are shown given a downward viewing angle. Holding the scanner in a horizontal position can provide that the viewing angle is likewise horizontal.

In some embodiments the handheld device comprises at least one user-interface element. A user-interface element is an element which the user may manipulate in order to activate a function on the user interface of the software. Typically the use interface is graphically presented on the display of the system.

The handheld device may furthermore be provided with an actuator, which switches the handheld device between performing the at least one action and remotely controlling the view. By providing such a manual switching function that enables the operator to switch between performing the at least one action and remotely controlling the view, the operator may easily control what is performed.

Such an actuator can for example be in the form of a button, switch or contact. In other embodiments it could be a touch sensitive surface or element.

In another embodiment the actuator could be a motion sensor provided in the handheld device that function as the actuator when it registers a specific type of movement, for example if the operator shakes the handheld device. Examples of such motion sensors will be described herein with respect to the user-interface element, however, the person skilled in the art will based on the disclosure herein understand that such motion sensors may also be used as actuators as discussed.

For example, the handheld device can in one embodiment be an intra-oral 3D scanner used by a dentist. The scanner is set to be performing the action of scanning a dental area when the actuator is in one position. When the actuator is switched into a second position the handheld is set to control the view with which the 3D environment is represented on the display. This could for example be that when the dentist have scanned a part of or the complete desired area of an dental arch he can activate the actuator which then allows the dentist to remotely control the view of the 3D representation of the scanned area on the display by using the handheld device.

For example, the actuator could be a button. When the button is pressed quickly the handheld device is prepared for scanning, i.e. it is set for performing at least one action, the scanning procedure, in the physical 3D environment. The scanning is stopped when the button is pressed quickly a second time.

While the scanning is performed a virtual 3D representation is visually built on the display.

The user can now press and hold the button. This will put the handheld in a controller mode, where the handheld device is adapted for remotely controlling the view with which the 3D environment, such as scanned teeth, is represented on the display. While holding the button pressed the system will use signals from a motion sensor in the handheld device to determine how to present the view of the virtual 3D environment. Thus, if the user turns or otherwise moves the hand that holds the handheld device the view of the virtual 3D environment on the display will change accordingly.

Thus, the dentist may use the same handheld device for both scanning an area and subsequently verifying that the scan has been executed correctly

without having to move away from the patient or touching any other equipment than already present in his hands.

In one embodiment the user-interface element is the same as the actuator, or where several user-interface elements are present at least one also functions as an actuator.
The system may be equipped with a button as an additional element providing the user-interface functionality.

In an example the handheld device is a handheld intraoral scanner, and the display is a computer screen. The operator or user may be a dentist, an assistant and/or the like. The operation functionality of the device may be to record some intraoral 3D geometry, and the user interface functionality may be to rotate, pan, and zoom the scanned data on the computer screen.

In some embodiments the at least one user-interface element is at least one motion sensor.

Thus the integration of the user interface functionality in the device may be provided by motion sensors, which can be accelerometers inside the scanner, whose readings determine the orientation of the display on the screen of the 3D model of the teeth acquired by the scanner. Additional functionality, e.g. to start/stop scanning, may be provided by a button. The button may be located where the operator's or user's index finger can reach it conveniently.

Prior art intraoral scanners use a touch screen, a trackball, or a mouse to determine the view in the display. These prior art user interface devices can be inconvenient, awkward and difficult to use, and they can be labor-intensive, and thus costly to sterilize or disinfect. An intraoral scanner should always be disinfected between scanning different patients, because the

scanner is in and may come in contact with the mouth or other parts of the patient being scanned.

The operator or user, e.g. dentist, may use one hand or both hands to hold the intraoral scanner while scanning, and the scanner may be light enough and comfortable to be held with just one hand for a longer time while scanning.

The device can also be held with one or two hands, while using the device as remote control for e.g. changing the view in the display. It is an advantage of the touchless user interface functionality that in clinical situations, the operator can maintain both hands clean, disinfected, or even sterile.

An advantage of the system is that it allows an iterative process of working in a 3D environment without releasing the handheld device during said process. For the above intraoral scanning system example, the operator, e.g. dentist, can record some teeth surface geometry with a handheld device that is an intraoral scanner, inspect coverage of the surface recording by using that same handheld device to move, e.g. rotate, the recorded surface on the display, e.g. a computer screen, detect possible gaps or holes in the coverage of the scanned teeth, and then for example arrange the scanner in the region where the gaps were located and continue recording teeth surface geometry there. Over this entire iterative cycle, which can be repeated more than once, such as as many times as required for obtaining a desired scan coverage of the teeth, the dentist does not have to lay the handheld intraoral scanner out of his or her hands.

In some embodiments, the 3D user interface functionality is exploited in a separate location than the operation functionality. For the above intraoral scanning system example, the scanning operation is performed in the oral cavity of the patient, while the user interface functionality is more flexibly

exploited when the scanner is outside the patient's mouth. The key characteristic and advantage of the system, again, is that the dentist can exploit the dual and integrated functionality, that is operation and user interface, of the scanner without laying it out of his or her hands.

The above intraoral scanning system is an example of an embodiment. Other examples for operation functionality or performing actions could be drilling, welding, grinding, cutting, soldering, photographing, filming, measuring, executing some surgical procedure etc..

The display of the system can be a 2D computer screen, a 3D display that projects stereoscopic image pairs, a volumetric display creating a 3D effect, such as a swept-volume display, a static volume display, a parallax barrier display, a holographic display etc.. Even with a 3D display, the operator has only one viewing position and viewing angle relative to the 3D environment at a time. The operator can move his/her head to assume another viewing position and/or viewing angle physically, but generally, it may be more convenient to use the handheld device with its built-in user interface functionality, e.g. the remote controlling, to change the viewing position and/or viewing angle represented in the display.

In some embodiments the system comprises multiple displays, or one or more displays that are divided into regions. For example, several sub-windows on a PC screen can represent different views of the 3D environment. The handheld device can be used to change the view in all of them, or only some of them.

In some embodiments the user interface functionality comprises the use of gestures.

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Gestures made by e.g. the operator can be used to change, shift or toggle between sub-windows, and the user-interface functionality can be limited to an active sub-window or one of several displays.

In some embodiments the gestures are adapted to be detected by the at least one motion sensor. Gestures can alternatively and/or additionally be detected by range sensors or other sensors that record body motion.

The operator does not have to constantly watch the at least one display of the system. In many applications, the operator will shift between viewing and possible manipulating the display and performing another operation with the handheld device. Thus it is an advantage that the operator does not have to touch other user interface devices. However, in some cases it may not be possible for the operator to fully avoid touching other devices, and in these cases it is an advantage that fewer touches are required compared to a system where a handheld device does not provide any user interface functionality at all.

In some embodiments the at least one display is arranged separate from the handheld device.

In some embodiments the at least one display is defined as a first display, and where the system further comprises a second display.

In some embodiments the second display is arranged on the handheld device.

In some embodiments the second display is arranged on the handheld device in a position such that the display is adapted to be viewed by the operator, while the operator is operating the handheld device.

In some embodiments the second display indicates where the handheld device is positioned relative to the 3D environment.

In some embodiments the first display and/or the second display provides instructions for the operator.

The display(s) can be arranged in multiple ways. For example, they can be mounted on a wall, placed on some sort of stand or a cart, placed on a rack or desk, or other.

In some embodiments at least one display is mounted on the device itself. It can be advantageous to have a display on the device itself because with such an arrangement, the operator's eyes need not focus alternatingly between different distances. In some cases, the operating functionality may require a close look at the device and the vicinity of the 3D environment it operates in, and this may be at a distance at most as far away as the operator's hand. Especially in crowded environments such as dentist's clinics, surgical operation theatres, or industrial workplaces, it may be difficult to place an external display closely to the device.

In some embodiments visual information is provided to the operator on one or more means other than the first display.

In some embodiments audible information to the operator is provided to the operator.

Thus in some embodiments, the system provides additional information to the operator. In some embodiments, the system includes other visual clues shown on means other than the display(s), such as LEDs on the device. In some embodiments, the system provides audible information to the operator, for example by different sounds and/or by speech.

Said information provided to the operator can comprise instructions for use, warnings, and the like.

The information can aid with improving the action performance or operation functionality of the device, for example by indicating how well an action or operation is being performed, and/or instructions to the operator aimed at improving the ease of the action or operation and/or the quality of the action or operation's results. For example, a LED can change in color and/or flashing frequency. In a scanner, the information can relate to how well the scanned 3D environment is in focus and/or to scan quality and/or to scan coverage. The information can comprise instructions on how best to position the scanner such as to attain good scan quality and/or scan coverage. The instructions can be used for planning and/or performing bracket placement. The instructions can be in the form of a messenger system to the operator.

In some embodiments, some 3D user interface functionality is provided by at least one motion sensor built into the device. Examples of motion sensors are accelerometers, gyros, and magnetometers and/or the like. These sensors can sense rotations, lateral motion, and/or combinations thereof. Other motion sensors use infrared sensing. For example, at least one infrared sensor can be mounted on the device and at least one infrared emitter can be mounted in the surroundings of the device. Conversely, the at least one emitter can be mounted on the device, and the at least one sensors in the surroundings. Yet another possibility is to use infrared reflector(s) on the device and both sensor(s) and emitter(s) on the surroundings, or again conversely. Thus motion can be sensed by a variety of principles.

Through proper signal processing, some sensors can recognize additional operator actions; for example gestures such as taps, waving, or shaking of the handheld device. Thus, these gestures can also be exploited in the 3D user interface functionality.

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In some embodiments the handheld device comprises at least two motion sensors providing sensor fusion. Sensor fusion can be used to achieve a better motion signal from for example raw gyro, accelerometer, and/or magnetometer data. Sensor fusion can be implemented in ICs such as the InvenSense MPU 3000.

In some embodiments the handheld device comprises at least one user-interface element other than the at least one motion sensor.

In some embodiments the at least one other user-interface element is a touch-sensitive element.

In some embodiments the at least one other user-interface element is a button.

In some embodiments the at least one other user-interface element is a scroll-wheel.

In some embodiments, user interface functionality is provided through additional elements on the device. Thus these additional elements can for example be buttons, scroll wheels, touch-sensitive fields, proximity sensors and/or the like.

The additional user interface elements can be exploited or utilized in a workflow suitable for the field of application of the device. The workflow may be implemented in some user software application that may also control the display and thus the view represented thereon. A given interface element can supply multiple user inputs to the software. For example, a button can provide both a single click and a double click. For example, a double click can mean to advance to a subsequent step in a workflow. For the example of

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intraoral scanning, three steps within the workflow can be to scan the lower mouth, the upper mouth, and the bite. A touch-sensitive field can provide strokes in multiple directions each with a different effect, etc. Providing multiple user inputs from a user interface elements is advantageous because the number of user interface elements on the device can be reduced relative to a situation where each user interface element only provides one user input.

The motion sensors can also be exploited in a workflow. For example, lifting the device, which can be sensed by an accelerometer, can represent some type of user input, for example to start some action. In a device that is a scanner, it may start scanning. Conversely, placing the device back in some sort of holder, which can be sensed by an accelerometer as no acceleration occur over some period of time, can stop said action.

If the action performed by the device is some kind of recording, for example scanning, for example 3D scanning, the results of the recording can also be exploited as user inputs, possibly along with user inputs from other user interface elements. For example, with a 3D scanner with a limited depth of field, it may be possible to detect whether any objects within the 3D environments are present in the volume corresponding to this depth of field by detecting whether any 3D points are recorded. User inputs can depend on such detected presence. For example, a button click on an intraoral scanner can provide a different user input depending on whether the scanner is in the mouth, where teeth are detectable, or significantly away from and outside the mouth. Also the effect of motion sensor signals can be interpreted differently for either situation. For example, the scanner may only change the view represented on the display when it is outside the mouth.

In some embodiments the handheld device is adapted to change a viewing angle with which the 3D environment is represented on the at least one display.

In some embodiments the handheld device is adapted to change a magnification factor with which the 3D environment is represented on the at least one display.

In some embodiments the handheld device is adapted to change a viewing position with which the 3D environment is represented on the at least one display.

In some embodiments the view of the 3D environment comprises a viewing angle, a magnification factor, and/or a viewing position.

In some embodiments the view of the 3D environment comprises rendering of texture and/or shading.

In some embodiments the at least one display is divided into multiple regions, each showing the 3D environment with a different view.

Thus in some embodiments the user interface functionality comprises changing the view with which the 3D environment is displayed. Changes in view can comprise changes in viewing angle, viewing position, magnification and/or the like. A change in viewing angle can naturally be effected by rotating the device. Rotation is naturally sensed by the aid of gyros and/or relative to gravity sensed by an accelerometer. Zooming, i.e. a change in magnification, can for example be achieved by pushing the handheld device forward and backward, respectively. A translational change of the viewing position, i.e., panning, can for example be achieved by pushing the handheld device up/down and/or sideways.

In some embodiments the user interface functionality comprises selecting or choosing items on a display or any other functionality provided by graphical user interfaces in computers known in the art. The operator may perform the selection. The Lava C.O.S scanner marketed by 3M ESPE has additional buttons on the handheld device, but it is not possible to manipulate the view by these. Their only purpose is to allow navigation through a menu system, and to start/stop scanning.

In some embodiments the user interface functionality comprises manipulating the 3D environment displayed on the screen. For example, the operator may effect deformations or change the position or orientation of objects in the 3D environment. Thus, in some embodiments the user interface functionality comprises virtual user interface functionality, which can be that the 3D data are manipulated, but the physical 3D environment in which the device operates may not be manipulated.

In some embodiments the handheld device is an intraoral scanner and/or an in-the-ear scanner. If the scanner comprises a tip, this tip may be exchanged whereby the scanner can become suitable for scanning in the mouth or in the ear. Since the ear is a smaller cavity than the mouth, the tip for fitting into an ear may be smaller than a tip for fitting in the mouth.

In some embodiments the handheld device is a surgical instrument. In some embodiments, the surgical instrument comprises at least one motion sensor, which is built-in in the instrument.

In some embodiments the handheld device is a mechanical tool. In some embodiments, the tool has at least one motion sensor built in. In other embodiments, other user-interface elements are built in as well, for example buttons, scroll wheels, touch-sensitive fields, or proximity sensors.

In some embodiment the 3D geometry of the 3D environment is known a-priori or a 3D representation of the environment is known a priori, i.e. before the actions (s) are performed. For example in surgery, a CT scan may have been taken before the surgical procedure. The handheld device in this example could be a surgical instrument that a physician needs to apply in the proper 3D position. To make sure this proper position is reached, it could be beneficial to view the 3D environment from multiple perspectives interactively, i.e. without having to release the surgical instrument.

An advantage of the system, also in the above surgery example, is the ability of the handheld device to record the 3D environment at least partially, typically in a 3D field-of-view that is smaller than the volume represented in the a-priori data. The 3D data recorded by the handheld device can be registered in real time with the a-priori data, such that the position and orientation of the device can be detected.

In some embodiments the 3D geometry comprises a 3D surface of the environment.

In some embodiments the 3D geometry comprises a 3D volumetric representation of the environment.

Thus the 3D environment can be displayed as volumetric data, or as surface, or a combination thereof. Volumetric data are typically represented by voxels. Voxels can comprise multiple scalar values. Surface data are typically represented as meshed, such as triangulated meshes, or point clouds.

The scanning may be performed by means of LED scanning, laser light scanning, white light scanning, X-ray scanning, and/or CT scanning.

The present invention relates to different aspects including the system described above and in the following, and corresponding systems, methods, devices, uses, and/or product means, each yielding one or more of the benefits and advantages described in connection with the first mentioned aspect, and each having one or more embodiments corresponding to the embodiments described in connection with the first mentioned aspect and/or disclosed in the appended claims.

In particular, disclosed herein is a method of interaction between a handheld device and at least one display, where the method comprises the steps of:

- performing at least one action in a physical 3D environment by means of the handheld device;
- visually representing the physical 3D environment by the at least one display; and
- remotely controlling the view of the represented 3D environment on the display by means of the handheld device.

Furthermore, the invention relates to a computer program product comprising program code means for causing a data processing system to perform the method according to any of the embodiments, when said program code means are executed on the data processing system, and a computer program product, comprising a computer-readable medium having stored there on the program code means.

According to another aspect, disclosed is a system comprising a handheld device for operating in a 3D environment and at least one display for visualizing said environment, where the display is adapted to represent said environment from multiple perspectives,
where said device is adapted to be held in one hand by an operator, and where the perspective represented in the at least one display is at least partly determined by the motion of the operator's hand holding said device.

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According to another aspect, disclosed is a system comprising a handheld device for operating in a 3D environment and at least one display for visualizing said environment, where the display is adapted to represent said environment in multiple views,
where said device is adapted to be held in one hand by an operator, where the view represented in the at least one display is at least partly determined by the motion of the operator's hand holding said device, and where the device has at least one touch-sensitive user interface element.

The motion of the operator's hand is typically determined by a motion sensor arranged in the handheld device.

Definitions

3D geometry: A constellation of matter or its virtual representation in a three-dimensional space.

3D environment: A constellation of physical objects each having a 3D geometry in a three-dimensional space.

View: The way a 3D environment is represented on a display. Geometrically, a view is determined by the virtual observer's/camera's position and orientation. If the display is two-dimensional, the view is also determined by the type of projection. A view may also be determined by a magnification factor. Graphically, a view can show the 3D environment by means of photographs or as some kind of virtual representation such as a computer graphic, or similar. A computer graphic can be rendered for example with texture and/or shading and/or virtual light sources and/or light models for surface properties. A computer graphic can also be a simplified

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representation of the 3D environment, for example a mesh, an outline, or an otherwise simplified representation. All or parts of the 3D environment can also be rendered with some degree of transparency. A view may represent the 3D environment in total or only parts thereof.

Functionality: A purpose or intended use.

Performing action(s) or operating functionality: Actions or functionality that includes some type of interaction with a 3D environment, such as measuring, modifying, manipulating, recording, touching, sensing, scanning, moving, transforming, cutting, welding, chemically treating, cleaning, etc. The term "operating" is thus not directed to surgical procedures, but operating may comprise surgical procedures.

User Interface Functionality: Functionality for interaction between a human user and a machine with a display.

Handheld device: An object that has at least one functionality and that is held by a human operator's hand or both hands while performing this at least one functionality.

3D scanner: A device that analyzes a real-world object or 3D environment to collect data on its shape and possibly its appearance.

Coverage of scan: The degree to which a physical surface is represented by recorded data after a scanning operation.

Motion sensor: A sensor detecting motion. Motion can be detected by: sound (acoustic sensors), opacity (optical and infrared sensors and video image processors), geomagnetism (magnetic sensors, magnetometers), reflection of transmitted energy (infrared laser radar, ultrasonic sensors, and