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(54) **IMAGE-GUIDED SURGERY WITH SURFACE RECONSTRUCTION AND AUGMENTED REALITY VISUALIZATION**

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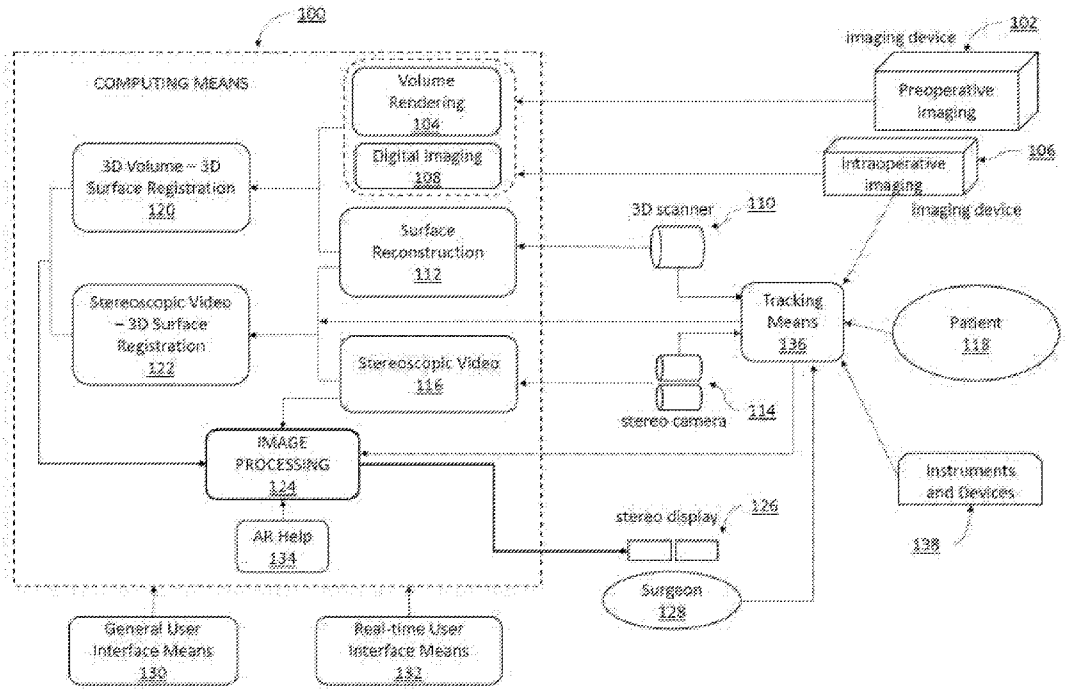
(57) **ABSTRACT**

Embodiments disclose a real-time surgery method and apparatus for displaying a stereoscopic augmented view of a patient from a static or dynamic viewpoint of the surgeon, which employs real-time three-dimensional surface reconstruction for preoperative and intraoperative image registration. Stereoscopic cameras provide real-time images of the scene including the patient. A stereoscopic video display is used by the surgeon, who sees a graphical representation of the preoperative or intraoperative images blended with the video images in a stereoscopic manner through a see through display.



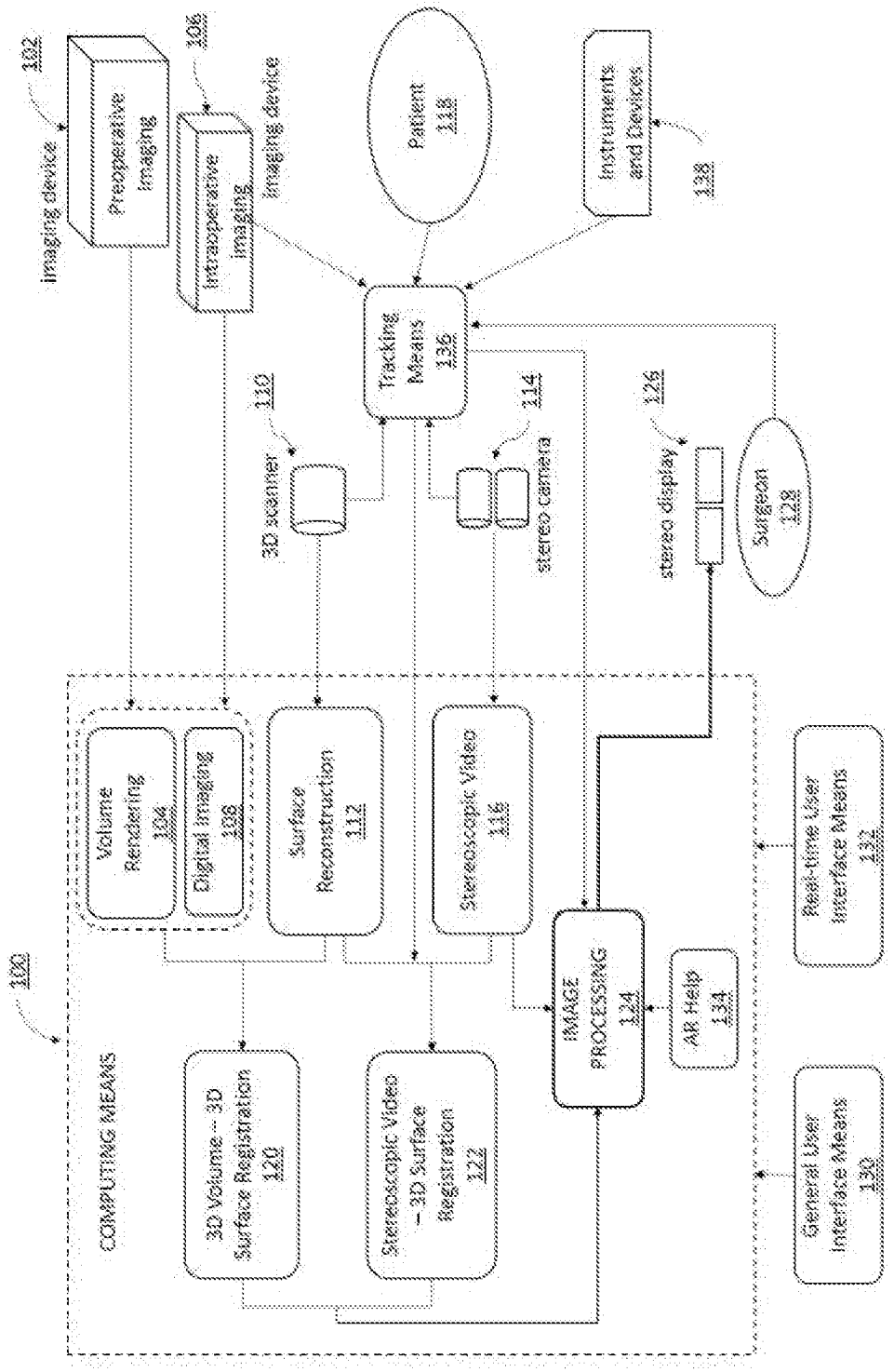
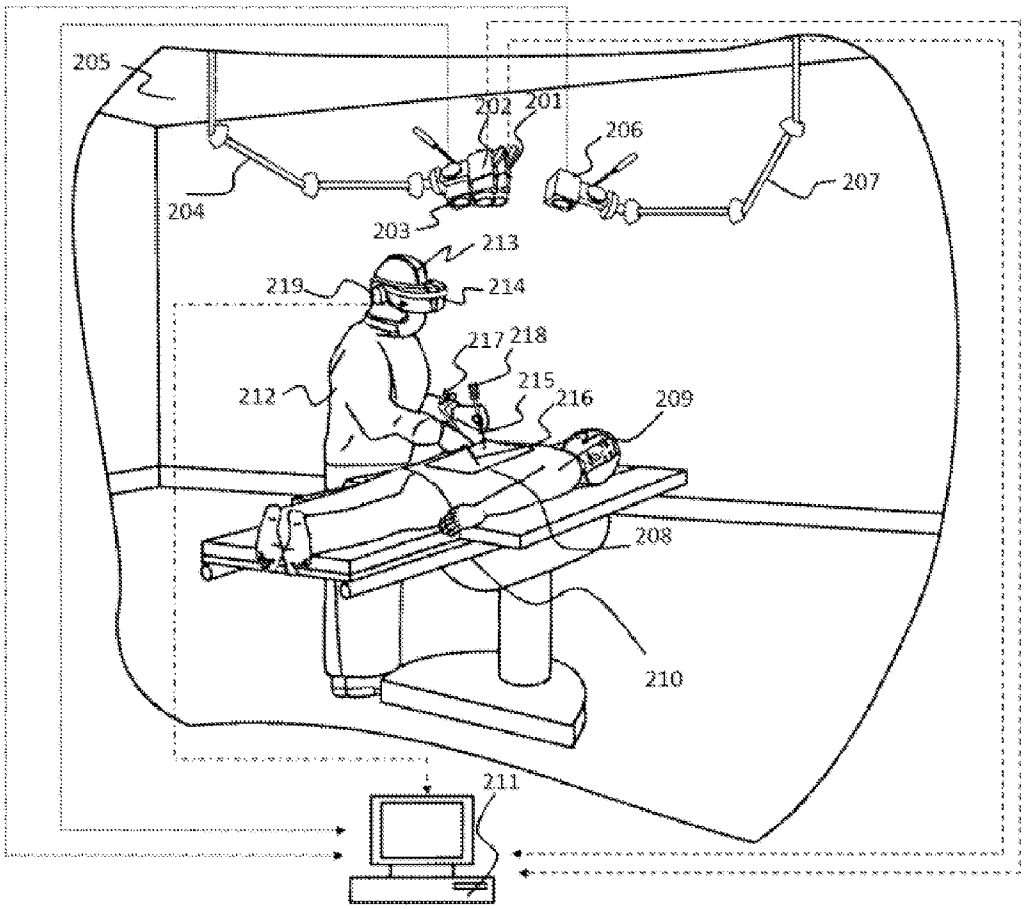

102
Imaging device
Preoperative Imaging
106
Imaging device
Intraoperative Imaging
Patient 118
Instruments and Devices
138
Tracking Means 136
110
3D scanner
114
stereo camera
126
stereo display
Surgeon 128
100
COMPUTING MEANS
Volume Rendering 104
Digital Imaging 108
Surface Reconstruction 112
Stereoscopic Video 116
IMAGE PROCESSING 124
AR Help 134
Real-time User Interface Means 132
General User Interface Means 130
3D Volume – 3D Surface Registration 120
Stereoscopic Video – 3D Surface Registration 122

FIG. 1


205
202
201
206
207
204
203
213
219
214
217
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215
212
216
209
208
210
211

FIG. 2

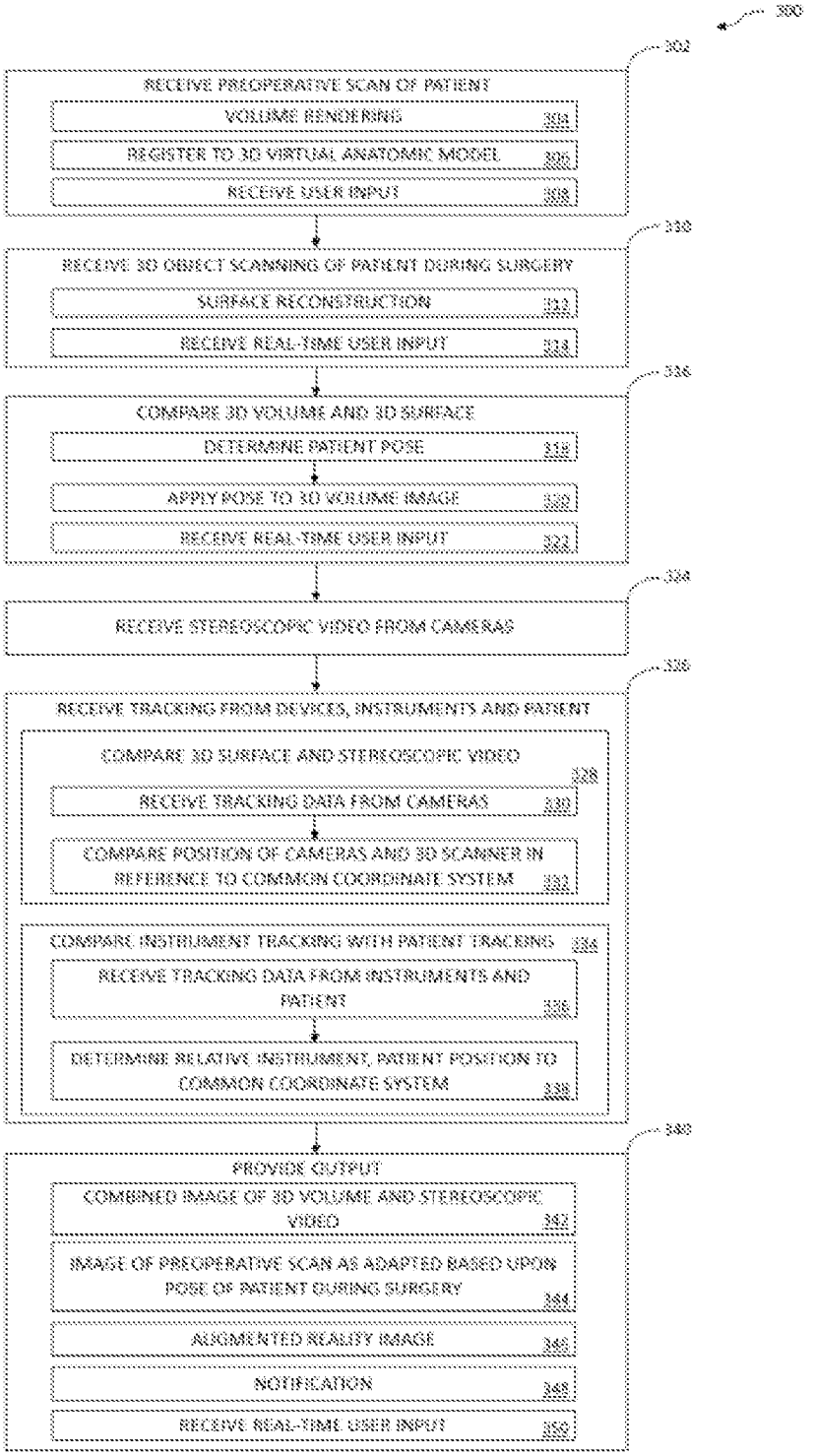
300
302
RECEIVE PREOPERATIVE SCAN OF PATIENT
VOLUME RENDERING 304
REGISTER TO 3D VIRTUAL ANATOMIC MODEL 306
RECEIVE USER INPUT 308
310
RECEIVE 3D OBJECT SCANNING OF PATIENT DURING SURGERY
SURFACE RECONSTRUCTION 312
RECEIVE REAL-TIME USER INPUT 314
316
COMPARE 3D VOLUME AND 3D SURFACE
DETERMINE PATIENT POSE 318
APPLY POSE TO 3D VOLUME IMAGE 320
RECEIVE REAL-TIME USER INPUT 322
324
RECEIVE STEREOSCOPIC VIDEO FROM CAMERAS
326
RECEIVE TRACKING FROM DEVICES, INSTRUMENTS AND PATIENT
COMPARE 3D SURFACE AND STEREOSCOPIC VIDEO 328
RECEIVE TRACKING DATA FROM CAMERAS 330
COMPARE POSITION OF CAMERAS AND 3D SCANNER IN REFERENCE TO COMMON COORDINATE SYSTEM 332
COMPARE INSTRUMENT TRACKING WITH PATIENT TRACKING 334
RECEIVE TRACKING DATA FROM INSTRUMENTS AND PATIENT 336
DETERMINE RELATIVE INSTRUMENT, PATIENT POSITION TO COMMON COORDINATE SYSTEM 338
340
PROVIDE OUTPUT
COMBINED IMAGE OF 3D VOLUME AND STEREOSCOPIC VIDEO 342
IMAGE OF PREOPERATIVE SCAN AS ADAPTED BASED UPON POSE OF PATIENT DURING SURGERY 344
AUGMENTED REALITY IMAGE 346
NOTIFICATION 348
RECEIVE REAL-TIME USER INPUT 350

FIG. 3

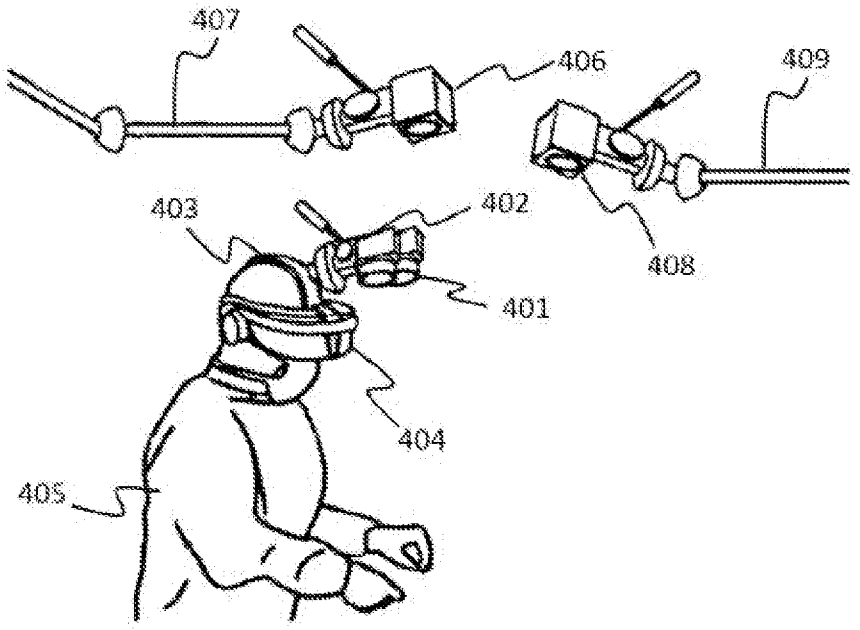

FIG. 4

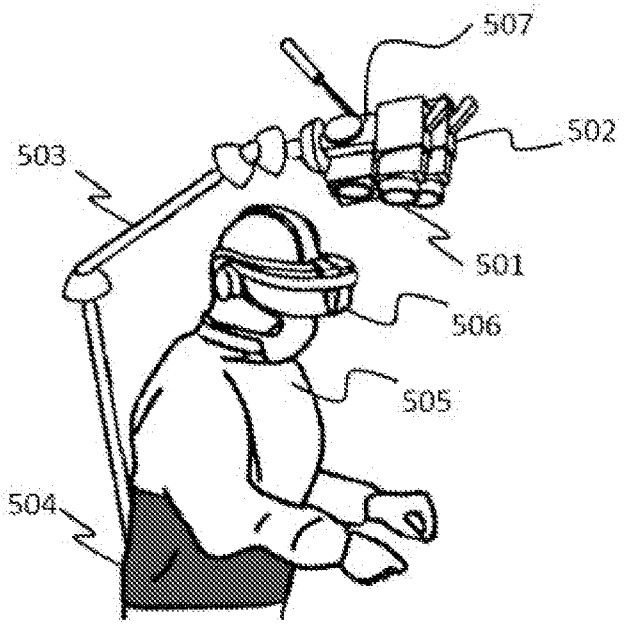

FIG. 5

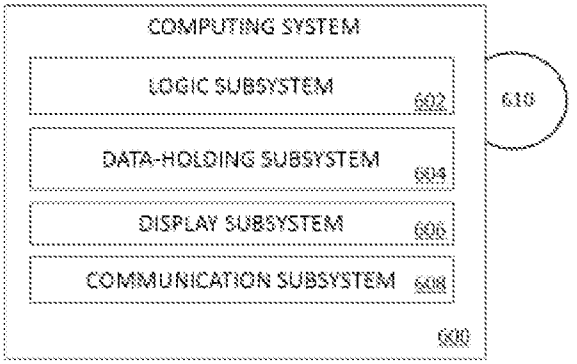
COMPUTING SYSTEM
LOGIC SUBSYSTEM
602
DATA-HOLDING SUBSYSTEM
604
DISPLAY SUBSYSTEM
606
COMMUNICATION SUBSYSTEM
608
600
610

FIG. 6

IMAGE-GUIDED SURGERY WITH SURFACE RECONSTRUCTION AND AUGMENTED REALITY VISUALIZATION

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims a benefit of priority under 35 U.S.C. §119 to Provisional Application No. 62/097,771 filed on Dec. 30, 2014, which is fully incorporated herein by reference in their entirety.

BACKGROUND INFORMATION

[0002] 1. Field of the Invention

[0003] Embodiments are directed towards image-guided surgery, and more particularly CT-guided, MR-guided, fluoroscopy-based or surface-based image-guided surgery, wherein images of a portion of a patient are taken in the preoperative or intraoperative setting and used during surgery for guidance.

[0004] 2. Background

[0005] In the practice of surgery, an operating surgeon is generally required to look back and forth between the patient and a monitor displaying patient anatomical information for guidance in operation. In this manner, a type of mental mapping is made by the surgeon to understand the location of the target structures. However, this type of mental mapping is difficult, has a steep learning curve, and compromises the accuracy of the information used.

[0006] Equipment has been developed by many companies to provide intraoperative interactive surgery planning and display systems, mixing live video of the external surface of the patient with interactive computer generated models of internal anatomy obtained from medical diagnostic imaging data of the patient. The computer images and the live video are coordinated and displayed to a surgeon in real time during surgery, allowing the surgeon to view internal and external structures and the relationship between them simultaneously, and adjust the surgery accordingly.

[0007] Preoperative or intraoperative image registration with surface reconstruction has been done in conventional surgery navigation systems either with a single 3D scanner device that functions at the same time as video camera (e.g. time-of-flight cameras). These conventional systems display the surgeon's main viewpoint, or a video camera or stereoscopic video cameras that are used as viewpoint for the surgeon are used for processing a surface reconstruction. These conventional systems may enhance the surface reconstruction or image registration with other techniques, such as optical or infrared techniques, markers, etc. However, these systems are limited in the availability of precise 3D surfaces, in their precision and speed of image registration of preoperative or intraoperative image with the 3D surfaces, and in blending such registered images with the viewpoint of the surgeon.

[0008] Accordingly needs exist for more effective systems and methods that combine real-time preoperative images with virtual graphics associated with the preoperative images, wherein the combination of the preoperative images and virtual graphics is displayed on a stereoscopic, see through, head mounted display.

SUMMARY OF THE INVENTION

[0009] Embodiments disclosed here describe a real-time surgery navigation method and apparatus for displaying an augmented view of the patient from the preferred static or dynamic viewpoint of the surgeon. Embodiments utilize a surface image, a graphical representation the internal anatomic structure of the patient processed from preoperative or intraoperative images, and a computer registering both images. Responsive to registering the images, a head mounted display may present to a surgeon an augmented view of the patient, wherein the augmented reality is presented via a head mounted display.

[0010] Embodiments disclosed herein include a stereoscopic camera system. The stereoscopic camera system may be configured to provide real-time stereoscopic images of a target portion of the patient. In embodiments, the stereoscopic camera system may include a 3D scanner system that is configured to determine location data and orientation data, wherein the location data and orientation data are determined in reference to a common coordinate system.

[0011] Responsive to the stereoscopic camera system recording media, and determining the location data and orientation data, a stereoscopic view of the 3D volume image may be output to a stereoscopic display to the surgeon in real time. The stereoscopic view of the 3D volume image may be blended in a same position as the patient appears in the stereoscopic video images during surgery. The stereoscopic view of the 3D volume image are displayed in the preferred manner, e.g. using background subtraction techniques, the 3D volume image appearing over the patient as background model, the hands and instruments appearing as foreground objects.

[0012] Embodiments may be configured to assist in real time during surgery, wherein the stereoscopic view of the 3D volume image is presented in a surgeon's field of view in a stereoscopic manner, e.g. graphical representations of instruments tracked, surgical guides or techniques, anatomical models, etc. as needed. Accordingly, utilizing the stereoscopic view of the 3D volume image, the surgeon may be able to make adjustments to the stereoscopic view of the 3D volume image. For example, the surgeon may modify the stereoscopic view of the 3D volume image by selecting a transparency, color and contrast of each image layer displayed, using an available real-time user interface means, which may include gesture recognition methods.

[0013] Embodiments may be independent devices and processes for each main task provided during surgery: surface reconstruction and image registration, stereoscopic video and stereoscopic image registration. Embodiments may also be configured to provide an enhanced depth perception through background subtraction methods, and real-time user interaction, which may change the separation of the stereoscopic video cameras, adjusting the position of the registered 3D volume, displaying the 3D volume in a precise manner, adapting for pose change detected in the surface, adjusting the degree of transparency, color and contrast, etc.

[0014] Embodiments disclosed herein disclose systems that are configured to record stereoscopic video with at least two mounted cameras. The media record by the cameras may be in the field of view of a surgeon. Utilizing a head-mounted display, the surgeon may freely move in the operating room, keeping the desired field of vision defined by the position and orientation of the mounted cameras. With the mounted cameras and the head mounted display, the surgeon would be able to view the media recorded by the mounted cameras.

[0015] Virtual graphics may be added to the media recorded by the two cameras. Responsive to the virtual graph-

ics being added to the recorded media, the surgeon may be presented on the head-mounted display a preoperative image, such as a 3D volume image of a previous CT. The preoperative image may be presented, recorded, or registered (referred to hereinafter collectively and individually as "registered") over the patient, in real time. Thus, the internal anatomical structures of the patient may be blended with the media recorded by the mounted cameras.

[0016] In embodiments, tracking may be configured to be added to instruments or implants within the preoperative image, wherein virtual graphics are associated with views inside the patient presented to the surgeon. Accordingly, embodiments may be configured to register preoperative images blended with virtual graphics over a target portion of a patient, wherein the blended images are presented over a visual field of a surgeon.

[0017] In embodiments, an intermediate 3D surface may be obtained by surface reconstruction via 3D scanners. The intermediate 3D surface may be used for registration with a 3D volume obtained by volume rendering via image data from a CT or MR scan. The 3D volume image of the patient may be automatically located in real time to the positioned of the patient based on a common coordinate system between the stereoscopic cameras, head mounted display, the virtual graphics, and/or the 3D surface. The 3D volume image may be any surface rendering of a preoperative image.

[0018] Tracking a 3D scanner's virtual camera and the mounted camera to the coordinate system, may define where an augmented view may be positioned on the head mounted display. Accordingly, the preoperative images may be utilized without markers, which may allow for more flexible and quicker registration.

[0019] These, and other, aspects of the invention will be better appreciated and understood when considered in conjunction with the following description and the accompanying drawings. The following description, while indicating various embodiments of the invention and numerous specific details thereof, is given by way of illustration and not of limitation. Many substitutions, modifications, additions or rearrangements may be made within the scope of the invention, and the invention includes all such substitutions, modifications, additions or rearrangements.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] Non-limiting and non-exhaustive embodiments of the present invention are described with reference to the following figures, wherein like reference numerals refer to like parts throughout the various views unless otherwise specified.

[0021] FIG. **1** shows a block diagram of the present invention;

[0022] FIG. **2** shows a perspective view of a surgery navigation system of the present invention;

[0023] FIG. **3** shows a flow diagram of a method of the present invention;

[0024] FIG. **4** shows a perspective view of the surgery navigation system of the present invention;

[0025] FIG. **5** shows a perspective view of the surgery navigation system of the present invention;

[0026] FIG. **6** shows a block diagram depicting a computing device of the present invention.

[0027] Corresponding reference characters indicate corresponding components throughout the several views of the drawings. Skilled artisans will appreciate that elements in the figures are illustrated for simplicity and clarity and have not necessarily been drawn to scale. For example, the dimensions of some of the elements in the figures may be exaggerated relative to other elements to help improve understanding of various embodiments of the present disclosure. Also, common but well-understood elements that are useful or necessary in a commercially feasible embodiment are often not depicted in order to facilitate a less obstructed view of these various embodiments of the present disclosure.

DETAILED DESCRIPTION OF THE INVENTION

[0028] In the following description, numerous specific details are set forth in order to provide a thorough understanding of the present embodiments. It will be apparent, however, to one having ordinary skill in the art that the specific detail need not be employed to practice the present embodiments. In other instances, well-known materials or methods have not been described in detail in order to avoid obscuring the present embodiments.

[0029] FIG. **1** shows an exemplary embodiment of the surgical navigation system. Surgical navigation system **100** may include devices configured to create a 3D rendering of a region of interest.

[0030] Using computer means **100**, volume data of a patient scanned with a preoperative imaging **102** or an intraoperative imaging **106** device (e.g. CT scanner) is rendered as a 3D volume image using a volume rendering technique **104** and stored for processing, wherein the volume data is associated with a volume of the patient. Preoperative **102** and intraoperative images **106** are also stored as digital images **108** for processing.

[0031] While computing means **110** is scanning the volume data, 3D scanner system **110** may be configured to capture a 3D surface **112** of the target portion of the patient **118**, and a stereoscopic camera system (e.g. pair of cameras) **114** may be configured to obtain a stereoscopic video **116** of the scene, including the target portion of the patient **118**.

[0032] Registration of the 3D volume and the 3D surface **120** is performed by computer means **100**, as is the registration of the stereoscopic video with the 3D surface **122**. In embodiments, registration of 3D volume **104** and stereoscopic video **116** is completed through an intermediate registration of both images with the 3D surface image **112** into a common coordinate system,

[0033] The images are processed **124** and sent to the stereoscopic display **126** used by the surgeon **128**. The registration and other image processing **124** by computer means **100** is adjusted by the surgeon **128** or other users through general user interface means **130** before surgery, or through real-time user interface means **132** during surgery, e.g. by interaction of the surgeon **128** with a device capable of gesture recognition (e.g. the same 3D scanner system **110** and/or stereoscopic display system **126**).

[0034] User interface means **130**, **132** may include graphical user interface means (e.g. virtual graphics like buttons) displayed within the surgeon's **128** view, through a 3D display **126**, which may be a virtual reality, augmented reality, etc. device. Augmented reality (AR) help **134** is added to the processed images sent to the stereoscopic display system **126**.

[0035] Tracking means **136**, such as optical markers, may be attached to the patient **118** providing anatomic landmarks of the patient during the preoperative **102** or intraoperative images **106**, and during the 3D scanning process for registration of the 3D volume with the 3D surface **120**. The optical

markers, alone or in combination with other tracking means, such as inertial measurement units (IMU), may be attached to the 3D scanner system **110**, stereoscopic camera system **114**, the surgeon **128** (e.g. in the head-mounted stereoscopic display **126**), as well as to any instruments and devices **138** (e.g. screws, plates, pins, nails, arthroplasty components, etc., broaches, screwdrivers, motors, etc.) used by the surgeon **128**. Utilizing tracking means, systems may offer real-time data for a more precise location and orientation of images and objects in the common coordinate system used. The stereoscopic video **116** may be sent directly to the stereoscopic display **126**, without undergoing image processing **124**, if the surgeon **128** or other users select that option using the available interface means **130**, **132**.

[0036] FIG. **2** shows an embodiment of an example of the perspective view of this navigation system in a model operating room. As depicted in FIG. **2**, a pair of video cameras **201**, **202** (corresponding to the stereoscopic camera system **114** in FIG. **1**) may be configured to capture a stereoscopic view **116** of a region of interest. In FIG. **2**, a 3D scanner **203** (corresponding to the 3D scanner system **110** in FIG. **1**) is positioned proximate to the stereoscopic cameras **201**, **202**, in a known location and orientation angle with respect to them. The cameras **201**, **202** and 3D scanner **203** are attached e.g. to an articulated mechanical arm **204** that is suspended from the ceiling **205**. A second 3D scanner **206** (also part of the 3D scanner system **110**), e.g. with motion tracking capabilities, is attached to another mechanical articulated arm **207**.

[0037] The 3D scanners **203**, **206** capture a 3D surface **112** of the target portion **208** of the patient **209** located on a surgical table **210**. Images and data obtained from 3D scanners **203**, **206** is stored and processed in the computer **211** (corresponding to the computer means in **100** in FIG. **1**) used for image processing, and the surgeon **212** and other users are able to interact with it through the available interface means **130**, **132** (e.g. gesture recognition, or mouse and keyboard). The processed images **124** (e.g. stereoscopic video **116** blended with stereoscopic 3D volumetric images **104** of the internal anatomical structures) are displayed to the surgeon **212** wearing the head-mounted **213** stereoscopic display **214** (corresponding to the stereoscopic display system **126** in FIG. **1**) in real time. Instruments **215**, **216** are tracked e.g. by markerless optical means (e.g. using the 3D scanners **203**, **206** in real time), by optical means using markers **217**, by inertial measurement units **218**, or a combination of these and other tracking means.

[0038] To the surgeon **212**, the internal structures of the patient **209** appear directly superimposed on the target portion of the patient **208** with the selected transparency, or the selected layers of the stereoscopic 3D volumetric images appear blended with the stereoscopic video **116**, or only the 3D volumetric images **104** are shown, or any other stereoscopic images from the sources available are shown to the surgeon **212**, modified by any software-implemented change, like zoom, color or contrast adjustments, depending on the previous 130 or real-time interaction **132** to modify the image processing **124**.

[0039] Responsive to surgeon **212** moving his or her head around to view the spatial relationship of the structures from varying positions, computer means **100** may be configured to provide the precise, objective registration between the digital images of the internal structures **104**, **108** and the surface reconstruction **112** of the portion of the patient **208**. This in situ or "augmented reality" visualization gives the surgeon **212** intuitively based, direct, and precise access to the image information in regard to the surgical task. Headphones **219** include sound to the augmented reality experience of the surgeon **212**, who can hear the different steps of the surgery as it develops, or the advice of other professionals in a different place, who may be seeing the same images displayed to the surgeon **212**, thanks to online communication.

[0040] FIG. **3** shows a flow diagram depicting an embodiment of a method **300** for integrating preoperative **102** and stereoscopic video **116** images. The operations of method **300** presented below are intended to be illustrative. In embodiments, method **300** may be accomplished with one or more additional operations not described, and/or without one or more of the operations discussed. Additionally, the order in which the operations of method **300** are illustrated in FIG. **3** and described below is not intended to be limiting.

[0041] At operation **302**, the computer **100** receives preoperative image data (e.g. CT scan) **102**.

[0042] At operation **304**, the preoperative image data is processed into a 3D volume by a volume rendering technique (which is the same as the volume rendering **104** in FIG. **1**). The volume rendering technique may be based e.g. on segmentation of the volume data of the anatomic internal parts of the portion of the patient **118**.

[0043] At operation **306**, one or more graphical representations of the imaged structures may be provided. Operation **306** may be performed with user interaction at Operation **308** (before or during surgery), using the available user interface means **130**, **132**.

[0044] At operation **310**, a 3D scan of the patient may be received.

[0045] At operation **312**, a precise surface reconstruction of the patient (which is the same as the surface reconstruction **112** in FIG. **1**) may be constructed automatically.

[0046] At operation **314**, the surface reconstruction of the patient may be adjusted with input from the surgeon **128** or other users.

[0047] At operation **316**, the 3D volume rendering and the surface reconstruction may be compared by automated means.

[0048] At operation **318**, the pose of the patient may be determined during surgery.

[0049] At operation **320**, the 3D volume may be adjusted according to the determined pose. More specifically, the 3D volume may be adjusted so that the orientation of the 3D volume as displayed to the surgeon matches the orientation of the portion of the patient on which the surgeon is operating.

[0050] At operation **322**, the surgeon or other users may be able to correct, in real time, the pose.

[0051] At operation **324**, the computer may receive stereoscopic video (which is the same as the stereoscopic video **116** in FIG. **1**) from the stereoscopic camera system.

[0052] At operation **326**, tracking means attached to the 3D scanner system **110**, stereoscopic camera system **114**, patient **118**, imaging devices **106**, and instruments **138**, may send data to the computer **100**. The computer may process and store the received data **326**. For example, the received data may include 3D surface and stereoscopic video.

[0053] At operation **328**, the 3D surface data and data associated with the stereoscopic video may be compared.

[0054] At operation **330**, orientation tracking data of each of the cameras that form the stereoscopic camera system may

be obtained. The obtained orientation tracking data may be used in combination with the appropriate tracking means **136** for location.

[0055] At operation **332**, a view of the 3D surface may be displayed to the surgeon, wherein the view corresponds to the precise position of each camera in the common coordinate system.

[0056] At operation **334**, patient tracking data may be compared with instrument or device tracking data, e.g. with data from inertial measurement units and optical markers placed on the patient **118**, and/or instruments **138**.

[0057] At operation **336**, the patient tracking data may be received by the computer.

[0058] At operation **338**, the patient tracking data may be automatically processed, which may be configured to locate all tracked objects within the common coordinate system. Utilizing the common coordinate system and the patient tracking data, a visualization associated with the patient tracking data within the common coordinate system may be displayed to the surgeon or other users in real time, e.g. in numeric or graphic format. Accordingly, the position of the cameras forming the stereoscopic camera system **114** may be dynamically determined, and utilizing the position of the cameras the precise location and orientation of the 3D surface model with respect to the view of each camera **114** may be determined. The position of the data recorded by each camera **114** in the common coordinate system corresponding to the position of the virtual cameras may offer a view of the 3D surface.

[0059] At operation **340**, a blended image output may be presented on the stereoscopic display **126**. At operation **342**, registration of the 3D volume and the stereoscopic video is done with help from an intermediate 3D surface reconstruction. This process may be fully automatic by software means, or may be performed with help from user interaction.

[0060] At operation **344**, the registration of the 3D volume and the stereoscopic video may account for pose changes of the patient, and it is displayed to the surgeon according to the precise location of the cameras **114**, so that there is a seamless integration of all views (e.g. video, 3D surface and 3D volume) to both eyes.

[0061] At operation **346**, the images are displayed stereoscopically to the surgeon **128** in real time. The images may depict an augmented reality image or "augmented view."

[0062] At operation **348**, the augmented reality image may include notification helps **348**.

[0063] At operation **350**, the surgeon **128** or other users may perform actions to input data into to the system in real time during surgery using the available user interface means **132**. Thus, modifying the image processing **124** and customizing the view shown in the display **126**.

[0064] Returning to FIG. **2**, the stereoscopic camera system **114** captures a stereoscopic view of the scene, wherein the stereoscopic camera system **114** is comprised of a pair of cameras **201**, **202**. The cameras **201**, **202** may be positioned at a certain distance from each other. This distance is adjusted depending on the interpupillary distance of the surgeon **212**, and on the distance from the cameras **201**, **202** to the target field of view, usually centered on the target portion of the patient **118**. The computer **211** receives the video images **116** and sends them to the stereoscopic display **219**, with or without modifications through image processing **124**, such as additional virtual graphics, zoom, color or contrast adjustments.

[0065] In embodiments, as depicted in FIG. **2**, the pair of cameras **201**, **202** may be attached to an articulated mechanical arm **204** that is e.g. suspended from the ceiling **205**. In this exemplary embodiment, the 3D scanner **203** is in a fixed position close to the cameras **201**, **202**, so that location and orientation tracking between the devices is not necessary. Alternatively, the 3D scanner **206** may not be in a fixed position with respect to the cameras **201**, **202**, and is e.g. attached to another articulated mechanical arm **206** suspended from the ceiling **207**.

[0066] Turning now to FIG. **4**, the cameras **401**, **402** are head-mounted **403** along with the stereo display **404**, and worn by the surgeon **405**. The 3D scanner **406** is attached to an articulated arm **407**, or alternatively, a 3D scanner is also head-mounted close to the cameras **401**, **402**. An additional 3D scanner **408** (e.g. with motion tracking capabilities, as a time-of-flight camera) is e.g. attached to an articulated mechanical arm **409** e.g. suspended from the ceiling, or placed on the ground, or in any other suitable location.

[0067] Turning now to FIG. **5**, the cameras **501**, **502** are mounted on a pole **503** attached to a belt **504** worn by the surgeon **505**, who sees the scene through the head-mounted stereo display **506**. The 3D scanner **507** is attached to the same pole **503**. Alternatively, or in combination with the other embodiments, a 3D scanner is attached to an articulated mechanical arm e.g. suspended from the ceiling, or placed on the ground. Alternatively, a 3D scanner is mounted on tripods standing on the ground. Alternatively, the camera system **114** is composed of a single, two-dimensional camera, used in combination with a camera from the 3D scanner system **110**. It will be understood that the above-described examples of the number and alternative positions of cameras composing the stereoscopic camera system **114** (as well as the number and position of devices composing the 3D scanner system **110**) are presented for the purpose of example, and are not intended to be limiting in any manner.

[0068] In embodiments, the surgeon **212** is able to move and rotate the cameras **201**, **202** during surgery. This is done for example through interaction with the computer system **211** that controls the mechanical arm **204** movement, e.g. with gesture recognition by the stereoscopic display **214** (e.g. virtual reality display), or by the 3D scanner **203** (e.g. time-of-flight camera with motion tracking), or with voice commands by voice recognition from an appropriate device. A third person can also interact directly with the computer **211**, e.g. according to the surgeon's **212** commands.

[0069] In embodiments the stereoscopic camera system **114** is mobile, fitting the evolving needs of the surgery through changes in location and orientation. Or alternatively the cameras **114** are placed fixed in a certain part of the operating room as previously designed, to fit the potential needs of the surgeon **128**.

[0070] In embodiments, the cameras composing the stereoscopic camera system **114** may have special lenses (e.g. fish-eye lenses, or wide-angle lenses) and they are arranged e.g. vertically side by side, to obtain a wider view and allow for the use of a virtual reality display, from those commercially available, according to each virtual reality device's preferred camera configuration. The movement of the surgeon's **128** head is tracked by the device, and the field of view of the surgeon **128** can change, while the cameras remain fixed.

[0071] In embodiments, the stereoscopic camera system **114** is composed of three or more cameras, used to obtain different stereoscopic views, e.g. arranged in circle for a

combined 360° view (for example in combination with a virtual reality display), or e.g. arranged following the outline of the target portion of the patient **118**. The stereoscopic video **116** of the scene displayed to the surgeon **128** changes by selecting a different camera pair through computer means **100**, without the need to move the cameras, for example automatically when the surgeon **128** traverses a certain location, or by interaction of the surgeon **128** or a third person through the real-time user interface means **132**.

[0072] The stereoscopic camera system **114** may be configured to provide the same images for all operating surgeons, or alternatively each surgeon may have a different stereoscopic video image displayed to him or her, or alternatively some surgeons share a view and others have individual views, depending on the needs of the surgery and the preferences of the individual surgeons.

[0073] Returning now to FIG. **1**, the preoperative **102** or intraoperative image **106** information, may be received from a CT scan or an MR scan, as well as ultrasound, PET, and C-arm cone-beam computed tomography. Preoperative X-ray and stereoscopic X-ray images, intraoperative fluoroscopic and stereoscopic fluoroscopic images, and other image modalities that allow for stereoscopic and 3D representations are also used, either directly in a digital format **108**, or as graphical 3D volumetric representations **104** of the image data.

[0074] The volume rendering may be a set of techniques used to display a two-dimensional (2D) projection of a 3D discretely sampled data set, typically a 3D scalar field. Computer means **100** may be configured to process the 3D data set (e.g. a group of 2D slice images acquired by a CT or MRI scan) with a volume rendering **104** technique, and provide one or more graphical representations of the imaged structures, which may include the 3D volume image representing the anatomic internal parts of a portion of the patient **118**.

[0075] The volume rendering **104** techniques include 3D surface rendering, 3D volume rendering, as well as fusion, parametric mapping, and multi-object rendering. More precisely, the volume rendering **104** may be done using one or more of the available methods, such as direct volume rendering (e.g. volume ray casting, splatting, shear warp, texture-based volume rendering, etc.), maximum intensity projection, hardware-accelerated volume rendering, and any of the available optimization techniques (e.g. empty space skipping, early ray termination, volume segmentation, image-based meshing, pre-integrated volume rendering, etc.). Such methods may be further helped by the user by using regions (ROI) or volumes of interest (VOI), lookup tables (LUT), and any of the available methods for refining the volume rendering **104**. It will be understood that these examples of volume rendering methods and their outputs are presented for the purpose of example, and are not intended to be limiting in any manner.

[0076] For example, 2D slice images are acquired by a CT scan, a virtual camera is defined in space relative to the volume, iso-surfaces are extracted from the volume and rendered e.g. as polygonal meshes, or directly as a block of data. In this context, a graphical representation may be a data set that is in a "graphical" format (e.g. stereolithography or STL format), ready to be efficiently visualized and rendered into an image. The surgeon **128** or other users can selectively enhance structures, color or annotate them, pick out relevant ones, include graphical objects as guides for the surgical procedure and so forth. This pre-processing may be completed offline, in preparation of the actual real-time image guidance, through the available general user interface means **130**, or it may be done (or the previous preparation adjusted) during surgery, using the available real-time user interface means **132**. In embodiments, virtual cameras that provide the 3D volume image may be positioned in space relative to the volume data, wherein the virtual cameras are correspondingly positioned to the common coordinate system, e.g. in the same position as the cameras composing the stereoscopic camera system **114**, and/or in the same position as the devices composing the 3D scanner system **110**, to allow for an easier and quicker registration of images, according to the different embodiments described.

[0077] In embodiments, two-dimensional images (e.g. fluoroscopic intraoperative images, X-rays, ultrasonographic images, etc.) are also used as 3D volume images of the target portion of the patient **118**, using any of the available methods, e.g. 2D-3D reconstruction using statistical shape models, as e.g. a distal femur 3D reconstruction from registration of an X-ray imaging (e.g. lateral and anteroposterior projections) of the femur, with a 3D statistical shape model of the distal femur, with adjustments made by the surgeon **128** or other user, through the available user interface means **130**, **132**.

[0078] In embodiments, that 2D-3D registration of intraoperative or preoperative 2D images is done with help from volume rendering **104** of the available images (e.g. from CT scan or MR scan of the target portion of the patient **118**) or from the surface reconstruction **112** of anatomical structures of the patient done during surgery. For example, in a pelvis fracture involving a hemipelvis, registration of the 2D or stereoscopic fluoroscopic intraoperative images **106** of the affected hemipelvis is done e.g. with a statistical shape model of a hemipelvis, or with the 3D volume of the CT scan of the healthy contralateral hemipelvis, or a combination of them, with interaction of the surgeon **128** and other users in real time, to obtain a precise 3D graphical representation of the fracture reduction obtained during surgery, before proceeding with the definitive fixation. In embodiments, a 3D scanner system **110** may be composed of one or more devices capable of capturing shapes of objects (and sometimes its appearance, e.g. color), usually outputting a point cloud as a data file, allowing for the construction of three-dimensional surface models of the object scanned. For example, a 3D scanner system **110** may include a laser scanner, a time-of-flight 3D laser scanner, a structured-light 3D scanner, hand-held laser scanner, a time-of-flight camera, a depth camera, or a combination of these or other devices.

[0079] The 3D scanner **110** may be moved around the target portion of the patient **118** to obtain a precise 3D surface image of it through surface reconstruction **112**. For example, computer means **100** may receive a dense 3D point cloud provided by the 3D scanning process, that represents the surface of the target portion of the patient **118** by a point cloud construction algorithm, e.g. by the intersection of two lines emanating from the camera center, or from the midpoint of a line perpendicular to these two lines. After the data acquisition, some type of smoothing of the data (e.g. Gaussian) may suppress random noise.

[0080] In embodiments, the point cloud obtained is used directly for registration purposes, e.g. by comparing it with point clouds used to represent volumetric data from preoperative **104** or intraoperative imaging **106**. In embodiments, computer means **100** make use of techniques of surface reconstruction **112** (e.g. Delaunay triangulation, alpha shapes, ball pivoting, etc.) for converting the point cloud to a

3D surface model (e.g. polygon mesh models, surface models, or solid computer-aided design models). The surface reconstruction **112** is fully automated by computer means **100**, and can be assisted **314** by the surgeon **128** or other users through the available user interface means **130**, **132**.

[0081] The 3D scanning and surface reconstruction **112** of the target portion of the patient **118** is made when the surgeon **128** desires the 3D scanning and surface reconstruction, through interaction with software means **132**. Alternatively, 3D scans are made after a predetermined amount of time has passed since the last scan. Alternatively, 3D scans are made whenever computer means **100** detect movement of the portion of the patient **118** (i.e. determining patient pose **318**), e.g. by comparing a surface reconstruction obtained from the stereoscopic video **116** to the last surface reconstruction **112** of the 3D scanner **110**, or by marker-based optical tracking, or by IMU tracking, or any other tracking means **136**.

[0082] In embodiments, multiple 3D scanners are used to make a reconstruction of the surface **112** of the target portion of the patient **118** without a need for movement of the devices composing the 3D scanner system **110**, or limiting the movement needed for each device. In another embodiment, multiple 3D scanners are also used for optical tracking **136** of instruments and devices **138**, and for determining their location and orientation. In another embodiment, a handheld 3D scanner is used, e.g. a portable 3D scanner forming part of the 3D scanner system **110** is held in the hand and moved around the target portion of the patient, and once the desired surface is obtained, it is placed in a previously defined fixed position.

[0083] In embodiments, the 3D scanner system **110** is composed of a dedicated stereoscopic camera system, composed of at least a pair of 2D video cameras. The stereoscopic camera system may be configured to capture stereoscopic video images, wherein the cameras are positioned in a desired position with respect to the other cameras forming the system to obtain the more precise surface reconstruction. The two-dimensional images taken by the cameras are converted to point clouds or mesh surfaces, or both, using known methods for surface reconstruction, for example range imaging methods (e.g. structure-from-motion). Such surface reconstruction from images of two-dimensional cameras may be used alone, or in combination with a more precise 3D scanner to make the surface model **112** obtained (and its location and orientation angle with respect to the stereoscopic camera system **114**), more accurate.

[0084] In embodiments, the 3D scanner system **110** is composed of time-of-flight cameras and/or other motion tracking devices, which are used for gesture recognition by software means, allowing for interaction of the surgeon **128** or other users with the computer **100** during surgery through the real-time user interface means **132**, without touching anything in the operating room. Alternatively or in addition to gesture recognition, voice commands are used to avoid touching the computer **100** or other devices included in this invention and controlled by computer means **100**.

[0085] In embodiments, the 3D scanner system **110** is composed of devices capable of real-time scanning (e.g. time-of-flight cameras), which are used to obtain an instant, real-time registration of the 3D surface **112** with the 3D volume **120** and the stereoscopic video **122** throughout the surgery. Blending that real-time 3D surface **112** with one acquired with a more precise device (e.g. 3D laser scanner), a more adaptable, real-time registered surface reconstruction is obtained, offering an instant, high-quality image registration during surgery.

[0086] In embodiments, the actual shape of the patient's body may be configured to be rendered into a 3D volume, such that fitting the overall shape of the 3D surface model to the patient **118** results in fitting of the model internal anatomy to the patient **118**.

[0087] The 3D/3D registration, such as the 3D volume-3D surface registration **120**, as well as 2D/3D registration, is done by computer means **100**. In embodiments, rigid registration methods are used, such as geometry-based, paired-point, surface-based, intensity-based, etc. In embodiments, nonrigid registration methods are used, e.g. feature-based, intensity-based, etc. In embodiments, biomechanical models, such as statistical shape models, are incorporated into the registration method. In embodiments, registration is done with the help of optical markers, e.g. color or reflective markers in certain predefined anatomical landmarks of the patient **118** for the 3D scanner system **110**, corresponding to markers of the same size and shape placed on the same predefined anatomical landmarks of the patient **118** during the preoperative **102** or intraoperative imaging **106** (e.g. radiopaque markers for CT or x-ray imaging), or virtual markers placed on the predefined anatomical parts in the graphical representation of the images obtained, in the preoperative or intraoperative setting, through the available user interface means **130**, **132**. In other embodiments, a combination of rigid and nonrigid registration methods are used.

[0088] For example, a markerless registration method may be used. More specifically, an output of the surface reconstruction **112** is stored in point sets or depth maps. The markerkless registration may be completed by applying known methods (e.g. the iterative closest point algorithm, the Curie point depth algorithm, or the scale invariant feature transform algorithm) to the output of volume rendering **104** (e.g. 3D volume image). This markerless registration may be completed by 2D or stereoscopic digital images **108** from previous imaging studies **102** or intraoperative images **106** (e.g. CT scans or MR scans).

[0089] Point matching is done either directly or with previous transformations to obtain more accurate outputs, e.g. calculating Gaussian curvature from the depth map, or excluding outliers (e.g. with random-sample consensus) during point matching. With the matching results, aligning the two coordinate systems is computed with software (e.g. Procrustes analysis). For a more precise registration, the preoperative images **102** are adjusted to the software needs (e.g. through segmentation by a histogram-based threshold). It will be understood that these registration methods are presented for the purpose of example, and are not intended to be limiting of the actual 3D volume-3D surface registration **120** method used in any manner.

[0090] In embodiments, registration **120** is done in a fully automated manner by computer means **100**. In embodiments, the surgeon **128** or other users may adjust **322** the 3D volume-3D surface registration **120** in real time during surgery through the available user interface means **132**, as described below in the different embodiments. In embodiments, the 3D volume-3D surface registration **120** is made before surgery matching the volume rendering **104** to a preoperatively done surface reconstruction **112** of the target portion of the patient **118** (e.g. in the most likely position that the patient **118** will have during surgery), and then a real-time 3D surface-3D surface registration is done during surgery.

[0091] Embodiments may be configured for real-time correction of patient pose in the 3D volume rendering **320**. For

example, the 3D scanner system **110** obtains the surface reconstruction **112** of a target portion of the patient **118**, the surface being e.g. the superficial skin of the patient **118**, and the 3D surface is blended by computer means **100** with the 3D volume of the preoperative imaging **102** (e.g. CT scan) of the patient **118**. The blended part being e.g. the 3D volume of the skin surface, preferably by using preselected constant anatomic landmarks, e.g. the prominent spinous processes in the skin surface of the patient's **118** spine.

[0092] The internal anatomic structures are therefore displayed based on the positioning of patient **118** was when the preoperative image **102** was obtained, e.g. with the patient **118** in the supine position during the CT or MR scan. Responsive to performing a medical procedure on the target anatomic structures, and e.g. bony structures or soft tissues are (partially) exposed, a new 3D scan is obtained with the 3D scanner system **110**. The new 3D surface obtained of the visible bones and soft tissues is blended with the 3D volume of bone and soft tissue structures, which may result in a more accurate registration of both images **120**. This may be due to skin and subcutaneous fat tissue of the patient **118** changing more than internal anatomic structures during the time passed between the preoperative imaging **102** and the actual surgery.

[0093] The 3D surface is therefore used to determine the pose of the portion of the patient **118** during surgery **318**, and adjust the presentation of the 3D volume, which is based upon a pose **320**, so that the location and orientation of the 3D volume as displayed to the surgeon **128** matches the location and orientation of the body part of the patient **118** on which the surgeon **128** is operating. That adjustment of the pose change correction **320** is done by automatically processing new surface reconstructions **112** in real time. Alternatively, creating pose change corrections **320** is done in fixed intervals; alternatively, it may be done at the surgeon's **128** discretion Alternatively, creating pose change corrections **320** is done whenever deeper dissection has been carried out, or when the patient **118** has moved, as detected e.g. by tracking means **136**. The surgeon **128** or other users are able to correct the pose change adjustments **320** made in real time **322** through the available user interface means **132**.

[0094] In embodiments, markers are attached to the selected anatomic landmarks of the patient **118**, to define and locate its position in the common coordinate system. Thus computer means **100** can calculate changes in position, and when a predetermined minimum (angle or distance) threshold is crossed, it rescans the portion of the patient **118** and constructs a new 3D surface **112**.

[0095] In embodiments, pose changes detected **318** in the surface reconstruction **112** are translated into the 3D volume image. The detected pose changes may be translated by adjusting the supposed movement of the internal anatomic mobile parts. The supposed movement of the internal anatomic mobile parts may be detected from external pose changes when anatomic parts are individualized in the 3D volume image, which may be done preoperatively, e.g. during or after the volume rendering **104** of preoperative images **102**, using the available user interface means **130**. The movement of the body is tracked and translated into the movement of internal anatomic parts of a virtual anatomical (e.g. skeletal) model **306**, with the help of computer means **100**. In that manner, instead of blending a 3D surface with a static 3D volume image directly, the pose change **318** in the 3D surface is interpreted by computer means **100** and applied **320** to a predefined virtual anatomical model **306**, to which the 3D volume of the patient is registered, obtaining more precise positions of the internal anatomic parts, e.g. location and orientation of joints and bones by using an anatomic skeletal model.

[0096] For example, if the target portion of the patient **208** is the spine, the volume rendering **104** of a previous CT scan may obtain individually rendered parts. A virtual 3D anatomic skeletal model **306** of a spine is previously developed, being mobile, and translating variations in trunk position into e.g. movement of the different vertebrae. By registration of the individualized vertebrae of the 3D volume images and the vertebrae of the virtual 3D anatomical model **306**, a virtual anatomic avatar of the patient's spine is developed. Pose changes in surface reconstructions **112** are recognized by software means **318**, and are automatically translated into movement of the individualized parts in the 3D anatomical avatar **320**. Thus, usually supine position of the patient **118** during CT scan image is automatically turned into the most common prone position of the patient **118** in the operating room. This may be performed by translating changes to the sagittal position of the reconstructed 3D surface **112** of the spine to the position of each individual vertebra and intervertebral disk in the anatomical model, which may be the 3D volume of each vertebra and intervertebral disk.

[0097] In that manner, the system may also be configured to determine changes in lateralization and rotation of the trunk in the 3D surface into the position of individual vertebrae, vessels and nerves in the 3D volumetric image. In this manner, bone structures are more precisely located when dissecting through soft tissue (to achieve the best possible exposure), or when targeting bony structures, as in positioning of transpedicular screws. For example, when dissection is carried out to the level of bone, and individual vertebrae are seen, a new surface reconstruction **112** more accurately delimits the position and rotation of processes, laminae, pedicles and posterior body of the vertebrae. Hence, the blending of 3D surface **112** with virtual 3D anatomical model, and registration with 3D volume **120**. Using appropriate segmentation and software that takes into account such variations, provides a more precise location and orientation of each individual bony and soft tissue structure, including adjacent vascular and neurological structures at risk.

[0098] As another example, in percutaneous surgery for fractures, an individualized volume rendering **104** is done of each fracture fragment in the injured portion of the patient **118**, as well as of the corresponding healthy part, usually the contralateral limb or hemipelvis. The computer **100** may be configured to determine pose changes in the different surface reconstructions **112** of external and internal structures in the injured part. The computer may be configured to translate these movements to the 3D rendered fracture fragments in the virtual anatomical model of the injured part, changing their position in the virtual representation to accurately reproduce their real-time location and orientation. Reduction of fragments is then adjusted with the help of the target virtual anatomical model of the healthy part (e.g. a skeletal virtual model), which is output superimposed with the desired level of transparency to the injured part.

[0099] Intraoperative images **106** in combination with computer vision methods and real-time user interface means **132** help the surgeon **128** position the 3D volume image of individual fragments where they are in real time, as seen on the stereoscopic video **116**.

[0100] When developing the virtual anatomical avatar for any location of the body, known detailed muscles, ligaments, etc., bone models are used to translate movements as precisely as possible. Such complex dynamic anatomical models are received and stored in the computer **100** from available dynamic simulation models, or they may be newly created based on the specialized literature. To apply these simulation models to a detailed 3D anatomical model, available models are stored and used, or a newly created 3D anatomy model may be created for that purpose.

[0101] In the exemplary embodiment described above in FIG. **2**, the stereoscopic cameras **201**, **202** and the 3D scanner **203** are closely arranged in a precise fixed and known relative position to each other, so that the precise relative location (x_1,y_1,z_1) and orientation angle $(\alpha_1,\phi_1,\theta_1)$ of the first camera **201** with respect to the 3D scanner **203**, and the relative location (x_2,y_2,z_2) and orientation angle $(\alpha_2,\phi_2,\theta_2)$ of the second camera **202** with respect to the 3D scanner **203** are known. The relative locations may be used by the computer **211** to automatically select the position of virtual cameras for stereoscopic views of the 3D surface, according to the precise position of the cameras **201**, **202** relative to the coordinate system used by the 3D scanner **203**. The virtual cameras that define the views of the 3D surface reconstruction **112** change their location and orientation angle simultaneously as the devices composing the stereoscopic camera system **114**, automatically by computer means **100**, with help from data acquired from tracking means **136** on the cameras.

[0102] In embodiments, the position of the 3D scanner system **110** may be the reference position of the 3D scanner devices when constructing a surface model **112** with respect to the object (e.g. the target portion of the patient **118**), according to its own coordinate system. This reference position is therefore selected as the virtual camera position from which the 3D surface model is seen in its own coordinate system, and may be the initial or the final position in the object scanning process, or it may be dynamic and moves with the scanner device (e.g. a time-of-flight camera), or it may be any other alternative position selected by the computer means **100** that processes the 3D scan. In the embodiments, the stereoscopic cameras **201**, **202** and the 3D scanner **203** may remain close to each other in a fixed position. This may offer the most precise possible surface reconstruction **112** from the perspective view of the stereoscopic video **116** obtained, and to do the stereoscopic video-3D surface registration **122** with the least effort on the side of computer means **100** of the system, so that registration is quick and user adjustments needed are limited to the minimum.

[0103] In embodiments, the 3D scanner **206** is separated from the stereoscopic cameras **201**, **202**. In embodiments, their relative position is fixed and known, and the same principles described for fixed positioning apply. In embodiments, multiple scanners and/or video cameras are used, or they are mobile, and their relative orientation angle is determined e.g. by IMUs attached to all devices, which show their orientation relative to each other. In embodiments, the stereoscopic camera system **114** is mobile, and the same 3D scanner system **110** functions as markerless optical tracking system, determining the relative position of the cameras forming the stereoscopic camera system **114**, if these are in the field of view of the 3D scanner **110**.

[0104] In embodiments, the 3D scanner system **110** is used in combination with multiple optical markers placed on the stereoscopic camera system **114**, for the precise real-time tracking of its location and orientation. Alternatively, or in addition to the 3D scanner system **110**, optical tracking means **136** are used for an accurate relative positioning of cameras **114**. Optical tracking is made with a tracker camera and markers that locate the 3D scanner devices **110** and stereoscopic cameras **114** in the common coordinate system, which may be based on 3D-2D point correspondences.

[0105] In embodiments, the device or devices composing the 3D scanner system **110** include one or more cameras (e.g. time-of-flight cameras). The camera or cameras may form part of the stereoscopic camera system **114**. Registration of 3D surface and stereoscopic video **122** is therefore done directly within the coordinate system of the device.

[0106] In embodiments, the cameras forming the stereoscopic camera system **114** are used to process a surface reconstruction of the portion of the patient **118**, for example using range imaging techniques (e.g. structure-from-motion). That surface reconstruction has a relative position that is determined with respect to the cameras forming the stereoscopic camera system **114**. The surface reconstruction may be used for registration **122** with the 3D surface obtained by the 3D scanner system **110**, which may reduce the need for other tracking devices.

[0107] In embodiments, this surface reconstruction obtained from images of the stereoscopic camera system **114** is used directly for 3D volume-3D surface registration, and this registered image is used for comparison with the 3D volume-3D surface registration **120** made with the surface reconstruction **112**, to more precisely define the precise position of the 3D volume in the coordinate system.

[0108] In embodiments, once the initial 3D volume-3D surface registration **120** and stereoscopic video-3D surface registration **122** are done, the tracked location and orientation angles of the two-dimensional cameras **114** with respect to the portion of the patient **118** (e.g. tracking the selected anatomic landmarks of the patient **118**) are used as the location and orientation parameters for the virtual cameras defined for capturing the 3D volume images. In this manner, 3D volume-stereoscopic video registration is done directly, without an intermediate surface reconstruction **112**. This direct 3D volume-stereoscopic video registration is further adjusted through real-time user interface means **132**, and it may be combined with other images through image processing **124**, according to the different embodiments.

[0109] In embodiments, tracking means **136** may include a tracking camera that works in conjunction with active or passive optical markers that are placed in the scene. In embodiments, the tracking camera may be part of the 3D scanner system **110**. In embodiments, tracking means **136** include passive or active optical markers that work in conjunction with the tracking camera. Different kinds of tracking systems may be employed, either alone or combined, such as magnetic tracking, inertial tracking, ultrasonic tracking, electromagnetic tracking, etc. Mechanical tracking is possible by fitting the joints of the mechanical arm **204** attached to the ceiling **205** with encoders.

[0110] In embodiments, known optical markerless or marker-based tracking systems are used and their data processed **326** by computer means **100** for the tracking of location and/or orientation of the instruments and devices **138**, the patient **118**, the imaging devices **106**, the surgeon **128**, and more precisely they are used for image processing **124**, e.g. for 3D volume-3D surface registration **120**, or for 3D surface-stereoscopic video registration **122**, or even for direct regis-

tration of 3D volume with stereoscopic video **116**, either alone or in combination with the other embodiments described. Such image registration examples involve also interaction of the surgeon **128** or other users with the computer **100**, through the available user interface means **130**, **132**.

[0111] In embodiments, the surgeon **128** uses a stereoscopic display **126** and can examine the spatial relationship between the anatomical structures from varying positions. Utilizing the stereoscopic display, the surgeon **128** may not need to look back and forth between monitors and patient **118**, and to mentally map the image information to the patient **118**. As a consequence, the surgeon **128** can better focus on the surgical task at hand and perform the operation more precisely and confidently.

[0112] In embodiments, the display **126** may be a simple stereoscopic video display, or alternatively it may be a stereoscopic virtual reality display, that allows for interaction of the surgeon **128** or other users with the virtual environment created by computer means **100**, e.g. through motion tracking and gesture recognition. In embodiments, as shown in FIG. **2**, the stereoscopic display **214** is head-mounted **213**, and it may include headphones **219** and a microphone, to receive information in audio format and be able to communicate with other users.

[0113] In embodiments, the stereoscopic display **126** is composed of a virtual reality device, and the stereoscopic camera system **114** is composed of fixed cameras, or cameras that do not move with the head of the surgeon **128**, so that the stereoscopic view displayed to the virtual reality device moves as the head of the surgeon **128** moves, using its own tracking means **136** (e.g. optical marker-based tracking), without the need to change the position of the cameras **114** to change the view. For example, if the stereoscopic camera system **114** obtains a 360° view of the target portion of the patient **118**, when the surgeon **128** moves his or her head, that movement is tracked by the head-mounted display **126**, changing the perspective view accordingly. Alternatively, the display **126** may not be head-mounted, but e.g. a 3D monitor mounted on an articulated mechanical arm, on a fixed pole, or any other suitable support, either fixed or mobile. Alternatively, the display **126** is a two-dimensional display, and 2D video images **116** are displayed.

[0114] The stereoscopic camera system **114** displays a real-time stereoscopic image to the surgeon **128** through the display system **126**, which is connected to the computer **100** by wired or wireless (e.g. Bluetooth or Wi-Fi) means, depending on the needs of surgery and on the possibilities of the operating room. Computer means **100** integrate information from the different devices used as described in the different embodiments, and different combinations of stereoscopic video **116**, 3D surface, and 3D volume images are shown in a stereoscopic manner to the surgeon **128**, with the modifications, additions and deletions as adjusted by the surgeon **128** or other users in real time, so that the surgeon **128** sees the information that he or she wants (from the data available) at any time during the procedure.

[0115] In embodiments, the stereoscopic display **126** is a virtual reality device that allows for gesture recognition (e.g. through motion tracking), displaying the real-time user interface means **132** within the field of view of the surgeon **128**. Such virtual graphics displayed within the field of view of the surgeon **128** allow for interaction with the computer **100**. For example, the surgeon **128** may see virtual buttons in a marginal position of his or her field of view, which may be pressed with a predetermined hand gesture. A virtual button, when pressed, may allow the surgeon **128** e.g. to select a virtual image (e.g. a 3D volume image), and translate and rotate it with his or her hand movements, to adjust its position with respect to the stereoscopic video **116**. In embodiments, voice recognition included in the display **126** or in another device connected to the display **126** through computer means **100** allows e.g. to show the virtual graphics (e.g. buttons) only when saying the appropriate word or words, so that virtual graphics for interaction do not interfere with surgery.

[0116] In embodiments, the stereoscopic video **116** may be directly sent to the display **126**, either by wired or wireless means. Through user interface means **130**, **132**, the surgeon **128** can select that the stereoscopic video **116** be directly sent to the display **126** after being received by the computer **100**. Alternatively, the surgeon **128** may select that the video signal from the stereoscopic cameras **114** be sent directly to the display **126**, through a direct wired or wireless connection between both devices. The stereoscopic video images **116** are received by the computer **100** for image processing **124**, e.g. for the stereoscopic video-3D surface registration **122**. The use of a direct connection between the video **116** (or the cameras **114**) and the display **126** makes the time lag negligible for practical purposes during surgery. Integration of the images processed **124** with the real-time stereoscopic video **116** sent directly to the display **126** may allow for real-time user interaction via user interface means **132**. For example, the display **126** may show the registered 3D volume blended with the real-time stereoscopic video **116** image directly sent to the stereoscopic display **126**, instead of the stereoscopic video image **116** processed **124** by computer means **100**. As another example, the display **126** may switch to the images processed **124** by computer means **100** only when the surgeon **128** allows for it, e.g. when more time lag is acceptable.

[0117] In an alternate embodiment, a stereoscopic optical see-through display is used as display system **126** from those commercially available (e.g. optical see-through glasses), and real-time images of the patient **118** are directly available to the surgeon's **128** point of view, instead of (or in combination with) the stereoscopic video images **116**. The 3D volume blended with the 3D surface is tracked in space to the location and orientation of the stereoscopic display **126**, by way of tracking means **136** (e.g. markerless optical tracking and IMU in both devices). Alternatively, the tracked position of the head of the surgeon **128** is used to define the location and orientation of the virtual cameras offering the stereoscopic view (or the virtual camera offering a 2D view) of the 3D volume image. Thus, allowing for an instant registration of the surgeon's **128** direct vision of the portion of the patient **118** and the 3D volume image, that may be adjusted with the available real-time user interface means **132**.

[0118] In an embodiment, the display system **126** is a projector which projects the processed images **124** over the target portion of the patient **118**. In order to achieve a seamless integration with the surgeon's **128** view of the patient **118** during surgery, tracking means **136** are used to accurately track in real time the position of the projector and of the head of the surgeon **128**, relative to the common coordinate system. Computer means **100**, taking into account the location, orientation and lens-characteristics of the projector, send the blended images that are projected over the patient **118**, so that the images appear to the surgeon **128** as a property of the target portion of the patient **118**, with the desired adjustments

in transparency, color, contrast, etc. In embodiments, the projector projects a stereoscopic view over the patient **118**, which is viewed by the surgeon **128** wearing the corresponding glasses, e.g. glasses with polarized filters for a projector that uses a polarization stereoscopic display system (a type of "passive" stereoscopic system).

[0119] In embodiments, changes in position of the surgeon's **128** head are tracked with a head-mounted virtual reality or any other stereoscopic display **126** (the preferred stereoscopic video display for this invention, or alternatively the optical see-through display or projector as described), so that the augmented reality view **346** offered to the surgeon **128** changes in real time. In embodiments, to limit the time lag of the stereoscopic video images **116**, the virtual graphics provided directly by computer means **100** using tracking **136** and software means are displayed directly to the surgeon's **128** field of view following his or her tracked head position. The virtual graphics are displayed alone, e.g. the registered 3D volume and 3D surface images, hence limiting the time lag effect, and guiding the surgeon **128** in the actual scene that is happening in the operating room. Alternatively, the virtual graphics are sent directly to the display **126**, but combined with the available stereoscopic video images **116** (sent directly to the display **126**, or after undergoing image processing **124**), sacrificing a more precisely blended image in exchange for less time lag with respect to the real scene.

[0120] Recording means allow one to record all images received by the computer **100**, and the augmented view **346** displayed to the surgeon **128**.

[0121] In embodiments, the augmented view **346** may comprise a real view blended with virtual graphics. The real view is provided as stereoscopic video images **116** of the scene. The virtual graphics is derived from computer means **100**, e.g. 3D volume or digital images **108** of preoperative images **102**, generally a CT scan, or an MR scan, or a combination of them. In this case the virtual graphics also correspond to views of real anatomic structures, available to the surgeon **128** only as computer graphics renderings.

[0122] The real view of the external structures and the virtual view **346** of the internal structures are blended with the help of a surface reconstruction **112**, as already described, and they are shown in-situ with an appropriate degree of transparency, which may vary as the field of view changes. Registration between real and virtual surfaces makes all structures in the augmented view **346** be positioned in the correct location with respect to each other, therefore the derived image of the internal anatomical structure is directly presented in the surgeon's workspace in a registered fashion.

[0123] The image display of the 3D volume obtained through volume rendering **104** is the virtual 3D representation of a volume data set as it is "flattened" onto one or more 2D planes. Different techniques are available using software-based and hardware-based solutions that may optimize image accuracy, speed, quality, or a combination of them. Nonlimiting examples of techniques for 3D volume image display include ray casting, fly-through, multiple views, obscured structure, shading depth cues, kinetic and stereo depth cues. Such techniques are available in the computer means **100**, and are selected by the surgeon through the available user interface means **130**, **132**.

[0124] According to the embodiments described for surface reconstruction **112**, the position of the devices that compose the stereoscopic camera system **114** and/or 3D scanner system **110** is dynamically tracked to display the precise location and orientation of the 3D surface model with respect to the view of each camera **114**, which may provide a blended image output **340** to the display **126**.

[0125] Therefore, when 3D volume-3D surface registration **120** is presented, a stereoscopic view of the 3D volume is presented **342** (either fully automatically by software or with user interaction **350**). The 3D volume may take into account the pose changes of the patient **344**, and it is displayed to the surgeon **128** according to the precise location of the cameras **114**. Accordingly, there may be a seamless integration of all views (e.g. stereoscopic video **116**, 3D surface and 3D volume) to both eyes as an augmented view **346** of the surgical field. The same principles apply to all images displayed stereoscopically to the surgeon **128**, when fitting the reconstructed 3D surface of the portion of the patient **118**, as well as to the different augmented reality helps **346** displayed, such as notifications **348**. For example, when using a pair of two-dimensional cameras as the stereoscopic camera system **114**, the virtual cameras (that define stereoscopic views of the 3D surface) are positioned by computer means **100** within the common coordinate system to the corresponding position of the two-dimensional cameras (and thus the specific interpupillary distance selected by the surgeon **128**), each image being displayed to each corresponding eye of the surgeon **128** by the stereoscopic display **126**, together with the corresponding stereoscopic video image **116**. The surgeon **128** and other users are able to define or adjust the position of the virtual cameras defining the 3D volume and/or the 3D surface using the available general user interface means **130**, and the real-time user interface means **132** during surgery.

[0126] In embodiments, the virtual cameras based on the position of the stereoscopic camera system **114** are also used to create views of the 3D volume for registration with the 3D surface, and the stereoscopic view of the registered image is automatically blended with the stereoscopic view of the registered 3D surface-stereoscopic video **122**. Alternatively, the virtual cameras defined are used for direct registration with the stereoscopic video **116**. Alternatively, the virtual cameras are based on the position of the head of the surgeon **128**, and they are used to be shown in the optical see-through display, or alternatively they are projected over the patient **118**, according to the different embodiments of the present invention.

[0127] Once the initial position of the virtual cameras is determined, computer means **100** translate their location and orientation changes in real time, with data acquired from tracking means **136**, e.g. according to the corresponding position of the devices forming the stereoscopic camera system **114**. Therefore, the position of the device or devices composing the stereoscopic camera system **114** is tracked, and changes in location and rotation (relative to their initial position during registration) are translated to the position of the corresponding virtual camera or cameras. In this manner, when using a mobile stereoscopic camera system **114**, the surgeon **128** sees a direct, seamless view of the inner anatomic structures of the patient **118** blended with the stereoscopic video **116** that defines his or her basic view. As another example, when using tracking data from a head-mounted stereoscopic display **126** (e.g. virtual reality device), changes in its position are translated to the position of the virtual cameras defined, so that the perspective view of the virtual graphics (e.g. the 3D volume) changes to fit the view of the surgeon **128**.

[0128] In embodiments, especially in settings where preoperative volumetric data is not available, and simple X-ray images and intraoperative fluoroscopic X-ray images are frequently used, a mirror system is used attached to the imaging device (e.g. a C-arm) that obtains intraoperative images **106**, making the video optical center of the 3D scanner device **112** (e.g. a time-of-flight camera) or the video camera **114** virtually coincide with the X-ray source. The depth sensor from the 3D scanner device **110** used (e.g. a time-of-flight camera) needs to be adjusted to the distance of X-ray source to the detector, and also to the distance from the mirror. In embodiments, a stereoscopic C-arm is used that contains two X-ray sources and detectors, each source with a video camera **114** or a 3D scanner device **110**, or both, attached to them in the described manner. Image registration is done according to the principles of the present invention, whereby the surgeon **128** sees real-time stereoscopic video images **116**, and the intraoperative X-ray images (either stereoscopic or not) blended with the video images in its precise location over the patient **118**.

[0129] In embodiments, the digital images **108** or the 3D volume of preoperative **102** or intraoperative **106** images, after being registered with the stereoscopic video **116** images, are displayed blended with the stereoscopic video **116** by means of classical alpha blending. During alpha blending, the registered digital images or virtual graphics are directly superimposed to the stereoscopic video **116** images, and the surgeon **128** sees the digital image **108** or 3D volume over the visible scene, with the selected transparency level, color adjustments, etc.

[0130] In other embodiments, the digital images **108** or the 3D volume of preoperative **102** or intraoperative **106** images, registered with the stereoscopic video **116**, are displayed blended with the stereoscopic video **116** by means of real-time background subtraction methods. In real-time background subtraction methods the foreground objects in the video or 3D surface images are detected from the different frames (by using reference frames), and thus a background image or model is obtained. For example, in an embodiment using a time-of-flight camera as 3D scanner system **110**, multiple real-time images with color and depth information are obtained, and an algorithm (e.g. random forests) is applied to the pixels. The pixels may be classified to belong to an object class, either foreground objects (including e.g. the surgeon's **128** hands and instruments **138**) or the background model (including the patient **118**), to obtain a probabilistic output of the objects. These objects are identified as label maps, creating then a pixel-wise alpha map, and then using a mixing look up table (LUT) that associates a specific alpha value to each label pair.

[0131] Once the mixing LUT is obtained, higher values are given to surgical instruments **138** and surgeon's **128** hands over the background, giving a better depth perception. As another example, foreground objects are similarly identified and classified from RGB data of stereoscopic video **116** or 3D scanner **112** images, especially metallic, bright, thin- and small-shaped instruments or devices **138** (e.g. drill, clamps or scalpels), which are not well reflecting infrared light. A combination of IR- and RGB-based information is calibrated in advance, according to the tools used and the light conditions, and can be further adjusted in real time through the available user interface means **132**.

[0132] In embodiments, the 3D surface corresponding to the foreground objects, obtained by the background subtraction methods applied to the 3D surface images, is superimposed to the registered and blended stereoscopic video **116** and 3D volume image, using the virtual camera position of each stereo camera **114** to give a perspective view of the surgeon's **128** hands and instruments **138** corresponding to each eye, giving a more realistic augmented view.

[0133] In an embodiment, the identified foreground objects from the stereoscopic video **116** are superimposed over the blended 3D volume-stereoscopic video images. In an embodiment, the precise location of the background model in the common coordinate system is used to superimpose the 3D volume over the background model located on each of the stereoscopic video **116** images, leaving the foreground objects (e.g. surgeon's **128** hands and instruments **138**) as the original stereoscopic video, without superimposed images.

[0134] These foreground objects can then be adjusted in transparency, color, etc. to permit the surgeon **128** to see the virtual graphics through them, e.g. the internal anatomy of the patient **118** in the registered 3D volume image, or the graphical representation of tracked instruments and devices **138**.

[0135] In embodiments, markers are placed in the target portion of the patient **208** (the target background model), or the surgeon's **128** hand or instruments **138** (the target foreground objects), or in both locations. These markers are tracked by the tracker camera (e.g. forming part of the 3D scanner system), and help obtain a quicker and more precise position of objects. In embodiments, background subtraction methods make use of hardware or software capabilities (e.g. motion detection) of the 3D scanner devices **110**, the 3D display **126**, or both, to locate the foreground or moving objects.

[0136] In embodiments, to take into account real-time, small adjustments in the moving foreground objects, an area surrounding the foreground objects in the target video image is defined by the user interface means **132**. This will adjust for minimal real-time movements of the hand or instruments, leaving the background model bigger or smaller than it actually is, depending on the preferences of the surgeon **128**. This defined area can be modified in real time (augmented or diminished) by the surgeon **128** by using the real-time user interface means **134**.

[0137] In embodiments, a motion controller is used, which can be a different device from those described, or one or more of those used in embodiments, such as the 3D scanner device **110** (e.g. time-of-flight camera) or the stereoscopic display **126** (e.g. virtual reality display), using their own computer-implemented software for gesture recognition. Gesture recognition is used as real-time user interface means **132** e.g. to more accurately adjust the position of the stereoscopic cameras **114**, the registration of 3D volume image and stereoscopic video **116**, the surface reconstruction **112** (or its parameters), the image processing **124** (e.g. stereoscopic views of the 3D volume and other images), and any other possible software-controlled task of this invention, avoiding the need to touch a device (e.g. mouse or keyboard). For example, when adjusting pose changes **320**, gesture recognition may also be used to adjust the position of the different individual bony or soft tissue structures in the 3D volume-3D surface registration **120**, in the stereoscopic video-3D surface registration **122**, or in any other image processing **124** task. In embodiments, voice recognition is used to interact with the computer **100** through spoken commands, alone or in combination with other computer interface means.

[0138] Gesture or voice recognition allows the surgeon **128** to adjust the level of transparency of each superimposed image and their order of visualization; to select the exact layer of the 3D volume image to show; to do with gestures or spoken commands any software-implemented task ideally without touching any device, although other interaction means are available, such as mouse and keyboard. Gesture or voice recognition are activated via a specific gesture, voice command, or by other users, so that it is not active all the time, to avoid real-time interpretation of normal hand movements and normal speech during surgery.

[0139] An optional remote user interface allows an additional user to see and interact with the augmented view during the system's real-time operation, as described in this invention. For example, the surgeon **128** may show another person the points to adjust, or tell this person what to change, and this person directly or indirectly interacts with the computer **100** to make the changes, as in the nonlimiting examples of augmented reality described below.

[0140] In embodiments, the registered 3D volume image is displayed to the surgeon **128** automatically by layers, e.g. each layer may correspond to the estimated depth that the surgeon's **128** instruments and devices **138** have achieved. Thus, when dissection is carried out e.g. through the subcutaneous tissue, the superficial layers of the 3D volume image are also automatically made fully transparent, and the deepest layer achieved with the scalpel is shown, or layers above or below the deepest layer are shown with transparency degree as determined by the surgeon **128** through the available interface means **132**, to obtain the most intuitive and useful augmented view of the target portion of the patient **118**. As another example, only the part of the 3D volume image layer that has been dissected and the selected margin width are made transparent, or other augmented reality modifications are made to them, while the region outside the surgical wound remains in the original state.

[0141] In embodiments, the maximum depth achieved by the instruments or devices **138** is obtained by optical tracking from the 3D scanner device **110**. For example, depth is estimated from the 3D surface reconstructed **112** according to the device's own coordinate system, in real time (e.g. with a time-of-flight camera). In embodiments, depth calculation is enhanced by using previously made 3D models of the instruments or devices **138**, hence more accurately tracking its actual depth and orientation with software-based calculations. In embodiments, depth is calculated by computer means **100** from the stereoscopic video images **116** (e.g. range imaging techniques as in stereo triangulation, or stereophotogrammetric techniques). In embodiments, marker-based optical tracking is used for real-time location and orientation of instruments and devices **138**. In embodiments, IMUs attached to the instruments and devices **138** help tracking their real-time orientation. Alternatively, depth is obtained by other tracking means **136** or a combination of them, as described in the different embodiments.

[0142] In embodiments, layers of the 3D volume image, blended with the stereoscopic video **116** in the preferred manner, is given a certain percentage of transparency. For example, beginning with 50% for the upper layer (that is the deepest layer achieved e.g. by the scalpel), and being increased following a certain increasing pattern for deeper layers. That way, the surgeon **128** is able to know or more precisely imagine (according to his or her own knowledge) which internal structures may lie ahead and be at risk if dissection is carried out deeper or to the sides of the surgical wound.

[0143] In embodiments, intraoperative images **106** (e.g. fluoroscopic images) are displayed directly to the surgeon **128**, usually in a marginal position relative to his or her field of view. In embodiments, intraoperative images **106** are tracked to the position of the patient **118** with the help of markerless optical tracking, or alternatively using optical markers (e.g. placed on selected anatomic landmarks of the patient **118**, and on the imaging device **106**), or by other tracking means **136** or a combination of them, as described in the different embodiments. For example, intraoperative CT scans or MR scans are tracked to the patient **118**, or alternatively e.g. with the help of optical markers on the patient **118** and the CT or MR scanner **106**, and/or with a tracker camera. As another example, stereoscopic fluoroscopic images taken intraoperatively (either with a specialized image intensifier, or by translating or rotating the image intensifier between images), are shown as a stereoscopic pair of images to the display **126**, each image to the corresponding eye of the surgeon **128**, either tracked previously to the position of the target portion of patient **118** or not. Alternatively, intraoperative images **106** like fluoroscopic images and CT scans or MR scans are indirectly tracked to the patient **118**, automatically by software using the already reconstructed and registered 3D volume-3D surface **120** and 3D surface-stereoscopic video **116**, and assisted manually by the surgeon **128** or other users by interaction with the computer **100**. Such markerless registration using other precise digital images **108** (e.g. CT scan) or the processed output based on them (e.g. 3D volume image) allows for real-time correction of scale of the fluoroscopic image, either fully automatically or adjusted by interaction of users with the software through the available user interface means **130**, **132**. In embodiments, tracking means **136** for location and orientation of the intraoperative imaging device **106** (e.g. image intensifier) and the selected anatomic landmarks of the patient **118** give enough data for automated calculation by computer means **100** of the actual size of the imaged structures, so that a precise positioning of the fluoroscopic images is done with e.g. the surface reconstruction **112**. The same principles apply to other intraoperative image sources **106**, e.g. arthroscopy or ultrasound.

[0144] In embodiments, registration of the stereoscopic video **116** is done with a 3D atlas model of the target part of the human body, that consists e.g. of another patient's 3D volume image, or a volume rendering of real anatomic slices (e.g. the Visible Human Project's corresponding male or female dataset), or stereoscopic videos previously recorded (e.g. from similar exposures and surgical techniques), or a 3D virtual anatomic atlas designed in a computer, etc. or a combination of such atlas models. Such registration is done automatically in the most accurate corresponding place over the target portion of the patient **118**, according to the principles of this invention, and with help from interaction of the surgeon **128** or other users, either preoperatively or during surgery, e.g. adjusting the size and position of the virtual patient to the real patient **118**, the position of their internal structures, etc. using the general user interface means **130**. In embodiments, the 3D atlas models are previously processed, e.g. clearly marking important anatomic landmarks and structures at risk, and also differentiating the individual parts and making them movable, to adjust for pose changes in the patient **320**, applying the principles of this invention. The registration is also

adjusted in real time, as the surgery develops, using the real-time user interface means **132**.

[0145] In embodiments, only the 3D surface obtained with a 3D scanner **110** is used (without registration with 3D volumetric image of the patient **120**), and thus only registration between the 3D surface and the stereoscopic video **122** is done. Measurements of distances and angles are automatically calculated by computer means **100** from the 3D surface model, with or without interaction by the surgeon **118** or other users through the available user interface means **130**, **132**. For example, the appropriate location and angulation of the tibial cut in a total knee arthroplasty, or the CORA in a proximal tibial osteotomy, are calculated and displayed graphically in real time to the surgeon **118**, using e.g. a surface reconstruction **112** of the lower limb or limbs of the patient **118**, with or without intraoperative imaging **106**, according to the principles of this invention. Measurements and calculations based on the 3D surface may therefore be improved by doing new surface reconstructions **112** when achieving deeper layers of dissection, e.g. when exposing distal femoral and proximal tibial bone during knee arthroplasty, and also when a 3D model atlas (e.g. of a knee) is used for registration of 3D surface-3D model atlas during surgery, according to the principles of the present invention.

[0146] In embodiments, optical tracking markers and IMUs are also placed in the selected landmarks of the patient **118**, and/or in instruments **138**, to offer a more precise positioning of the internal structures of the target portion of the patient **118**, for example in cup positioning during total hip arthroplasty. In embodiments, measurements and calculations are made directly over the stereoscopic video **116**, with range imaging techniques (e.g. stereo triangulation, or structure-from-motion) or stereophotogrammetric techniques, alone or in combination with the other embodiments.

[0147] In embodiments, the registered 3D volume is adjusted during surgery, according to the images taken intraoperatively **106**, such as fluoroscopic images. For example, after reduction of fracture fragments, by comparing the newer fluoroscopic images to the previously obtained 3D volume, each fragment individualized in the 3D volume is translated and rotated to the most exact current position, either automatically by computer means **100** (e.g. by computer vision software) or generally with interaction of the surgeon **128** or other users through the real-time user interface means **132**.

[0148] In an alternate embodiment, intraoperative images **106** (e.g. multiple fluoroscopic projections, stereoscopic or not) are registered with the reconstructed 3D surface. Thus, for example, fluoroscopic images taken intraoperatively are displayed to the surgeon **128** in the corresponding planes with respect to the position of the target portion of the patient **118**, blending it with the stereoscopic video **116**, and with the preferred transparency, color and contrast values, so that the appropriate entry site location and orientation angle for screw or pin placement is more easily and intuitively determined, e.g. in fractures of the pelvis, after reduction of the fragments, or in scoliosis surgery, for screw positioning.

[0149] In embodiments, the general user interface **130** and the real-time user interface **132** allow the surgeon **128** and other users to control the image processing **124** before and during surgery, i.e. to control the augmented reality help **134** sent to the display **126**. It allows the surgeon **128** to interactively change the augmented view, e.g. invoking an optical or digital zoom, switching between different degrees of transparency for the blending of real and virtual graphics, show or turn off different graphical structures, etc.

[0150] In embodiments, a graphical representation of the instruments and devices **138** used during surgery is available as virtual graphics in the computer **100**, and may be selected through the available general user interface means **130**, or through the real-time user interface means **132** during surgery. That graphical representation of the instruments and devices **138** is available as a 3D virtual representation (e.g. in STL file format). The 3D virtual representation is obtained directly from the manufacturer; or automatically acquired as a 3D surface by the 3D scanner device **110** (either done before or during surgery), or by software from the video images **116** (e.g. by range imaging techniques); or as a 3D volume rendered **104** from a CT or MR scan data; or as registration of 2D radiographic or fluoroscopic imaging with 3D statistical shape models of similar instruments or devices; or as a simple graphical representation drawn or designed with the known size and shape and added to computer means **100** using the general **130** or real-time user interface means **132**.

[0151] In embodiments, motion tracking software from the 3D scanner device **110** (e.g. time-of-flight camera) or from the stereoscopic display **126** (e.g. virtual reality device) automatically recognizes the size and shape of the instrument or device **138** used, and automatically selects the corresponding shape and sizes as the virtual graphics for the instrument or device **138**. In embodiments, automatic recognition of size and shape of instruments and devices **138** is done by computer means **100** from stereoscopic images taken by the stereoscopic camera system **114** (e.g. by range imaging techniques as stereo triangulation, or stereophotogrammetric techniques), or from stereoscopic radiographic images (e.g. by Roentgen stereophotogrammetry). The real-time location and rotation of the instruments or devices **138** represented as virtual graphics are tracked according to the different embodiments already described, and blending of the virtual graphics with the available images is done using the common coordinate system, through image processing **124** (e.g. with background subtraction techniques) as already described, with interaction from the surgeon **128** and other users.

[0152] For example, during percutaneous surgery of e.g. pelvis fracture, when reduction is achieved and a pin is inserted as a guide for the definitive screw, both the pin and the screw have a virtual representation in shape, size, and length, and their rotation and orientation is tracked with the available tracking means **136**. Therefore, when the pin or screw enters the inner structures of the body, a graphical representation of a pin or screw with its corresponding shape and size, and with its real-time location and orientation, is displayed to the surgeon **128** in its precise position in the common coordinate system, e.g. blended with the 3D volume image (which is in turn blended with the stereoscopic video **116**), according to the principles of this invention, assigning the desired transparency level, color adjustment, etc. In this manner, the surgeon **128** directly sees an intuitive graphical representation of the inner anatomic structures of the target portion of the patient **118**, and of the instruments or devices **138** inserted, in their precise real-time position.

[0153] In embodiments, the preoperative images **102** and the real-time video images **116** are processed, via classification, to identify structures in the images. Various statistical image-based classification methods allow images of healthy anatomical structures to be distinguished from unhealthy structures (e.g. diseased, malignant, torn/broken/ruptured,

etc.), and therefore aid in the identification of conditions by stereoscopic imaging. Functions for performing such classifications may be trained using a training set of image data comprising a variety of different tissue conditions for each anatomical structure of interest to allow conditions of anatomical structures to be distinguished. It will be understood that such processing may occur at the time of image acquisition and storage (e.g. prior to surgery for the preoperative images **102**), and/or may be performed at the time of surgery.

[0154] In embodiments, image rendering principles and algorithms are applied to the real 2D or stereoscopic video images **116**, or to the 3D surface, to detect structures at risk, using color data or texture pattern recognition software, to automatically identify certain structures by their usual color or texture, such as nerves or vessels. They are then displayed by computer means **100** automatically through image processing **124** as determined by the surgeon **128** or other users through available user interface means before **130** or during surgery **132**, e.g. in enhanced or different colors (e.g. bright red for arteries), to alert the surgeon **128** of their existence and position. In embodiments, such recognition of structures at risk is done with the help of registration with the 3D volume, e.g. with the previous classification of anatomical structures at risk, either fully automatically through software with statistical image-based classification methods, and/or through interaction of the surgeon **128** or other users with the computer **100**, using the available user interface means **130**, **132**.

[0155] In embodiments, markerless motion capture software is used for recognition of moving structures (e.g. vessels), and these structures are displayed by computer means **100** automatically through image processing **124** to the surgeon **128** with a predefined alert notification, e.g. color or contrast change, or showing the suspected (arterial vs. venous) flow, similar to the visual graphics aids shown in Doppler ultrasound. In embodiments, real-time ultrasound or Doppler ultrasound devices are used for identification of structures, blending images according to the principles of this invention (e.g. with tracking of the ultrasound device to the patient **118** and/or to the common coordinate system, and placing the ultrasound images in their corresponding plane), as already described, so that the precise location and orientation of structures is done to the images available through image processing **124**.

[0156] In embodiments, motion capture software used for human movement recognition is used for skeletal tracking (e.g. with a time-of-flight camera with the appropriate software), and with a previously defined anatomic model (and software for registration of the anatomic model with the 3D volume), each pose change in the patient's **118** skeleton is automatically tracked by software means, and automatic registration of 3D volume-3D surface **120** is done, either as a whole or with anatomic parts individualized, as already described above in the different embodiments.

[0157] In embodiments, tracking of joint movement of the patient **118** is used for defining the center of rotation of each joint, and the location and orientation of each joint in their different defining planes. Such information is displayed as numbers and as virtual graphics directly and in real time to the surgeon **128**. For example, when applying an articulated elbow external fixator, the most precise center of rotation of the elbow of the patient **118** is identified in real time by the software during surgery, so that the best flexion/extension arc of the elbow is permitted after the surgery.

[0158] In embodiments, where color or light changes are used for the identification of internal anatomic structures of the patient **118**, as in fluorescence-guided surgery (e.g. 5-ALA PDT in malignant gliomas), even when the eye cannot see the color change under certain circumstances, computer means **100** recognize it from the stereoscopic video **116**, and image processing **124** is applied (e.g. changes in color or contrast) to the video image displayed to the surgeon **128**, to make such changes visible for the surgeon **128** under the usual light. In this manner, the need to change ambient light and observe fluorescence, change ambient light again to continue the surgery, change light and observe fluorescence again, and so on is avoided. Accordingly, surgical time may be minimized and precision is enhanced.

[0159] In embodiments, the computer **100** is connected to an intranet or the Internet, allowing for interactive communication with other people. The augmented view displayed to the surgeon **128** is provided to devices connected to the computer **100**, so that the augmented view provided to the surgeon **128** is shared. In this manner, the surgeon **128** and other users (e.g. an observer or associate) may communicate, the other users watching the augmented view on a monitor, stereo monitor, a head-mounted display, or any other 2D or stereo display. For example, the augmented view can be observed by a staff when the resident is operating, or by another expert like a radiologist, pathologist or oncologist. They can perform actions to enter data, such as by way of an interface to the computer **100** (mouse, keyboard, Trackball, etc.) or e.g. through gesture recognition software, certain features to the surgeon **128** by adding extra graphics to the augmented view or highlighting existing graphics that is being displayed as part of the augmented view.

[0160] In embodiments, virtual reality headsets are used in combination with a 3D model of the surgeon **128** and/or the other users (e.g. obtained with a 3D scanner), and/or a motion capture device (e.g. time-of-flight camera) pointing at each user interacting with the system, and appropriate software (that e.g. uses a 3D virtual anatomical model of a person with articulated and moveable joints, blending with it the available 3D surface models of the users) to show the users within the field of view of the surgeon **128**, and/or the surgeon **128** within the field of view of the users, in real time during surgery, showing their movements, e.g. movements of their hands, for example with real or virtual instruments or devices, over the target portion of the patient **118**. In this manner, any user is able to interact directly with the surgeon **128** as a 3D avatar in his field of view in real time during surgery, through the virtual reality display, without the need to share the same room.

[0161] In embodiments, a notification system **348** is developed preoperatively. Examples of notifications include, but are not limited to, an alert when approaching certain zones or depth layers (or a location matching both, a zone and a depth layer) of the 3D volume or 3D atlas, to avoid certain important structures at risk of lesion during surgery. Such notifications are output visually to the display **126**, audibly via headphones **219** or a speaker in the operating room, or in any other suitable manner. Another example includes that, when the instruments **138** are near those zones or layers, the preferred notification is displayed directly within the surgeon's **128** field of view. The same principle is used to mark the incision lines of the preferred exposures, or trajectory for instruments or devices **138** (e.g. pins or screws), according to previously defined data, similar to a GPS-based auto navigation system.

[0162] In another example, information of nearby structures and their distance and precise position is displayed graphically to the surgeon's **128** field of view, according to the automated calculations made by computer means **100**, following the principles of the present invention, e.g. while carrying out a dissection, or while reducing a fracture, or positioning an implant. Another example involves using color codes for certain alarms displayed, wherein graphical representations of the instruments or devices **138** used may be turned red when approaching vital structures or when moving away from the desired rotation or location, or green when following the preoperative planning, or when moving closer to the desired rotation or location.

[0163] In embodiments, automatic measurements are made and instantly displayed to the surgeon **128** by computer means **100** from the stereoscopic video images **116** or a combination of images taken from some or all of the devices from the stereoscopic camera system **114** and/or 3D scanner system **110**, e.g. by range imaging techniques (e.g. structure-from-motion), or stereophotogrammetric techniques. These automatic measurements of portions of the patient **118** and/or instruments and devices **138**, may help with accuracy of depth of penetration of instruments or devices **138** into the target portion of the patient **118**, or determining the current pose and pose changes of the patient **318**, etc. Using the same principles in X-rays, with markerless or marker-based Roentgen stereophotogrammetry (with stereoscopic fluoroscopic images), further adjustments are made for the correct positioning of e.g. instruments and devices **138**, or determining patient pose **318**, or positioning of fracture fragments reduced during surgery, etc.

[0164] In embodiments, preoperative planning done by software means is shown in real time blended with the preoperative **102** and intraoperative images **106** or their graphical representation, e.g. blended with the 3D volume, with the proposed measurements, angles, incisions, osteotomies, etc. drawn and marked. The planning is done and displayed as virtual graphics, either as a 2D drawing or design, or as 3D representation in any of the available file (e.g. STL) or video formats, in stereoscopic manner or not. For example, the appropriate step in surgical technique or guide (from the manufacturer of equipment, or self-made by the surgeon **128** or other users) is shown each time a predefined previous step is completed or skipped (as interpreted automatically by computer means **100**, or indicated by the surgeon **128** through real-time interface means **132**): graphical representations of the correct or possible instruments and devices **138** are shown, or marked when on the surgeon's **128** field of view; the incorrect ones are marked (e.g. with colors); possible alternative steps and instruments are shown. This intraoperative help includes e.g. any aspect of the surgery or technique, such as plates, screws, sutures, or any other instruments or devices **138**, their different sizes, shapes, materials, or a combination of them, available as virtual graphical representations.

[0165] In embodiments, augmented reality helps predict the outcome of a procedure. As one example, a virtual model of a flap drawn and displayed stereoscopically blended with the patient's **118** 3D surface or 3D volume can be manipulated virtually by the surgeon **128** within his or her field of view, for demonstrating potential outcomes of microsurgery, by adding shape-mapped, scale-mapped, and texture-mapped images blended with the target donor or acceptor portion of the patient **118**, or both.

[0166] In embodiments, graphical representations (e.g. digital 2D or 3D templates) of instruments and devices **138** (e.g. plates or nails) are displayed stereoscopically and "tried" virtually in real time blended with any of the images displayed to the surgeon **128**. For example, once a fracture is reduced or certain steps in surgery have been accomplished, virtual representations of e.g. a plate are virtually tried in the processed images **124** displayed to the surgeon **128** (e.g. blended with the 3D volume and stereoscopic video **116** according to the principles of the present invention), so that the surgeon **128** does not need to try the real plates (or needs to try less plates) over the fracture fragments, hence reducing surgery time and avoiding complications derived from e.g. making a bigger incision, stripping more periosteum for exposure, etc. In embodiments, automated measurements and calculations of instruments and devices **138** are made by computer means **100** and displayed to the surgeon **128** in the same manner. For example when broaching or reaming bone, or when inserting pins, their estimated depth within bone is automatically calculated, so that measuring of depth with mechanical devices, for estimation of the size of the definitive nail or screw to be inserted, is not necessary.

[0167] In embodiments, computer vision algorithms are used for real-time augmented reality help **134**. Thus, computer means **100** display directly to the surgeon **128** e.g. which fracture fragments may correspond with which by automatic segmentation software for bone contouring (or e.g. by registration with an image representing the healthy structure, as described above for a fracture involving a hemipelvis), which location and rotation is ideal for arthroplasty or ligament plasties, which layers and borders of the wound correspond with which (to close the wound more precisely), and so forth. As another example, computer vision software helps in classification (as a statistical image-based classification method, as described in the different embodiments above), e.g. detecting soft tissue or bony lesions, by patterns of typical fractures, or patterns of typical tendinous or ligamentous pathology.

[0168] In embodiments, 3D volume analysis is done comparing preoperative and intraoperative 3D surfaces obtained from 3D scans of the patient **118**, to evaluate for deformity correction during surgery, for example a thorax surface reconstruction is used for pectus excavatum or pectus carinatum correction, cervico-thoraco-lumbo-sacral surface reconstruction is used for scoliosis correction, or pelvic and limb surface reconstruction is used for limb deformity correction.

[0169] In embodiments, the stereoscopic camera system **114** has a digital or optical zoom feature that can be utilized during surgery according to the surgeon's **128** needs, to see a magnified augmented view, interacting with the computer **100** through the available user interface means **132**. Their precision is enhanced by software (e.g. color, contrast) and external (e.g. light, camera loupes) means as necessary, to more clearly appreciate the anatomy, thus eliminating or reducing the need for other external devices, like surgical loupes or microscopes. The zoom values are also applied to the blended images (e.g. 3D volume, graphical representations) displayed automatically by computer means **100**.

[0170] In embodiments, the surgeon **128** may input information regarding the condition of the patient **118** for storage with the preoperative images **102**. Such information may include, but is not limited to, information related to the diagnosis of the patient **118**, and information related to a surgical procedure to be performed on the patient **118**. With such

information, real-time video images **116** may be compared with the preoperative images **104**, **108** or the graphical representation of them (e.g. 3D volume) to determine whether the observed surgical images match expected surgical images based upon the patient condition information. Further, notifications may be generated and output based upon such comparisons. For example, in embodiments, the 3D surface may be compared to such data used to determine whether a surgery is performed on a correct body part or side. As a more specific example, the 3D volume-3D surface registration acquired during surgery may be analyzed to determine that a surgeon **128** is operating on a particular limb of a patient **118**, on the correct vertebra or bone within the target portion of the patient **118**. Such information may be compared to condition-related information to determine whether the procedure is being performed on the correct limb, target portion or level of the portion of the patient **118**.

[0171] In embodiments, surgical or technical videos (stereoscopic or not) stored in the computer **100** or streamed from the intranet or Internet may be displayed directly to the surgeon's **128** field of view, blended with the other images displayed, at his or her own discretion (through real-time user interface means **132**). Other examples of images that may be displayed include images from surgical atlas, book pages and illustrations, surgical techniques and guides, etc. Therefore, virtually anything available in digital format that helps the surgeon **128** outside the operating room may be displayed in real time during surgery in the surgeon's **128** field of view, according to this invention.

[0172] In embodiments, arthroscopy is done with the video images from the arthroscope displayed directly to the surgeon **128** in his own field of view. For example, the images displayed include registered (external) stereoscopic video **116**, 3D surface, 3D volume, and other digital images **108**, as well as any augmented reality help **134**.

[0173] In case the arthroscopic imaging is stereoscopic, each image is displayed to the corresponding eye of the surgeon **128** through the stereoscopic display **126**. Through tracking means **136** on the arthroscope, the principles of this invention are applied for automated registration of internal (arthroscopic) stereoscopic video with 3D surface, 3D volume, digital images **108**, and external stereoscopic video **116**. Accordingly, stereoscopic video images of the external surface and internal structures may be displayed, either alone or combined in the surgeon's **128** field of view, registered and blended with the available preoperative **102** or intraoperative **106** images. Augmented view examples include its use to observe how potential stitches (using the available images, such as the 3D volume rendering **104**) may interact with other anatomy, and to choose stitch locations based upon such demonstrations. Another example involves the use of image registration and augmented reality help to achieve the best possible position for tibial and femoral tunnels during ligamentoplasty.

[0174] In case of ultrasound and ultrasound-guided surgery, ultrasound images may undergo automatic registration and be blended with the other images available, or may be displayed directly to the surgeon's field of view **128**. An example includes tracking the ultrasound probe positioning, which is done with any combination of the aforementioned tracking means **136**, to allow for an automatic registration of stereoscopic video **116** with the ultrasound images, positioning the ultrasound images on the precise plane over the target portion of the patient **118**, with the images displayed as viewed from a virtual camera sharing the location and orientation angles of the stereoscopic camera system **114**, blended according to the principles of the present invention.

[0175] As examples of robotic feedback, gloves and other hand-wearable devices are used for active motion, and also for passive feeling. In embodiments, "active" wearable gloves are used during surgery, limiting the movement of fingers, hand, and wrist of the surgeon **128**, by augmenting resistance, or even completely blocking movement of the joints, when the instruments and devices **138** approach predetermined structures at risk. The computer **100** sends the signal to the gloves to block flexion (and/or extension) of the surgeon's **128** hand and wrist joints when getting closer e.g. to the incision's border or depth planned, the limits of a tumor, when using scalpels, saws, broaches, or any other instrument or device **138**, and having a predefined workspace for them, or when approaching structures at risk. As another example, in "passive" hand-wearable devices, computer means **100** interpret e.g. the pressure done by the surgeon's **128** fingers and joints while operating (e.g. while dissecting, or broaching), e.g. with pressure sensors, and compares such pressure with the "normal" pressure in the current and nearby layers (or from statistical pressure range from the different tissues), to determine if the instruments are near to structures at risk, to display alert notifications to the field of view of the surgeon **128**, or directly send blocking feedback to the same hand-wearable device with "active" capabilities.

[0176] The same principles described above are used in case of a fully automated robotic device, where the surgeon **128** may operate without physically being in the same room as the patient **118**.

[0177] In embodiments, the principles of this invention are used as a surgical training system, wherein surgery is done over an object, instead of a portion of the real patient **118**. For example, to train the surgical skills in spine surgery, the surgeon **128** may operate on an object, e.g. a surgical phantom of a trunk, or the trunk of a cadaver donor, or dead biological tissue with a similar form to a human trunk, or any other suitable object. Registration is done between the available 3D anatomical image (e.g. 3D volume obtained from a CT scan of the trunk of a real patient) and the 3D surface of the real object (e.g. a surgical phantom of a trunk). The 3D volume-3D surface registration **120**, and the registration of stereoscopic video-3D surface registration **122** are adjusted before surgery or during surgery by the surgeon **128** or other users through user interface means **130**, **132**, according to the principles of this invention, to obtain the best possible blending of both structures, the phantom and the preoperative images **102**. Alternatively or in combination with the embodiment above, the 3D surface of the real patient **118** (to whom the preoperative images **102** correspond) is used for an intermediate registration of 3D (phantom) surface-3D (patient) surface, to offer a more precise registration of stereoscopic video **116** and 3D volume. Stereoscopic video **116** is blended with the 3D anatomical images (e.g. the 3D volume, or a 3D anatomic atlas), following the principles of this invention, and the stereoscopic display **126** (e.g. virtual reality display) combined with the different augmented reality helps **134** already described in the different embodiments offer thus an augmented reality environment. In this augmented reality environment, the surgeon **128** is able to perform surgery on objects, while seeing real external and internal anatomic structures. In embodiments, the virtual surgery performed (as seen on the display **126**) is recorded in video format, and the

virtual stereoscopic result of the surgery is stored as virtual graphics any suitable file format (e.g. STL), whereby the surgeon **128** and other users may study the end result of surgery, e.g. the incision made, the reduction of fracture fragments, the positioning of screws, etc.

[0178] In embodiments, the augmented reality training system in accordance to the principles of this invention is used in combination with 3D printing of soft tissues and bone of the target portion of the real patient **118**. The 3D printing is based e.g. on the 3D volume obtained from CT and/or MR scans of the patient **118**, to obtain a surgical phantom that shares the same shape and size as the real patient **118**. The phantom printed includes the structures selected by the user through computer interface means, and these structures are printed in the preferred materials. In this manner, any surgery that has to be done on the real patient **118** may be trained beforehand, according to the principles of this invention, over phantoms that reproduce in detail the target portions of the patient **118**. In embodiments, the 3D surface obtained from the real patient **118** is used for image registration with the 3D printed phantom, as already described. In embodiments, phantoms that are 3D printed from real patients are used for training of similar surgical cases, even if the phantom does not exactly correspond to the actual patient **118** that will undergo surgery. The stored video of the surgery, or the stored graphical representation of the end result (e.g. in STL file format), as described above, may thus be used for preoperative planning, for displaying notifications, for identifying structures at risk, etc. to the surgeon **128**, during further surgical training on the same or a similar object, or during real surgery to the patient **118**, according to the different embodiments described.

[0179] In embodiments, the above described methods and processes may be tied to a computing system including one or more computers. Examples of such computing systems may include, but are not limited to, imaging devices **102**, **104**, computing system **100**, 3D scanner system **110**, stereo camera system **114**, tracking means **136**, stereo display **126**. In particular, the methods and processes described herein may be implemented as a computer application, computer service, computer API, computer library, and/or other computer program product.

[0180] FIG. **6** schematically shows a nonlimiting computing system **600** that may perform one or more of the above described methods and processes. Computing system **600** is shown in simplified form. It is to be understood that virtually any computer architecture may be used without departing from the scope of this disclosure. In different embodiments, computing system **600** may take the form of a mainframe computer, server computer, desktop computer, laptop computer, tablet computer, home entertainment computer, network computing device, mobile computing device, mobile communication device, gaming device, etc.

[0181] Computing system **600** includes a logic subsystem **602** and a data-holding subsystem **604**. Computing system **600** may optionally include a display subsystem **606**, communication subsystem **608**, and/or other components not shown in FIG. **6**. Computing system **600** may also optionally include user input devices such as keyboards, mice, game controllers, cameras, microphones, touch screens, gesture and/or voice recognition devices, for example.

[0182] Logic subsystem **602** may include one or more physical devices configured to execute one or more instructions. For example, logic subsystem **602** may be configured to execute one or more instructions that are part of one or more applications, services, programs, routines, libraries, objects, components, data structures, or other logical constructs. Such instructions may be implemented to perform a task, implement a data type, transform the state of one or more devices, or otherwise arrive at a desired result.

[0183] Logic subsystem **602** may include one or more processors that are configured to execute software instructions. Additionally or alternatively, logic subsystem **602** may include one or more hardware or firmware logic machines configured to execute hardware or firmware instructions. Processors of logic subsystem **602** may be single core or multicore, and the programs executed thereon may be configured for parallel or distributed processing. Logic subsystem **602** may optionally include individual components that are distributed throughout two or more devices, which may be remotely located and/or configured for coordinated processing. One or more aspects of logic subsystem **602** may be virtualized and executed by remotely accessible networked computing devices configured in a cloud computing configuration.

[0184] Data-holding subsystem **604** may include one or more physical, non-transitory, devices configured to hold data and/or instructions executable by logic subsystem **602** to implement the herein described methods and processes. When such methods and processes are implemented, the state of data-holding subsystem **604** may be transformed (e.g., to hold different data).

[0185] Data-holding subsystem **604** may include removable media and/or built-in devices. Data-holding subsystem **604** may include optical memory devices (e.g., CD, DVD, HD-DVD, Blu-Ray Disc, etc.), semiconductor memory devices (e.g., RAM, EPROM, EEPROM, etc.) and/or magnetic memory devices (e.g., hard disk drive, floppy disk drive, tape drive, MRAM, etc.), among others. Data-holding subsystem **604** may include devices with one or more of the following characteristics: volatile, nonvolatile, dynamic, static, read/write, read-only, random access, sequential access, location addressable, file addressable, and content addressable. In embodiments, logic subsystem **602** and data-holding subsystem **604** may be integrated into one or more common devices, such as an application specific integrated circuit or a system on a chip.

[0186] FIG. **6** also shows an aspect of the data-holding subsystem in the form of removable computer-readable storage media **610**, which may be used to store and/or transfer data and/or instructions executable to implement the herein described methods and processes. Removable computer-readable storage media **610** may take the form of CDs, DVDs, HD-DVDs, Blu-Ray Discs, EEPROMs, and/or floppy disks, among others.

[0187] It is to be appreciated that data-holding subsystem **604** includes one or more physical, non-transitory devices. In contrast, in embodiments aspects of the instructions described herein may be propagated in a transitory fashion by a pure signal (e.g., an electromagnetic signal, an optical signal, etc.) that is not held by a physical device for at least a finite duration. Furthermore, data and/or other forms of information pertaining to the present disclosure may be propagated by a pure signal.

[0188] The terms "module," "program," and "engine" may be used to describe an aspect of computing system **600** that is implemented to perform one or more particular functions. In some cases, such a module, program, or engine may be instantiated via logic subsystem **602** executing instructions

held by data-holding subsystem **604**. It is to be understood that different modules, programs, and/or engines may be instantiated from the same application, service, code block, object, library, routine, API, function, etc. Likewise, the same module, program, and/or engine may be instantiated by different applications, services, code blocks, objects, routines, APIs, functions, etc. The terms "module," "program," and "engine" are meant to encompass individual or groups of executable files, data files, libraries, drivers, scripts, database records, etc.

[0189] It is to be appreciated that a "service," as used herein, may be an application program executable across multiple user sessions and available to one or more system components, programs, and/or other services. In some implementations, a service may run on a server responsive to a request from a client.

[0190] When included, display subsystem **606** may be used to present a visual representation of data held by data-holding subsystem **604**. As the herein described methods and processes change the data held by the data-holding subsystem, and thus transform the state of the data-holding subsystem, the state of display subsystem **606** may likewise be transformed to visually represent changes in the underlying data. Display subsystem **606** may include one or more display devices utilizing virtually any type of technology. Such display devices may be combined with logic subsystem **602** and/or data-holding subsystem **604** in a shared enclosure, or such display devices may be peripheral display devices.

[0191] When included, communication subsystem **608** may be configured to communicatively couple computing system **600** with one or more other computing devices. Communication subsystem **608** may include wired and/or wireless communication devices compatible with one or more different communication protocols. As nonlimiting examples, the communication subsystem may be configured for communication via a wireless telephone network, a wireless local area network, a wired local area network, a wireless wide area network, a wired wide area network, etc. In embodiments, the communication subsystem may allow computing system **600** to send and/or receive messages to and/or from other devices via a network such as the Internet.

[0192] In embodiments, the stereoscopic video image **116** is taken as the adaptable basic view of the surgeon **128** or surgeons, and may follow the surgeon's **128** head movements, or be independent of his or her position in the operating room. Digital images and virtual graphics blended with the stereoscopic video **116** enhance the displayed image, and may even substitute it completely, through image processing **124**, which may provide a fully customizable view to the surgeon **128**.

[0193] 3D scanner devices **112** described in embodiments may offer an intermediate step for registration between stereoscopic video **116** and the graphical representation (e.g. 3D volume) of a preoperative **102** or intraoperative image **106**, which allows for a more accurate, quicker, real-time image registration with automatic patient **118** pose change adaptation, within a simple image-guided navigation system, using the available markerless or marker-based registration methods. The surgeon's **128** viewpoint (the stereoscopic camera system **114**) in turn, is independent from the 3D scanner system **112**, and can be fixed or dynamic. Accordingly, embodiments may be a more cost effective, in initial investment as well as in fungibles (e.g. markers). Embodiments may make use of anatomical models and volume rendering **104** of individualized parts allowing for a precise registration of pose changes of the patient **118** to the 3D volume **320**, by determining pose changes in real time **318** and translating them into a predefined 3D anatomical model with moveable inner structures. Image processing **124** (including the precise blending of the available images) and augmented reality help **134** are adjusted during surgery through real-time user interaction **132** e.g. through gesture recognition (without the need to physically touch interface means), outpacing the current limitations of the available navigation systems.

[0194] Tracking of imaging devices **106**, patient **118**, instruments and devices **138**, is done with optical marker-based or markerless means, e.g. with tracker cameras forming part of the 3D scanner system **110**. Tracking data is made available as virtual graphics directly into the surgeon's view **128** in a stereoscopic way, offering a direct, precise and intuitive guide for positioning of instruments and devices **138** during surgery. Preoperative **102** and intraoperative images **106** are also displayed directly to the surgeon's **128** field of view, and stereoscopic views offer more accurate representations of the available digital and virtual (e.g. 3D volume) images during surgery. All preoperative **102** and intraoperative images **106** may tracked to the current pose of the patient **118** during surgery, according to the principles of this invention.

[0195] With this navigation system there is real-time interaction of the surgeon **128** with software-based tasks through the general **130** or real-time user interface means **134**, e.g. by gesture or voice recognition. Gestures are recognized by motion tracking software, e.g. from images by the 3D scanner device **110**, or the stereoscopic display **126**, or from stereoscopic video images **116**. That makes the navigation system even more accurate, with instant adjustments made by the surgeon **128** or other users to image processing **124**, e.g. to the registration of images, or to the augmented reality help **134** displayed. Computer means **100** in accordance with this invention, and especially with the stereoscopic display **126**, offer a wide range of augmented reality possibilities that are of great help to the surgeon **128** during surgery.

[0196] As already described in the embodiments above, stereoscopic video **116** may be sent directly to the display **126**, and then undergo registration in the computer **100** being blended with the other images available, making the real time lag between actual scene and stereoscopic video **116** negligible. Also, as already described in the embodiments above, changes in position of the patient **118**, instruments and devices **138** and/or surgeon's **128** head are tracked, so that the perspective view of the virtual graphics composing the augmented reality view change in real time. Therefore, images available to computer means **100** (e.g. 3D surface, 3D volume, or virtual representation of instruments or devices **138**) may adjust more quickly to changes in the position of the patient **118**, instruments or devices **138**, or the surgeon's **128** head than registered stereoscopic video (that needs to pass from the cameras **114** to the computer **100** as digital video **116**, and then processed **124** for registration), or even than stereoscopic video **116** sent directly to the display **126**. When the available digital images (e.g. 3D surface, 3D volume) and virtual graphics are sent directly to the display **126** (once the initial registration of images has been done), without blending with the stereoscopic video **116**, the time lag between the real scene and the surgeon's **128** view is still less appreciable.

[0197] Other embodiments may be utilized in combination with an optical see-through display, tracking the surgeon's

128 head, using any of the commercially available devices for this task (e.g. optical see-through glasses). Alternatively, a stereoscopic display **126** is used that works as a video see-through device during the surgery, but turns into an optical see-through display, thanks to the percentage of transparency applied to the display's special glasses. Alternatively, a projector is used that projects the processed images **124** directly to the target portion of the patient **118**. Alternatively, the surgeon **128** may ask for a change of display during surgery, having them both head-mounted, or being helped by another member of the surgical team who changes them, whenever the surgeon **128** feels the need for a lag-less vision.

[0198] While the foregoing written description of the invention enables one of ordinary skill to make and use what is considered presently to be the best mode thereof, those of ordinary skill will understand and appreciate the existence of variations, combinations, and equivalents of the specific embodiment, method, and examples herein. The invention should therefore not be limited by the above described embodiment, method, and examples, but by all embodiments and methods within the scope and spirit of the invention as claimed.

What is claimed is:

1. An image guided surface reconstruction and augmented visualization system, comprising:

a computer configured to receive a graphical representation of an anatomical structure of a target portion of a patient, and a three dimensional surface image of the target portion;

a registration processor configured to register the three dimensional surface image with the graphical representation of the anatomical structure of the target portion;

a stereoscopic camera configured to capture a stereoscopic video including the target portion;

a rendering processor configured to combine the stereoscopic video with the three dimensional surface image and the graphical representation of the anatomical structure of the target portion;

a display configured to present the combined stereoscopic video with the three dimensional surface image and the graphical representation of the anatomical structure of the target portion in a stereoscopic augmented image.

2. The system of claim **1**, wherein three dimensional surface image is received during surgery, and the three dimensional surface image includes a raw 3D scan data of the target portion obtained by at least one 3D scanner device.

3. The system of claim **1**, wherein the stereoscopic video is a stereoscopic view captured by at least two cameras, wherein each of the two cameras are directed towards the target portion.

4. The system of claim **3**, wherein the stereoscopic augmented image is obtained by blending the stereoscopic view captured by the at least two cameras and the graphical representation of the anatomical structure of the target portion of the patient.

5. The system of claim **4**, wherein the stereoscopic augmented image is presented on the display via a head mounted device.

6. An image guided surface reconstruction and augmented visualization system comprising:

a computer configured to receive an image of a patient;

a processor configured to process the image to provide a graphical representation of an anatomical structure of the patient in the image;

a scanner processor configured to receive a three dimensional surface image of the patient during surgery, wherein the three dimensional surface image of the patient includes a coordinate system;

a comparing processor configured to compare the graphical representation of the anatomical structure associated with the image with the three dimensional surface image of the patient;

an image processor configured to receive stereoscopic media of the patient during the surgery from a plurality of cameras, wherein the stereoscopic media includes data associated with the coordinate system, position data, and orientation data associated with each of the plurality of cameras;

a stereoscopic output processor configured to combine the stereoscopic media with the graphical representation of an anatomical structure of the patient in the image responsive to determining a position and an orientation of the plurality of cameras based on the position data, orientation data, and coordinate system;

a display configured to present the combined the stereoscopic media with the graphical representation of an anatomical structure of the patient as a single image.

7. The system of claim **6**, wherein the image of the patient is a preoperative or intraoperative image.

8. The system of claim **6**, wherein the stereoscopic media includes a pair of images corresponding to the graphical representation of the anatomical structure of the patient in the image and the three dimensional surface image of an external anatomical surface of the patient.

9. The system of claim **6**, wherein the stereoscopic media includes a pair of images corresponding to the graphical representation of the anatomical structure of the patient in the image and the three dimensional surface image of an internal anatomical surface of the patient.

10. The system of claim **6**, further comprising:

a tracking system configured to measure pose data of the plurality of cameras, wherein the pose data is determined based on a predetermined relationship of the plurality cameras.

11. The system of claim **6**, wherein the combining the stereoscopic media with the graphical representation of the anatomical structure of the patient in the image includes determining

the position and the orientation of the plurality of cameras in reference to the coordinate system.

12. The system of claim **11**, further comprising:

virtual cameras capturing the stereoscopic media with the graphical representation of the anatomical structure of the patient, wherein the virtual cameras include the same position and orientation as the plurality of cameras.

13. The system of claim **6**, wherein the display is configured to apply background subtraction methods to the combined the stereoscopic media with the graphical representation of an anatomical structure of the patient as a single image, wherein the background subtraction methods superimpose a background model in a degree of transparency.

14. A method utilizing an image guided surface reconstruction and augmented visualization, the method comprising:

receiving an image of a patient;

processing the image to provide a graphical representation of an anatomical structure of the patient in the image;

receiving a three dimensional surface image of the patient during surgery, wherein the three dimensional surface image of the patient includes a coordinate system;

comparing the graphical representation of the anatomical structure associated with the image with the three dimensional surface image of the patient;

receiving stereoscopic media of the patient during the surgery from a plurality of cameras, wherein the stereoscopic media includes data associated with the coordinate system, position data, and orientation data associated with each of the plurality of cameras;

combining the stereoscopic media with the graphical representation of an anatomical structure of the patient in the image responsive to determining a position and an orientation of the plurality of cameras based on the position data, orientation data, and coordinate system;

presenting the combined the stereoscopic media with the graphical representation of an anatomical structure of the patient as a single image.

15. The method of claim **14**, wherein the image of the patient is a preoperative or intraoperative image.

16. The method of claim **14**, wherein the stereoscopic media includes a pair of images corresponding to the graphical representation of the anatomical structure of the patient in the image and the three dimensional surface image of an external anatomical surface of the patient.

17. The method of claim **14**, wherein the stereoscopic media includes a pair of images corresponding to the graphical representation of the anatomical structure of the patient in the image and the three dimensional surface image of an internal anatomical surface of the patient.

18. The method of claim **14**, further comprising:

measuring pose data of the plurality of cameras, wherein the pose data is determined based on a predetermined relationship of the plurality cameras.

19. The method of claim **14**, wherein the combining the stereoscopic media with the graphical representation of the anatomical structure of the patient in the image includes determining the position and the orientation of the plurality of cameras in reference to the coordinate system.

20. The method of claim **19**, further comprising:

capturing the stereoscopic media with the graphical representation of the anatomical structure of the patient, wherein the virtual cameras include the same position and orientation as the plurality of cameras.

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