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PTO/SB/21 (09-04)

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TRANSMITTAL FORM (to be used for all correspondence after initial filing)	Application Number	60/761,078	
	Filing Date	January 20, 2006	
	First Named Inventor	Ilya A. Kriveshko	
	Art Unit	N/A	
	Examiner Name	N/A	
Total Number of Pages in This Submission	4	Attorney Docket Number	BRNT-0002-P60

ENCLOSURES (Check all that apply)		
☐ Fee Transmittal Form	☐ Drawing(s)	☐ After Allowance Communication to TC
☐ Fee Attached	☐ Licensing-related Papers	☐ Appeal Communication to Board of Appeals and Interferences
☒ Amendment/Reply	☐ Petition	☐ Appeal Communication to TC (Appeal Notice, Brief, Reply Brief)
☐ After Final	☐ Petition to Convert to a Provisional Application	☐ Proprietary Information
☐ Affidavits/declaration(s)	☐ Power of Attorney, Revocation	☐ Status Letter
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Remarks 4 pages including this transmittal and excluding the return postcard.		
SIGNATURE OF APPLICANT, ATTORNEY, OR AGENT		
Firm Name	Strategic Patents, PC	
Signature		
Printed name	Robert A. Mazzaresse	
Date	February 22, 2006	Reg. No. 42,852

CERTIFICATE OF TRANSMISSION/MAILING		
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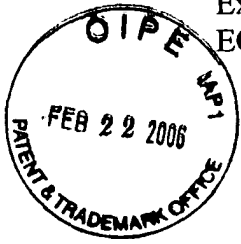
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3SHAPE EXHIBIT 1003

3Shape v. Medit

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PATENTS
BRNT-0002-P60



Inventor	Ilya A. Kriveshko, et al.
Serial No.	60/761,078
Confirmation No.	N/A
Filed	January 20, 2006
Entitled	DIGITAL DENTISTRY
Examiner	N/A
TC/A.U.	N/A

Commissioner of Patents
P.O. Box 1450
Alexandria, VA 22313-1450

AMENDMENT TO CORRECT INVENTORSHIP

Sir/Madam:

Kindly amend inventorship in the above application pursuant to 37 CFR 1.48(d) as set forth below. A Form PTO-2038 authorizing charges of \$50.00 as specified by 37 CFR 1.17(q) is attached in support of this amendment.

Please amend inventorship in this application by adding the additional inventor identified below:

Additional inventors:

- First Name: Janos
Middle Initial:
Last Name: Rohaly, Jr
City : Acton
State: MA

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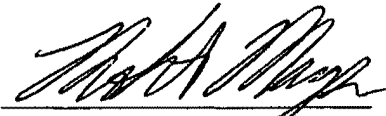
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PATENTS
BRNT-0002-P60

The additional inventor was omitted from the originally filed provisional application without deceptive intent on the part of the omitted inventor or the originally named inventors.

Respectfully submitted,
STRATEGIC PATENTS, P.C.

A handwritten signature in black ink, appearing to read 'Robert A. Mazzaresse', written over a horizontal line.

Robert A. Mazzaresse
Reg. No. 42,852
Tel.: (781) 453-9993

February 22, 2006

012006

17224 U.S. PTO

PTO/SB/16 (12-04)

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PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

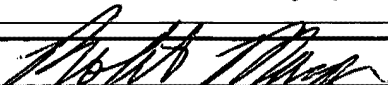
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112935 U.S. PTO
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012006

INVENTOR(S)		
Given Name (first and middle [if any])	Family Name or Surname	Residence (City and either State or Foreign Country)
Ilya A.	Kriveshko	Littleton, MA
Additional inventors are being named on the _____ separately numbered sheets attached hereto.		
TITLE OF THE INVENTION (500 characters max):		
DIGITAL DENTISTRY		
Direct all correspondence to: CORRESPONDENCE ADDRESS		
☒ The address corresponding to Customer Number: 43520		
OR		
☐ Firm or Individual Name		
Address		
City	State	Zip
Country	Telephone	Fax
ENCLOSED APPLICATION PARTS (check all that apply)		
☐ Application Data Sheet. See 37 CFR 1.76		
☐ CD(s), Number of CDs _____		
☒ Specification Number of Pages <u>191</u>		
☒ Other (specify) <u>return postcard</u>		
☐ Drawing(s) Number of Sheets _____		
Application Size Fee: If the specification and drawings exceed 100 sheets of paper, the application size fee due is \$250 (\$125 for small entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).		
METHOD OF PAYMENT OF FILING FEES AND APPLICATION SIZE FEE FOR THIS PROVISIONAL APPLICATION FOR PATENT		
☒ Applicant claims small entity status. See 37 CFR 1.27.		TOTAL FEE AMOUNT (\$)
☐ A check or money order is enclosed to cover the filing fee and application size fee (if applicable).		350.00
☒ Payment by credit card. Form PTO-2038 is attached		
☐ The Director is hereby authorized to charge the filing fee and application size fee (if applicable) or credit any overpayment to Deposit		
Account Number: _____ A duplicative copy of this form is enclosed for fee processing.		
The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.		
☒ No.		
☐ Yes, the name of the U.S. Government agency and the Government contract number are: _____		

SIGNATURE



Date 1/20/06

TYPED or PRINTED NAME Robert A. Mazzaresse

REGISTRATION NO. 42,852

(if appropriate)

TELEPHONE (781) 453-9993

Docket Number: BRNT-0002-P60

USE ONLY FOR FILING A PROVISIONAL APPLICATION FOR PATENT

This collection of information is required by 37 CFR 1.51. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 8 hours to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.

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PROVISIONAL APPLICATION COVER SHEET
Additional Page

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First Named Inventor	Kriveshko	Docket Number	BRNT-0002-P60
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INVENTOR(S)/APPLICANT(S)		
Given Name (first and middle (if any))	Family or Surname	Residence (City and either State or Foreign Country)
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Number 1 of 1

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In the United States Patent Office
a provisional patent application for

DIGITAL DENTISTRY

Exp. Mail No. EQ505636588US
Date of Deposit: January 20, 2006

The following disclosure describes various aspects of three-dimensional data acquisition, digital dentistry, visualization in a dental context, and fabrication of various dental objects. This material is set out as three separate documents as follows:

Digital Dentistry written description (70 pages)
Digital Dentistry drawings (7 sheets)

Visualization written description (46 pages)
Visualization drawings (8 sheets)

Fabrication written description (49 pages)
Fabrication drawings (10 pages)

While presented as three separate disclosures, it will be understood that numerous combinations of these disclosures are possible, and more particularly, numerous combinations within a dental context are possible. All such variations and combinations of the subject matter herein, whether in one or several of the following documents, are intended to fall within the scope of inventive subject matter disclosed herein.

DIGITAL DENTISTRY

BACKGROUND

1. Field of the Invention.

[0001] The invention relates to dentistry, and more particularly for dental applications of digital, three-dimensional representations of dentition.

2. Description of the Related Art.

[0002] Dentistry today largely continues in the mold of the past, using techniques pioneered by ancient Egyptians. One basic technique for manufacturing a dental restoration, the so-called lost wax method, employs a wax pattern from which a metal casting is made. A mold of the wax pattern is made using a high-heat investment material. The mold is then heated in a furnace, the pattern is then burned out, and the investment ring is cast or filled with some type of alloy or some other substance to provide a final version of a dental restoration. A dentist bonds this prosthetic to a site in a patient's mouth that has been hand-prepared to match the prosthetic. As a significant disadvantage, a substantial burden is placed on practicing dentists to physically match restorations and tooth surfaces. Further complicating this process, the wax model itself is typically created from a physical cast of the patient's mouth. The casting process can introduce errors into a final restoration, as can material handling in the multiple steps carried out by a dental laboratory to go from the original dental impression to the final restoration.

[0003] In theory, digital dentistry offers manifest advantages of quality, portability, and durability as compared to cast models of physical impressions. However, advances in dentistry have been muted, at least in part due to the inability to easily capture adequate three-dimensional data for teeth and surrounding soft tissue. In addition, dentistry has achieved only limited gains from general improvements in manufacturing technologies because each dental patient and restoration presents a unique, one-off product.

[0004] There remains a need for dentistry tools that capture high-quality digital dental models, as well as tools that permit the design and manufacture of dental hardware from such models.

SUMMARY

[0005] The systems and methods disclosed herein employ a scanning system for capturing highly detailed digital dental models. These models may be used within a dentist's office for a wide array of dental functions including quality control, restoration design, and fitting. These models may also, or instead, be transmitted to dental laboratories that may, alone or in collaboration with the originating dentist or other dental professionals, transform the digital model into a physical realization of a dental hardware item.

[0006] A method disclosed herein includes acquiring a three-dimensional representation of one or more intraoral structures of a dental patient using an intraoral scanner; and providing the three-dimensional representation to a dental fabrication facility.

[0007] The method may further include fabricating a dental restoration at the dental fabrication facility using the three-dimensional representation. The dental fabrication facility may include a dental laboratory. The one or more intraoral structures may include at least one dental implant, at least one tooth, at least one tooth surface prepared for a dental restoration, at least one previously restored tooth, and/or at least one area of soft tissue. The method may further include fabricating a dental prosthesis at the dental fabrication facility using the three-dimensional representation.

[0008] The method may further include transmitting the three-dimensional representation to a dental laboratory and, in response, receiving an assessment of quality for the three-dimensional representation from the dental laboratory. The assessment of quality may be received before the dental patient leaves a dentist's office. The assessment of quality may include an assessment of acceptability of the three-dimensional representation. The method may further include transmitting the three-dimensional representation to a dental laboratory and, in response, receiving an assessment of quality of the at least one prepared tooth surface. Transmitting the three-dimensional representation to a dental fabrication facility may include transmitting to a remote dental laboratory for fabrication of a dental restoration for

the one or more intraoral structures. The method may further include transmitting the three-dimensional representation to a dental data hub. The method may further include transmitting a prescription for the dental restoration with the three-dimensional representation. The method may further include transmitting the three-dimensional representation to a model production laboratory. The model production laboratory may be a milling facility, a manufacturing facility, or a three-dimensional rapid prototyping facility. Transmitting the three-dimensional representation to a dental fabrication facility may include providing the three-dimensional representation to an in-office dental laboratory for fabrication of a dental restoration for the one or more intraoral structures.

[0009] A computer program product disclosed herein includes computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, may perform the steps of: acquiring one or more images of one or more intraoral structures of a dental patient from an intraoral scanner; converting the one or more images into a three-dimensional representation of the one or more intraoral structures; and transmitting the three-dimensional representation to a dental fabrication facility.

[0010] The computer program may further include computer code that performs the step of comparing quality of the three-dimensional representation to predefined quality criteria. The predefined quality criteria may include acceptability of the three-dimensional representation for fabrication. The computer program may further include computer code that performs the steps of: retrieving a prescription for at least one of a prosthesis or an appliance by a dentist; and combining the prescription with the three-dimensional representation prior to transmitting the three-dimensional representation. The one or more intraoral structures may include at least one dental implant, one tooth, or one tooth surface prepared for a dental restoration. The computer program may further include computer code that performs the step of comparing quality of the at least one prepared tooth surface to predefined quality criteria. The one or more intraoral structures may include at least one area of soft tissue.

[0011] A system disclosed herein includes an intraoral scanner for acquiring a three-dimensional representation of one or more intraoral structures of a dental patient; and a transmission means for transmitting the three-dimensional representation to a dental fabrication facility.

[0012] The system may further include a first fabrication means for fabricating a dental restoration at the dental fabrication facility using the three-dimensional representation. The one or more intraoral structures may include at least one dental implant, one tooth, least one tooth surface prepared for a dental restoration, or one area of soft tissue. The system may further include a second fabrication means for fabricating a dental prosthesis at the dental fabrication facility using the three-dimensional representation. The system may further include a quality assessment means for assessing quality of the three-dimensional representation. The quality assessment means may include a means for determining acceptability of the three-dimensional representation for use with the first fabrication means. The quality assessment means may include a means for determining acceptability of the three-dimensional representation for use with the second fabrication means. The one or more intraoral structures may include at least one tooth surface prepared for a dental restoration, wherein the quality assessment means includes a means for determining quality of the at least one prepared tooth surface.

[0013] In another aspect, a method disclosed herein includes receiving a three-dimensional representation of a tooth, the tooth prepared for a dental restoration; specifying a cementation void between the tooth surface and the dental restoration; and fabricating the dental restoration such that the dental restoration, when mated to the tooth surface, defines an empty space corresponding to the cementation void.

[0014] The method may include adjusting the cementation void, such as according to a dentist's preferences or according to the type of cement to be used in the cementation void. The cementation void may be specified by a dentist. The dentist may send the specification to a dental laboratory. The cementation void may be specified by a dental laboratory. The method may include three-dimensionally printing a die including the cementation void. The method may include fabricating a die including the cementation void with a stereo lithography apparatus. The method may include three-dimensionally printing a wax-up including the cementation void. The method may include milling a die

including the cementation void. The method may include integrating the cementation void into a digital surface representation of the tooth. The method may include integrating the cementation void into a dental model. The three-dimensional representation may include a digital surface representation of the tooth. Fabricating the dental restoration may include fabricating the dental restoration in an in-house laboratory in a dentist's office. The method may further include fabricating an opposing arch for an arch including the tooth, the opposing arch including a die spacer having a predetermined thickness.

[0015] In another aspect, a computer program product disclosed herein includes computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of: acquiring one or more images of a tooth of a dental patient from an intraoral scanner, the tooth including a tooth surface prepared for a dental restoration; converting the one or more images into a three-dimensional representation of the tooth; specifying a cementation void between the tooth surface and the dental restoration; combining the specification for the cementation void with the three-dimensional representation into a fabrication specification; and transmitting the fabrication specification to a dental fabrication facility.

[0016] A dentist may specify the cementation void. The computer program product may include code that performs the step of receiving a specification of the cementation void from the dental fabrication facility. The computer program product may include code for three-dimensionally printing the cementation void to a die. The computer program product may include code for three-dimensionally printing the cementation void to a wax up. The computer program product may include code that performs the step of integrating the cementation void into a digital surface representation of the tooth.

[0017] In another aspect, a system disclosed herein includes a first means for three-dimensionally representing a tooth, the tooth prepared for a dental restoration; a second means for specifying a cementation void, the cementation void representing an empty space between the tooth surface and the dental restoration; and a fabrication means for fabricating the dental restoration such that the dental restoration, when mated to the tooth surface, defines an empty space corresponding to the cementation void.

[0018] The system may include an adjustment means for adjusting the cementation void. The adjustment means may include means for incorporating a dentist's preferences. The adjustment means may include means for adjusting the cementation void according to a type of cement. The system may include a first printing means for three-dimensionally printing a die including the cementation void. The system may include a second printing means for three-dimensionally printing a wax-up including the cementation void. The system may include a milling means for milling a die including the cementation void. The system may include a milling means for milling an investment chamber for casting including the cementation void. The system may include a model means for integrating the cementation void into a model of a dental impression. The three-dimensional representation of a tooth may include a digital surface representation of the tooth.

[0019] In another aspect, a method disclosed herein includes fabricating a dental object; acquiring a first three-dimensional representation of the object; and measuring a dimensional accuracy of the first three-dimensional representation.

The first three-dimensional representation may include a digital surface representation. The dental object may include a dental prosthesis, a dental implant, a dental appliance, a dental restoration, a restorative component, or an abutment. The method may include acquiring a second three-dimensional representation of one or more teeth including at least one tooth surface prepared for the dental object, wherein measuring a dimensional accuracy may include evaluating a fit between the item of the first three-dimensional representation and the at least one tooth surface of the second three-dimensional representation. The method may further include acquiring a second three-dimensional representation of one or more teeth including at least one tooth surface prepared for the dental object, wherein measuring a dimensional accuracy may include evaluating one or more contact points between the item of the first three-dimensional representation and the one or more teeth of the second three-dimensional representation when the item is virtually affixed to the at least one tooth surface. The method may further include acquiring a second three-dimensional representation of one or more teeth including at least one tooth

surface prepared for the dental object and at least one opposing tooth, wherein measuring a dimensional accuracy may include evaluating one or more contact points between the item of the first three-dimensional representation and the at least one opposing tooth of the second three-dimensional representation when the item is virtually affixed to the at least one tooth surface. The second three-dimensional representation may be acquired as a plurality of separate scans. The second three-dimensional representation may be acquired as a continuous scan of the at least one tooth surface and the at least one opposing tooth in occlusion. A dentist may specify tightness of fit of the dental object. Measuring a dimensional accuracy may include quantifying tightness of fit of the dental object. Measuring a dimensional accuracy includes measuring quality of a margin.

[0020] A computer program product may include computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of: acquiring one or more images of a dental object; converting the one or more images of the dental object into a first three-dimensional representation of the item; and measuring a dimensional accuracy of the first three-dimensional representation. The first three-dimensional representation may include a digital surface representation.

[0021] The dental object may include a dental prosthesis, a dental implant, a dental appliance, a dental restoration, a restorative component, or an abutment. The computer program product may include code that performs the steps of: acquiring one or more images of one or more teeth including at least one tooth surface prepared for the dental object; and converting the one or more images of the one or more teeth into a second three-dimensional representation of the one or more teeth, wherein measuring a dimensional accuracy includes evaluating a fit between the item of the first three-dimensional representation and the at least one tooth surface of the second three-dimensional representation. The computer program product may include code that performs the steps of: acquiring one or more images of one or more teeth including at least one tooth surface prepared for the dental object; converting the one or more images of the one or more teeth into a second three-dimensional representation of the one or more teeth; and generating one or more contact points between the item of the first three-dimensional representation and the one or more teeth of the second three-dimensional representation by virtually affixing the item to the at least one tooth surface, wherein measuring includes evaluating one or more contact points.

[0022] The computer program product may further include computer code that performs the steps of: acquiring one or more images of one or more teeth including at least one tooth surface prepared for the dental object and at least one opposing tooth; converting the one or more images of the one or more teeth and the at least one opposing tooth into a second three-dimensional representation of the one or more teeth and the at least one opposing tooth; and generating one or more contact points between the item of the first three-dimensional representation and the at least one opposing tooth of the second three-dimensional representation by virtually affixing the item to the at least one tooth surface, wherein measuring includes evaluating one or more contact points. Measuring a dimensional accuracy may include quantifying tightness of fit of the dental object. Measuring a dimensional accuracy may include measuring quality of a margin.

[0023] A system disclosed herein includes a fabrication means for fabricating a dental object; a first means for acquiring a first three-dimensional representation of the item; and a measurement means for measuring a dimensional accuracy of the first three-dimensional representation. The first three-dimensional representation may include a digital surface representation.

[0024] The dental object may include a dental prosthesis, a dental implant, a dental appliance, a dental restoration, a restorative component, or an abutment. The system may further include a second means for acquiring a second three-dimensional representation of one or more teeth including at least one tooth surface prepared for the dental object, wherein measuring a dimensional accuracy may include evaluating a fit between the item of the first three-dimensional representation and the at least one tooth surface of the second three-dimensional representation. The system may further include a second means for acquiring a second three-dimensional representation of one or more teeth including at least one tooth surface prepared for the dental object, wherein measuring a dimensional accuracy may include evaluating

one or more contact points between the item of the first three-dimensional representation and the one or more teeth of the second three-dimensional representation when the item is virtually affixed to the at least one tooth surface. The system may further include a second means for acquiring a second three-dimensional representation of one or more teeth including at least one tooth surface prepared for the dental object and at least one opposing tooth, wherein measuring a dimensional accuracy may include evaluating one or more contact points between the item of the first three-dimensional representation and the at least one opposing tooth of the second three-dimensional representation when the item is virtually affixed to the at least one tooth surface. A dentist may specify tightness of fit of the dental object. Measuring a dimensional accuracy may include quantifying tightness of fit of the dental object. Measuring a dimensional accuracy includes measuring quality of a margin.

[0025] A method disclosed herein includes acquiring a three-dimensional representation including three-dimensional surface data for at least two independent dental structures; and acquiring motion data characterizing a relative motion of the at least two independent dental structures with respect to one another within a mouth.

[0026] The method may include deriving TMJ condyle paths of rotation and translation from the motion data and the three-dimensional surface data. The method may include providing input to a virtual dental articulator. The method may include providing specifications for a physical dental articulator. The method may include providing specifications for a disposable dental articulator. Acquiring the three-dimensional representation may include acquiring the three-dimensional representation using an intraoral scanner. Acquiring motion data may include acquiring motion data from a video source.

[0027] A computer program product disclosed herein includes computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, may perform the steps of: acquiring one or more images of at least two independent dental structures of a dental patient from an intraoral scanner; converting the one or more images into a three-dimensional representation of the at least two independent dental structures; acquiring motion data characterizing a relative motion of the at least two independent dental structures with respect to one another; and combining the three-dimensional representation with the motion data to derive TMJ condyle paths of rotation and translation.

[0028] The computer program may include code that performs the steps of: generating an image sequence of the combined three-dimensional representation and the motion data; generating a display signal of the image sequence. Acquiring motion data may include acquiring motion data from a video source.

[0029] A system disclosed herein includes a first means for acquiring one or more images of at least two independent dental structures of a dental patient; a conversion means for converting the one or more images into a three-dimensional representation of the at least two independent dental structures; and a second means for acquiring motion data characterizing a relative motion of the at least two independent dental structures with respect to one another. The system may include an analysis means for deriving TMJ condyle paths of rotation and translation using the three-dimensional representation and the motion data.

[0030] The system may include an action means for combining the three-dimensional representation and the motion data to generate an articulation input. The system may include a first model means for virtually articulating the articulation input. The system may include a second model means for physically articulating the articulation input. The system may include a disposable model means for physically articulating the articulation input. The first means may include a means for acquiring the one or more images using an intraoral scanner. The second means may include a means for acquiring the motion data from a video source.

[0031] In another aspect, a method disclosed herein includes receiving an electronic dental prescription including prescription data, a first three-dimensional representation of one or more intraoral structures including at least one tooth surface prepared for an artificial dental object, and a second three-dimensional representation of the at least one tooth surface prior to preparation for the artificial dental

object; and fabricating the artificial dental object for the one or more intraoral structures using the electronic dental prescription.

[0032] Receiving an electronic dental prescription may include receiving a three-dimensional representation from a dental data hub or from a dentist. Receiving a three-dimensional representation may include receiving a prescription for a dental restoration for the tooth surface. At least one of the first and second three-dimensional representations may include a digital surface representation of a full arch. The electronic dental prescription may include a prescription for an appliance, a prosthesis, or an item of dental hardware. Fabricating an artificial dental object may include fabricating a dental restoration in an in-house laboratory in a dentist's office.

[0033] A system disclosed herein includes a communication means for receiving a prescription data, a first three-dimensional representation of one or more intraoral structures including at least one tooth surface prepared for an artificial dental object, and a second three-dimensional representation of the at least one tooth surface prior to preparation for the artificial dental object; and a fabrication means for fabricating a dental restoration for the one or more intraoral structures using the three-dimensional representation.

[0034] The communication means may include a means for receiving the electronic dental prescription from a dental data hub or a dentist. The electronic dental prescription may include a prescription for a dental restoration. At least one of the first and second three-dimensional representations may include a digital surface representation of a full arch. The electronic dental prescription may include a prescription for one or more of an appliance, a prosthesis, and an item of dental hardware. The fabrication means may include in an in-house laboratory in a dentist's office.

[0035] In another aspect, a method disclosed herein includes a single dental visit, the steps of: acquiring a three-dimensional representation of one or more intraoral structures from a dental patient, the intraoral structures may include at least one tooth surface prepared for an artificial dental object; and processing the three-dimensional representation to provide feedback to a dentist concerning the at least one tooth surface.

[0036] The feedback may identify corrective action. The corrective action may include acquiring an additional three-dimensional representation of the one or more intraoral structures. The corrective action may include additional surface preparation of the at least one tooth. The feedback may identify a margin for fitting the dental restoration to the at least one tooth surface. The margin for fitting may be edited. The feedback may include a visual display of one or more regions of inadequate margin for fitting the dental restoration to the at least one tooth surface. The feedback may include a visual display recommending additional preparatory work required for the at least one tooth surface. The feedback may include a visual display recommending acquiring additional three-dimensional representations of one or more regions of the one or more intraoral structures. The feedback may include identifying an incomplete three-dimensional representation. The feedback may include identifying errors in the three-dimensional representation. The feedback may include visual highlighting of a margin line on a display of the three-dimensional representation.

[0037] A computer program product disclosed herein includes computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of: acquiring one or more images of one or more intraoral structures of a dental patient, the intraoral structures including at least one tooth surface prepared for an artificial dental object; converting the one or more images into a three-dimensional representation of the one or more intraoral structures; analyzing the at least one tooth surface within the three-dimensional representation; generating a feedback signal, the feedback signal representative of the result of analyzing the at least one tooth surface; and outputting the feedback signal to provide feedback to a dentist.

[0038] The feedback signal may identify corrective action. The corrective action may include acquiring an additional one or more images of the one or more intraoral dental structures. The corrective action may include additional surface preparation of the at least one tooth. The feedback signal may identify a margin for fitting the dental restoration to the at least one tooth surface. The margin for fitting may be edited.

[0039] In another aspect, a system disclosed herein includes a scanning device configured to intraorally capture surface image data from a surface within a mouth of a dental patient; a computer coupled to the scanning device and receiving the surface image data therefrom, the computer configured to resolve the surface image data into a digital surface reconstruction, the computer further configured to generate a visualization of the digital surface reconstruction and provide the visualization as a display signal; and a display coupled to the computer and receiving the display signal therefrom, the display converting the display signal into a viewable image of the visualization. The surface may include dentition.

[0040] The scanning device may capture surface image data at a video frame rate. The system may include a user interface controlled by the computer and rendered on the display. The user interface may provide at least one tool for analyzing the surface. The user interface may include a tool that may provide real time feedback to the user. The real time feedback may include visual cues within the rendered image. The at least one tool may include a distance measurement tool, a tool that may evaluate adequacy of tooth structure removal from a dental restoration surface preparation, a tool that may evaluate adequacy of margin preparations, a tool that evaluates taper, a tool that evaluates undercut, or a tool that identifies scan deficiencies. The scan deficiencies may include holes in the surface. The at least one tool may include a tool that evaluates adequacy of removal path in multiple unit preparation. The at least one tool may include a tool that identifies irregularities in one or more occlusal surfaces requiring further preparation. Analyzing the surface may include an evaluation of suitability for three-dimensional printing, of suitability for milling, or of suitability for manual fabrication.

[0041] The computer may be further configured to automatically annotate the visualization with a visual indication of an evaluation. The visual indication includes an evaluation of contour of a surface preparation. The surface image data may include at least two tooth surfaces in occlusion. The visual indication may include an evaluation of margin of a surface preparation. The visual indication includes an evaluation of occlusal clearance of a surface preparation. The surface may include at least one surface prepared for a dental restoration, the evaluation including an evaluation of an adequacy of the at least one surface for receiving the dental restoration. The visual indication may include display of a contour of an actual tooth and a computer-generated surface preparation. The computer-generated surface preparation may be based upon intact configuration of the actual tooth prior to preparation.

[0042] In another aspect, a method disclosed herein includes receiving a three-dimensional representation that may include three-dimensional surface data from an intraoral structure including at least one tooth having a tooth surface prepared for a dental restoration; and presenting the three-dimensional representation in a user interface, the user interface may include a first tool for identifying a margin line for the dental restoration on the at least one tooth and a second tool for recessing a region of the three-dimensional representation below the margin line.

[0043] The first tool may provide automated identification of the margin line. The method may include removing a portion of the three-dimensional representation below the margin line with the second tool. The method may include removing a portion of the three-dimensional representation below the margin line with the second tool to provide a virtual ditched die, and three-dimensionally printing the ditched die.

[0044] A system disclosed herein includes a means for receiving a three-dimensional representation including three-dimensional surface data from an intraoral structure that may include at least one tooth having a tooth surface prepared for a dental restoration; and a user interface means for presenting the three-dimensional representation to a user, the user interface means may include a first tool means for identifying a margin line for the dental restoration on the at least one tooth and a second tool means for recessing a region of the three-dimensional representation below the margin line.

[0045] The first tool means may include a means for providing automated identification of the margin line. The system may include a means for removing a portion of the three-dimensional representation below the margin line. The system may include a means for removing a portion of the three-dimensional representation below the margin line to provide a virtual ditched die, and a means for three-dimensionally printing the ditched die.

[0046] In another aspect, a method disclosed herein includes acquiring a digital dental impression that may include three-dimensional surface data for at least two independent dental structures; and acquiring orientation data that may define a relative position of at least a portion of each of the at least two independent dental structures while in occlusion.

[0047] The orientation data may include three-dimensional surface data that spans the at least two independent dental structures while in occlusion. The orientation data may include three-dimensional surface data from each of the at least two independent dental structures while in occlusion. The occlusion may include a centric occlusion. The method may include applying the orientation data to position a virtual model of the at least two independent dental structures in a virtual articulator. The method may include fabricating models of each of the at least two independent dental structures and may apply the orientation data to position the models within a dental articulator. Acquiring orientation data may include acquiring three-dimensional data of a buccal side of dentition. Acquiring orientation data may include acquiring three-dimensional data of a labial side of dentition.

[0048] A system disclosed herein includes a first acquisition means for acquiring a digital dental impression including three-dimensional surface data for at least two independent dental structures; and a second acquisition means for that may acquire orientation data defining a relative position of at least a portion of each of the at least two independent dental structures while in occlusion.

[0049] The orientation data may include three-dimensional surface data that spans the at least two independent dental structures while in occlusion. The orientation data may include three-dimensional surface data from each of the at least two independent dental structures while in occlusion. The occlusion may include a centric occlusion. The system may include a model means for virtually articulating the at least two independent dental structures. The system may include a fabrication means for fabricating models of each of the at least two independent dental structures; and a model means for physically articulating the fabricated models. The orientation data may include three-dimensional data of a buccal side of dentition. The orientation data may include three-dimensional data of a labial side of dentition.

[0050] In another aspect, a method disclosed herein includes providing an intraoral three-dimensional scanning device; and scanning a plurality of teeth in an arch with the device in a scan path that may include a motion that begins at a first lingual point, traverses laterally over a first occlusal point and a first buccal point, translates to a second buccal point adjacent to the first buccal point, and then traverses laterally over a second occlusal point adjacent to the first occlusal point and a second lingual point adjacent to the first lingual point.

[0051] The method may include scanning the plurality of teeth in the arch with the device using a motion that translates to a third lingual point, and then may traverse laterally over a third occlusal point adjacent to the second occlusal point and a third buccal point adjacent to the second buccal point. The first lingual point and the second lingual point may be spaced apart such that a field of view of the scanning device includes at least one overlapping portion of the plurality of teeth when the scanning device is positioned to image the first and second lingual points respectively. The scan path may begin at a third buccal point, a third palatal point, or a third labial point.

[0052] In another aspect, a method disclosed herein includes within a single dental visit, the steps of: acquiring a three-dimensional representation of one or more intraoral structures including at least one tooth prepared for a dental restoration; and processing the three-dimensional representation that may provide feedback to a dentist concerning the at least one tooth.

[0053] The feedback may include a physical dimension, a dimension of the at least one tooth prior to preparation for the dental restoration, a contour of the at least one tooth, a clearance relative to one or more adjacent teeth for a dental restoration associated with the at least one tooth, or a position of the at least one tooth. The feedback may include a clearance relative to one or more teeth in an opposing occluded arch.

[0054] A computer program product disclosed herein includes computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of: acquiring a three-dimensional representation of one or more intraoral structures that may include at least one tooth prepared for a dental restoration; analyzing the three-dimensional

representation; generating a feedback signal, the feedback signal may represent the analysis of the three-dimensional representation; and outputting the feedback signal to a dentist.

[0055] The feedback signal may include a physical dimension, a dimension of the at least one tooth prior to preparation for the dental restoration, a contour of the at least one tooth, a clearance relative to one or more adjacent teeth for a dental restoration associated with the at least one tooth, or a position of the at least one tooth. The feedback may include a clearance relative to one or more teeth in an opposing occluded arch.

[0056] A system disclosed herein includes an acquisition means for acquiring a three-dimensional representation of one or more intraoral structures including at least one tooth prepared for a dental restoration; an analysis means for analyzing the three-dimensional representation; a means for generating a feedback signal, the feedback signal representing the analysis of the three-dimensional representation; and a signal means for providing the feedback signal to a dentist.

[0057] The feedback signal may include a physical dimension, a dimension of the at least one tooth prior to preparation for the dental restoration, a contour of the at least one tooth, a clearance relative to one or more adjacent teeth for a dental restoration associated with the at least one tooth, or a position of the at least one tooth. The feedback may include a clearance relative to one or more teeth in an opposing occluded arch.

[0058] In another aspect, a method disclosed herein includes acquiring a three-dimensional representation from a dental patient including a digital surface representation of one or more intraoral structures; and providing a visual display of the three-dimensional representation in real time. The visual display of the three-dimensional representation may be superimposed on a real time two-dimensional video image of the one or more intraoral structures.

[0059] The one or more intraoral structures may include at least one tooth, at least one tooth surface prepared for a dental restoration, at least one restored tooth, at least one implant, or at least one area of soft tissue. The method may include processing the three-dimensional representation to generate user feedback concerning the one or more intraoral structures, and may provide a visual display of the user feedback. The feedback may include highlighting areas in the three-dimensional representation requiring additional attention.

[0060] A computer program product disclosed herein includes computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of: acquiring one or more images of one or more intraoral structures; processing the one or more images into a three-dimensional representation including a digital surface representation of the one or more intraoral structures; and generating a first visual display signal of the three-dimensional representation in real time.

[0061] The computer program product may include computer code that performs the step of generating a second visual display signal wherein the three-dimensional representation is superimposed on a real time two-dimensional video image of the one or more intraoral structures. The one or more intraoral structures may include at least one tooth, at least one tooth surface prepared for a dental restoration, at least one restored tooth, at least one implant, or at least one area of soft tissue. The computer program product may include computer code that performs the steps of: analyzing the three-dimensional representation; may generate a feedback signal representative of the analysis of the three-dimensional representation; generate a third visual display signal including the feedback signal. The third visual display signal may include highlighted areas of the three-dimensional representation requiring additional attention.

[0062] A system disclosed herein includes: an acquisition means for acquiring a three-dimensional representation from a dental patient, the three-dimensional representation may include a digital surface representation of one or more intraoral structures; and a display means for visually displaying the three-dimensional representation in real time.

[0063] The display means may include a means for superimposing the three-dimensional representation on a real time two-dimensional video image of the one or more intraoral structures. The one or more intraoral structures may include at least one tooth, at least one tooth surface prepared for a

dental restoration, at least one restored tooth, at least one implant, or at least one area of soft tissue. The system may include: an analysis means for analyzing the three-dimensional representation; a feedback means for generating a feedback signal representative of the analysis of the three-dimensional representation, wherein the display means includes a means for visually displaying the feedback signal. The feedback means may include a means for highlighting areas in the three-dimensional representation requiring additional attention.

[0064] In another aspect, a handheld imaging device for a three-dimensional imaging system disclosed herein includes: an elongated body including a first end, a second end, and a central axis; a video rate three-dimensional scanning device within the elongated body, the video rate three-dimensional scanning device may have an optical axis for receiving images, the optical axis substantially perpendicular to the central axis at a position near the first end of the elongated body; and the second end adapted for gripping by a human hand, and the second end may include a user input responsive to user manipulation to generate control signals for transmission to a processor associated with the imaging system. The user input may include a mouse, track ball, button, switch, mini joystick, touchpad, keypad, or thumb wheel. The control signals may be transmitted to the processor through a wireless communication medium. The user input may control a user interface associated with the imaging system.

[0065] A handheld imaging device for a three-dimensional imaging system disclosed herein includes: an elongated body including a central axis, a first end, and a second end, the second end adapted for gripping by a human hand and a central axis; a video rate three-dimensional scanning device within the elongated body, the video rate three-dimensional scanning device having an optical axis for receiving images, the optical axis substantially perpendicular to the central axis at a position near the first end of the elongated body; and a physical offset shaped and sized to maintain a desired distance of the first end from an imaging subject along the optical axis. The physical offset may include one or more wheels for slidably engaging a surface of the imaging subject.

[0066] In another aspect, a method disclosed herein includes: acquiring a three-dimensional representation from a dental patient including a digital surface representation of one or more intraoral structures, the intraoral structures may include a dental arch; processing the three-dimensional representation that may provide a digital dental model including one or more alignment guides to aid in positioning an orthodontic fixture; and fabricating a physical model from the digital dental model.

[0067] The method may include constructing the orthodontic fixture on the physical model using the alignment guides. The method may include constructing a support for the orthodontic fixture on the digital dental model. The alignment guides may include visual markings. The alignment guides may include at least one substantially horizontal shelf for the orthodontic fixture. Processing may include virtually placing a plurality of orthodontic brackets onto the three-dimensional representation, and adding a plurality of bracket supports to the digital dental model to support a physical realization of the plurality of orthodontic brackets on the physical model. The method may include fabricating the physical realization of the plurality of orthodontic brackets, positioning each one of the plurality of orthodontic brackets onto the physical model, and vacuum forming an appliance over the plurality of orthodontic brackets, the appliance maintaining the plurality of orthodontic brackets in fixed relation to one another. The method may include applying the appliance with the plurality of orthodontic brackets to the dental arch. The appliance may be formed of a soft, clear material. The method may include transmitting the digital dental model to a remote dental laboratory. Processing may include virtually placing a plurality of orthodontic brackets onto the three-dimensional representation in a bracket arrangement, and generating a digital model of a bracket guide adapted to position a physical realization of the plurality of orthodontic brackets in the bracket arrangement on the dental arch. The method may include three-dimensionally printing the bracket guide. The physical model may include fabricating the physical model in an in-house dental laboratory in a dentist's office.

[0068] In another aspect, a method disclosed herein includes: acquiring a three-dimensional representation from a dental patient including a digital surface representation of one or more intraoral structures, the intraoral structures may include a dental arch; adding a plurality of virtual brackets to the three-dimensional representation to provide a bracket model; processing the bracket model to generate a

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

[0069] A computer program product disclosed herein includes computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of: acquiring one or more images of one or more intraoral structures, the intraoral structures may include a dental arch; processing the one or more images into a three-dimensional representation of the one or more intraoral structures; transforming the three-dimensional representation into a digital dental model, the digital dental model including one or more orthodontic fixture alignment guides; and generating a virtual orthodontic fixture using the alignment guides.

[0070] The computer program product may include code that performs the step of constructing a support for the virtual orthodontic fixture on the digital dental model. The alignment guides may include visual markings. The alignment guides may include at least one substantially horizontal shelf for the virtual orthodontic fixture. Transforming may include virtually placing a plurality of orthodontic brackets onto the dental arch of the three-dimensional representation, and adding a plurality of bracket supports to the digital dental model. The computer program product may include code that performs the step of transmitting the digital dental model to a remote dental laboratory.

[0071] A system disclosed herein includes: an acquisition means for acquiring a three-dimensional representation from a dental patient including a digital surface representation of one or more intraoral structures, the intraoral structures may include a dental arch; a processing means for processing the three-dimensional representation that may provide a digital dental model including one or more alignment guides to aid in positioning an orthodontic fixture; and a first fabrication means for fabricating a physical model from the digital dental model.

[0072] The system may include a means for constructing the orthodontic fixture on the physical model using the alignment guides. The processing means may include a means for constructing a support for the orthodontic fixture on the digital dental model. The alignment guides may include visual markings. The alignment guides may include at least one substantially horizontal shelf for the orthodontic fixture. The processing means may include a means for virtually placing a plurality of orthodontic brackets onto the three-dimensional representation, and adding a plurality of bracket supports to the digital dental model to support a physical realization of the plurality of orthodontic brackets on the physical model. The system may include a second fabrication means for fabricating the physical realization of the plurality of orthodontic brackets, a positioning means for positioning each one of the plurality of orthodontic brackets onto the physical model, and a forming means for vacuum forming an appliance over the plurality of orthodontic brackets, the appliance maintaining the plurality of orthodontic brackets in fixed relation to one another. The system may include a means for applying the appliance with the plurality of orthodontic brackets to the dental arch. The appliance may be formed of a soft, clear material. The system may include a communication means for transmitting the digital dental model to a remote dental laboratory. The processing means may include a means for virtually placing a plurality of orthodontic brackets onto the three-dimensional representation in a bracket arrangement, and a model means for generating a digital model of a bracket guide adapted to position a physical realization of the plurality of orthodontic brackets in the bracket arrangement on the dental arch. The system may include a printing means for three-dimensionally printing the bracket guide. The fabrication means may include a means for fabricating the physical model in an in-house dental laboratory in a dentist's office.

[0073] A three-dimensional data acquisition system adapted for intraoral acquisition of dental data from one or more intraoral structures, as disclosed herein, may include a first operating mode for capturing scan data and rendering a low-quality three-dimensional image from the scan data in real time, and a second operating mode for generating a high-quality three dimensional image from the scan data after exiting the first operating mode, the high-quality three-dimensional image may have greater spatial resolution than the low-quality three-dimensional image.

[0074] The system may further including a display that renders the low-quality three-dimensional image superimposed on a video image of the one or more intraoral structures. Rendering a low-quality three-dimensional image may include rendering the low-quality three-dimensional image at a frame rate of the video image. The system may include a communications interface for transmitting the high-quality three-dimensional image to a dental laboratory.

[0075] In another aspect, a system disclosed herein includes: a scanning device configured to intraorally capture surface image data from a surface within a mouth of a dental patient; a computer coupled to the scanning device and receiving the surface image data therefrom, the computer configured to resolve the surface image data into a three-dimensional representation, the computer may be further configured to generate a visualization of the three-dimensional representation and to provide the visualization as a display signal; and a display coupled to the computer and receiving the display signal therefrom, the display adapted to convert the display signal into a viewable image, the display being a touch-screen display adapted to receive a user input through direct contact with a surface of the display, wherein the user input is interpreted by the computer to affect manipulation of the three-dimensional representation. The user input may affect rotational orientation of the visualization on the display.

[0076] The display may include areas for one or more user controls accessible through the touch-screen display. The user controls may include a zoom control, a pan control, or case management controls. The case management controls may include a control to transmit the three-dimensional representation to a dental lab, a control to evaluate quality of the three-dimensional representation, a tool to edit the three-dimensional representation, or a control to create a dental prescription.

[0077] The user controls may include a control to define a cementation void, a control to define a margin line, a control to infer a margin line from the three-dimensional representation, a control to recess a region of the three-dimensional representation below a margin line, a control to virtually fit a dental restoration to a prepared tooth surface, include a virtual dental articulator, or include a tool to design a dental restoration fitted to the surface within the mouth of the dental patient.

[0078] The three-dimensional model may include two arches; the display may include an area for one or more user controls accessible through the touch-screen display to permit positioning the two arches within a virtual articulator. The system may include a user interface displayed on the display and controlled by the computer. The user interface may be accessible through the touch-screen.

[0079] A system disclosed herein includes: a digital dental impression that may include three-dimensional digital surface data for one or more intraoral structures, the digital dental impression may be captured using a three-dimensional intraoral scanning device and stored in a computer readable medium; a first computer may be configured to render the digital dental impression from a point of view; and a second computer at a remote location may be configure to simultaneously render the digital dental impression from the point of view.

[0080] The system may include a control for passing control of the point of view between the first computer and the second computer. The system may include the first computer and the second computer including a collaborative tool for manipulating the model, for sectioning the model, or for rearranging one or more sections of the model. The system may include the first computer and the second computer including a collaborative cursor control tool. The system may include the first computer and the second computer connected by a communication channel. The communication channel may include one or more of VoIP, IRC, video conferencing, or instant messaging. The second computer may be operated by a consulting dentist, a dental technician, in a dental laboratory, or by an oral surgeon. The second computer may be operated by a dental specialist including one or more of a periodontist, a prosthodontist, a pedodontist, an orthodontic specialist, an oral and maxillofacial surgery specialist, an oral and maxillofacial radiology specialist, an endodontist, and an oral and maxillofacial pathologist.

[0081] A method disclosed herein includes: seating a dental patient in a clinical office; acquiring a digital dental impression that may include three-dimensional digital surface data for one or more intraoral structures from an intraoral scan of the dental patient; transmitting the digital dental impression to a dental laboratory before the patient leaves the office; receiving an evaluation of the digital

dental impression from the dental laboratory before the patient leaves the office; and if the evaluation is unfavorable, repeating the step of acquiring the digital dental impression.

[0082] If the evaluation includes an identification of at least one region of the one or more intraoral structures requiring additional preparation, the method may include preparing the one or more intraoral structures according to the evaluation. The evaluation may include an evaluation of surface continuity, an evaluation of data density, or an evaluation of feature detail. The one or more intraoral structures may include a tooth surface prepared for a dental restoration. The digital dental impression may include a case plan for the restoration. The case plan may include a type of restoration, a design of restoration, or a list of restoration components. The list of restoration components may include a full ceramic component. The list of restoration components may include a PFM component. The case plan may include a specification of one or more restoration materials.

[0083] A system disclosed herein includes: a means for acquiring a digital dental impression, the digital dental impression may include three-dimensional digital surface data for one or more intraoral structures from an intraoral scan of a dental patient seated in a clinical office; a request means for transmitting the digital dental impression to a dental laboratory before the patient leaves the office; an evaluation means for determining if the digital dental impression must be reacquired before the patient leaves the office; and a response means for transmitting the determination to the clinical office.

[0084] The evaluation means may include a means for evaluating surface continuity, a means for evaluating data density, or a means for evaluating feature detail. The one or more intraoral structures may include a tooth surface prepared for a dental restoration. The digital dental impression may include a case plan for the restoration, a type of restoration, a design of restoration, or a list of restoration components. The list of restoration components may include a full ceramic component. The list of restoration components may include a PFM component. The case plan may include a specification of one or more restoration materials.

[0085] A system disclosed herein includes: a scanning device for real time capture of three-dimensional surface data; a monitor that may render the three-dimensional surface data in real time; a processor that may be configured to evaluate quality of the three-dimensional surface data, and may generate a signal representative of a data quality during a scan; and a feedback device that may be responsive to the signal to produce a user alert concerning the data quality when the data quality degrades below a predetermined threshold.

[0086] The scanning device may resolve the three-dimensional surface data from a plurality of two-dimensional image sets, and wherein the evaluation of quality may include evaluation of ability to determine spatial relationships from the plurality of two-dimensional image sets. The evaluation of quality may include evaluation of point cloud density. The evaluation of quality may include evaluation of scanning device motion. The feedback device may include an LED, a speaker, a buzzer, a vibrator, or a wand. The feedback device may be positioned on the wand. The feedback device may be further responsive to the signal to produce a second user alert when the data quality is within an acceptable range.

[0087] In another aspect, a method disclosed in herein may include: scheduling a preparation visit for a dental restoration for a patient; obtaining a digital surface representation of one or more intraoral structures of the patient, this may include at least one tooth associated with the dental restoration; and fabricating a temporary restoration based upon the digital surface representation.

[0088] Fabricating a temporary restoration may include transmitting the digital surface representation to a dental laboratory. Fabricating a temporary restoration may include applying the digital surface representation to prepare a design for the temporary restoration and transmitting the design to a dental laboratory. The method may include three-dimensionally printing the temporary restoration. The method may include three-dimensionally printing the temporary restoration at a dentist's office where the preparation visit is scheduled. The method may include milling the temporary restoration. The method may include milling the temporary restoration at a dental office where the preparation visit is scheduled. Obtaining a digital surface representation may include three-dimensionally scanning the one or more intraoral structures on a day of the preparation visit. Obtaining a digital surface representation may include retrieving the digital surface representation from prior dental data for the patient. Fabricating the

temporary restoration may include fabricating the temporary restoration prior to the preparation visit, the temporary restoration may include one or more characteristics of the at least one tooth. The method may include, on the day of the preparation visit, adapting a surface of the at least one tooth to receive the temporary restoration. The method may include, on the day of the preparation visit, adapting the temporary restoration to fit a prepared surface of the at least one tooth. The step of fabricating may be performed at an in-house dental laboratory at a dentist's office.

[0089] A method disclosed herein includes: acquiring a digital dental impression including three-dimensional digital surface data for one or more intraoral structures, the intraoral structures may include at least one tooth surface prepared for a dental restoration; and acquiring additional three-dimensional data with greater spatial resolution around the at least one tooth surface prepared for the dental restoration.

[0090] The acquiring additional three-dimensional data may include acquiring additional data from the at least one tooth surface, post-processing source data for the digital dental impression, or post-processing the three-dimensional digital surface data.

[0091] A computer program product disclosed herein includes computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, may perform the steps of: acquiring one or more images of one or more intraoral structures, the intraoral structures may include at least one tooth surface prepared for a dental restoration; and generating a digital dental impression that may include three-dimensional digital surface data from the one or more images.

[0092] The computer program product may include code that performs the step of post-processing source data for the digital dental impression to generate additional three-dimensional data with greater spatial resolution. The computer program product may include code that performs the step of post-processing the three-dimensional digital surface data to generate additional three-dimensional data with greater spatial resolution.

[0093] A system disclosed herein includes: a first means for acquiring a digital dental impression that may include three-dimensional digital surface data for one or more intraoral structures, the intraoral structures may include at least one tooth surface prepared for a dental restoration; and a second means for acquiring additional three-dimensional data with greater spatial resolution around the at least one tooth surface prepared for the dental restoration.

[0094] The second means may include a means for acquiring additional data from the at least one tooth surface, a means for post-processing source data for the digital dental impression, or a means for post-processing the three-dimensional digital surface data.

[0095] A method disclosed herein includes: acquiring a digital surface representation for one or more intraoral structures, the intraoral structures may include at least one tooth surface prepared for a dental restoration; fabricating a kit from the digital surface representation, the kit may include two or more components suitable for use in fabrication of the dental restoration; and sending the kit to a dental laboratory for fabrication of the dental restoration. The kit may include one or more of a die, a quad model, an opposing quad model, an opposing model, a base, a pre-articulated base, and a waxup.

[0096] The method may include transmitting the digital surface representation to a production facility. The step of fabricating may be performed at the production facility. The kit may include one or more components selected from the group of pre-cut components, pre-indexed components, and pre-articulated components. The step of fabricating may be performed at a dentist's office.

[0097] An artificial dental object disclosed herein includes an exposed surface, the exposed surface finished with a texture to enhance acquisition of three dimensional image data from the exposed surface with a multi-aperture three-dimensional scanning device. The texture may include pseudo-random three-dimensional noise.

[0098] The artificial dental object may include an impression coping, a fixture, a healing abutment, or a temporary impression coping. The artificial dental object may include a dental prosthesis, a dental restoration, a dental appliance, or an item of dental hardware.

[0099] In another aspect, a method disclosed herein includes acquiring a three-dimensional representation of one or more intraoral structures, the intraoral structures including at least one intraoral

surface suitable for an artificial dental object; transmitting the three-dimensional representation to a dental insurer; and receiving authorization from the dental insurer to perform a dental procedure including the artificial dental object.

[00100] The artificial dental object may include one or more of an implant, a crown, an impression coping, a bridge, a fixture, and an abutment. The intraoral surface may include at least one edentulous space. The intraoral surface may include at least one tooth surface.

[00101] A computer program product disclosed herein may include code that, when executed on one or more computer devices, performs the steps of: acquiring a three-dimensional representation of one or more intraoral structures, the intraoral structures including at least one intraoral surface suitable for an artificial dental object; transmitting the three-dimensional representation to a dental insurer; and receiving authorization from the dental insurer to perform a dental procedure including the artificial dental object.

[00102] The artificial dental object may include one or more of an implant, a crown, an impression coping, a fixture, a bridge, and an abutment. The intraoral surface may include at least one edentulous space. The intraoral surface may include at least one tooth surface.

[00103] A system disclosed herein includes a means for acquiring a three-dimensional representation of one or more intraoral structures, the intraoral structures including at least one intraoral surface suitable for an artificial dental object; a first communication means for transmitting the three-dimensional representation to a dental insurer; and a second communication means for receiving authorization from the dental insurer to perform a dental procedure including the artificial dental object.

[00104] The artificial dental object may include one or more of an implant, a crown, an impression coping, a fixture, a bridge and an abutment. The at least one intraoral surface may include an edentulous space. The at least one intraoral surface includes a tooth surface.

[00105] In another aspect, a method disclosed herein includes acquiring a three-dimensional representation of one or more intraoral structures, the intraoral structures including at least one intraoral surface related to a dental procedure; and transmitting the three-dimensional representation to a dental insurer as a record of the dental procedure.

[00106] The dental procedure may relate to one or more of an implant, a crown, an impression coping, a fixture, a bridge, and an abutment. The method may include receiving a payment from the insurer for a procedure involving the artificial dental object. The intraoral surface may include an edentulous space. The intraoral surface may include a tooth surface prepared for an artificial dental object. The intraoral surface may include a restored tooth.

[00107] A computer program product disclosed herein includes computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of: acquiring a three-dimensional representation of one or more intraoral structures, the intraoral structures including at one intraoral surface related to a dental procedure; and transmitting the three-dimensional representation to a dental insurer as a record of the dental procedure.

[00108] The dental procedure may relate to one or more of an implant, a crown, an impression coping, a bridge, and an abutment. The code may further include code that performs the step of receiving a record of payment from the insurer for the dental procedure. The intraoral surface may include an edentulous space. The intraoral surface may include a tooth surface prepared for an artificial dental object. The intraoral surface may include a restored tooth.

[00109] A system disclosed herein may include a means for acquiring a three-dimensional representation of one or more intraoral structures, the intraoral structures including at least one intraoral surface related to a dental procedure; and a communication means for transmitting the three-dimensional representation to a dental insurer as a record of the dental procedure.

[00110] The dental procedure may to one or more of an implant, a crown, an impression coping, a bridge, and an abutment. The communication means may include a means for receiving a payment from the insurer for the dental procedure.

[00111] In another aspect, a method disclosed herein includes receiving a three-dimensional representation of one or more intraoral structures from a dentist; receiving a proposed dental procedure

from the dentist; determining whether the proposed dental procedure is appropriate for the one or more intraoral structures; and transmitting a reply to the dentist. The reply may include an approval to perform the dental procedure. The reply may include a denial to perform the dental procedure. The method may include authorizing payment for the dental procedure.

[00112] A computer program product disclosed herein includes computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, may perform the steps of: receiving a three-dimensional representation of one or more intraoral structures from a dentist; receiving a proposed dental procedure from the dentist; comparing the proposed dental procedure to a predetermined list of appropriate procedures for the one or more intraoral structures; and transmitting a reply to the dentist. The reply may include an approval to perform the dental procedure. The reply may include a denial to perform the dental procedure. The computer program product may include computer code that performs the step of authorizing payment for the dental procedure.

[00113] A system disclosed herein includes: a first means for receiving a three-dimensional representation of one or more intraoral structures from a dentist; a second means for receiving a proposed dental procedure from the dentist; an evaluation means for determining whether the proposed dental procedure is appropriate for the one or more intraoral structures; and a reply means for transmitting a reply to the dentist. The reply may include an approval to perform the dental procedure. The reply may include a denial to perform the dental procedure. The system may include a means for authorizing payment for the dental procedure.

[00114] A system disclosed herein includes: a dental data repository coupled to a communications network, the dental data repository may be adapted to receive dental data including three-dimensional representations of intraoral structures and prescriptions for dental procedures from a plurality of dentists.

[00115] The dental data repository may be adapted to transmit prescriptions and three-dimensional representations to a plurality of dental laboratories. The at least one of the prescriptions may identify a specific one of the plurality of dental laboratories. The dental data repository may be further adapted to communicate with one or more dental insurers for authorization of dental procedures. The dental data repository may be further adapted to communicate with one or more dental insurers to coordinate payment for dental procedures. The system may include a dental laboratory interface for the plurality of dental laboratories to provide status on work in progress. The system may include a dental laboratory interface for the plurality of dental laboratories to receive work assignments. The system may include a dentist interface for the plurality of dentists to monitor work in progress. The system may include a dentist interface for the plurality of dentists to submit prescriptions and three-dimensional representations. The system may include a transaction engine for transmitting payments among two or more of one of the plurality of dentists, one of the plurality of dental laboratories, and one of the one or more dental insurers. The system may include a collaboration interface for two or more of the plurality of dentists to collaborate on a dental matter.

BRIEF DESCRIPTION OF THE FIGURES

[00116] The invention and the following detailed description of certain embodiments thereof may be understood by reference to the following figures.

[00117] Fig. 1 shows a dental image capture system.

[00118] Fig. 2 shows entities participating in a digital dentistry network.

[00119] Fig. 3 shows a user interface that may be used in a digital dental system.

[00120] Fig. 4 depicts a quality control procedure for use in a digital dental system.

[00121] Fig. 5 shows a dental laboratory procedure using a digital dental model.

[00122] Fig. 6 illustrates a scan path that may be used with a three-dimensional image capture system.

[00123] Figs. 7A and 7B show a modeling environment for creating alignment guides for orthodontic hardware.

DETAILED DESCRIPTION

[00124] Described are a wide array of systems and methods for digital dentistry. However, it will be appreciated that the inventive concepts disclosed herein are not limited to the specific embodiments disclosed. For example, the general techniques disclosed herein may be usefully employed in any environment where precise, three-dimensional data might be usefully captured and processed, including orthopedics, digital animation, and customized manufacturing. In addition, while numerous variations and implementations of digital dentistry techniques are described, it will be appreciated that other combinations of the specific scanning, processing, and manufacturing techniques described herein may be used, and that such variations are intended to fall within the scope of this disclosure.

[00125] In the following description, the term “image” generally refers to a two-dimensional set of pixels forming a two-dimensional view of a subject within an image plane. The term “image set” generally refers to a set of related two dimensional images that might be resolved into three-dimensional data. The term “point cloud” generally refers to a three-dimensional set of points forming a three-dimensional view of the subject reconstructed from a number of two-dimensional views. In a three-dimensional image capture system, a number of such point clouds may also be registered and combined into an aggregate point cloud constructed from images captured by a moving camera. Thus it will be understood that pixels generally refer to two-dimensional data and points generally refer to three-dimensional data, unless another meaning is specifically indicated or clear from the context.

[00126] The terms “three-dimensional surface representation”, “digital surface representation”, “three-dimensional surface map”, and the like, as used herein, are intended to refer to any three-dimensional surface map of an object, such as a point cloud of surface data, a set of two-dimensional polygons, or any other data representing all or some of the surface of an object, as might be obtained through the capture and/or processing of three-dimensional scan data, unless a different meaning is explicitly provided or otherwise clear from the context.

[00127] A “three-dimensional representation” may include any of the three-dimensional surface representations described above, as well as volumetric and other representations, unless a different meaning is explicitly provided or otherwise clear from the context.

[00128] In general, the terms “render” or “rendering” refer to a two-dimensional visualization of a three-dimensional object, such as for display on a monitor. However, it will be understood that three-dimensional rendering technologies exist, and may be usefully employed with the systems and methods disclosed herein. As such, rendering should be interpreted broadly unless a narrower meaning is explicitly provided or otherwise clear from the context.

[00129] The term “dental object”, as used herein, is intended to refer broadly to subject matter specific to dentistry. This may include intraoral structures such as dentition, and more typically human dentition, such as individual teeth, quadrants, full arches, pairs of arches which may be separate or in occlusion of various types, soft tissue (e.g., gingival and mucosal surfaces of the mouth, or perioral structures such as the lips, nose, cheeks, and chin), and the like, as well bones and any other supporting or surrounding structures. As used herein, the term “intraoral structures” refers to both natural structures within a mouth as described above and artificial structures such as any of the dental objects described below. While the design and fabrication of artificial dental structures is the subject of much of the following discussion, it will be understood that any of these artificial structures might be present in the mouth during a scan, either as a result of prior dental work (e.g., a previously restored tooth) or during an evaluation of fit and other aspects of a current procedure. Dental objects may include “restorations”, which may be generally understood to include components that restore the structure or function of existing dentition, such as crowns, bridges, veneers, inlays, onlays, amalgams, composites, and various substructures such as copings and the like, as well as temporary restorations for use while a permanent restoration is being fabricated. Dental objects may also include a “prosthesis” that replaces dentition with removable or permanent structures, such as dentures, partial dentures, implants, retained dentures, and the like. Dental objects may also include “appliances” used to correct, align, or otherwise temporarily or permanently adjust dentition, such as removable orthodontic appliances, surgical stents, bruxism appliances, snore guards, indirect bracket placement appliances, and the like. Dental objects may also

include “hardware” affixed to dentition for an extended period, such as implant fixtures, implant abutments, orthodontic brackets, and other orthodontic components. Dental objects may also include “interim components” of dental manufacture such as dental models (full and/or partial), wax-ups, investment molds, and the like, as well as trays, bases, dies, and other components employed in the fabrication of restorations, prostheses, and the like. As suggested above, dental objects may also be categorized as natural dental objects such as the teeth, bone, and other intraoral structures described above or as artificial dental objects such as the restorations, prostheses, appliances, hardware, and interim components of dental manufacture as described above. It will be understood that any of the foregoing, whether natural or artificial, may be an intraoral structure when present within the mouth. Thus, for example, a previous restoration or an implant for a crown might be present within the mouth, and may be an intraoral structure scanned during an intraoral scan.

[00130] Terms such as “digital dental model”, “digital dental impression” and the like, are intended to refer to three-dimensional representations of dental objects that may be used in various aspects of acquisition, analysis, prescription, and manufacture, unless a different meaning is otherwise provided or clear from the context. Terms such as “dental model” or “dental impression” are intended to refer to a physical model, such as a cast, printed, or otherwise fabricated physical instance of a dental object. Unless specified, the term “model”, when used alone, may refer to either or both of a physical model and a digital model.

[00131] Fig. 1 shows an image capture system. In general, the system 100 may include a scanner 102 that captures images from a surface 106 of a subject 104, such as a dental patient, and forwards the images to a computer 108, which may include a display 110 and one or more user input devices such as a mouse 112 or a keyboard 114. The scanner 102 may also include an input or output device 116 such as a control input (e.g., button, touchpad, thumbwheel, etc.) or a status indicator (e.g., LCD or LED display or light, a buzzer, or the like) to provide status information.

[00132] The scanner 102 may include any camera or camera system suitable for capturing images from which a three-dimensional point cloud may be recovered. For example, the scanner 102 may employ a multi-aperture system as disclosed, for example, in U.S. Pat. Pub. No. 20040155975 to Hart et al., the entire contents of which is incorporated herein by reference. While Hart discloses one multi-aperture system, it will be appreciated that any multi-aperture system suitable for reconstructing a three-dimensional point cloud from a number of two-dimensional images may similarly be employed. In one multi-aperture embodiment, the scanner 102 may include a plurality of apertures including a center aperture positioned along a center optical axis of a lens and any associated imaging hardware. The scanner 102 may also, or instead, include a stereoscopic, triscopic or other multi-camera or other configuration in which a number of cameras or optical paths are maintained in fixed relation to one another to obtain two-dimensional images of an object from a number of slightly different perspectives. The scanner 102 may include suitable processing for deriving a three-dimensional point cloud from an image set or a number of image sets, or each two-dimensional image set may be transmitted to an external processor such as contained in the computer 108 described below. In other embodiments, the scanner 102 may employ structured light, laser scanning, direct ranging, or any other technology suitable for acquiring three-dimensional data, or two-dimensional data that can be resolved into three-dimensional data.

[00133] In one embodiment, the scanner 102 is a handheld, freely positionable probe having at least one user input device 116, such as a button, lever, dial, thumb wheel, switch, track ball, mini joystick, touchpad, keypad, or the like, for user control of the image capture system 100 such as starting and stopping scans, or interacting with a user interface on the display 110. In an embodiment, the scanner 102 may be shaped and sized for dental scanning. More particularly, the scanner 102 may be shaped and sized for intraoral scanning and data capture, such as by insertion into a mouth of an imaging subject and passing over an intraoral surface 106 at a suitable distance to acquire surface data from teeth, gums, and so forth. This may include a shape resembling an electric toothbrush or a dental tool, and including an elongated body with an optical port on one end that receives scan data, and user controls on the other end.

[00134] A physical offset may be provided for the optical port that physically maintains an appropriate distance from scanning subject matter. More particularly, the physical offset may prevent the

optical port from getting too near the scanned subject matter, which permits a user to maintain proper distance through a steady application of pressure toward the subject matter. The physical offset may be adapted for particular subject matter and may include a simple rod or other rigid form extending toward the optical path of the scanner, or the physical offset may include contoured forms for mating with more complex surfaces. The physical offset may include wheels or plates for slidably engaging a surface of scanned subject matter, or other structures or surface treatments to improve operation in various applications.

[00135] The scanner 102 may, through a continuous acquisition process, capture a point cloud of surface data having sufficient spatial resolution and accuracy to prepare dental objects such as restorations, hardware, appliances, and the like therefrom, either directly or through a variety of intermediate processing steps. In other embodiments, surface data may be acquired from a dental model such as a dental restoration, to ensure proper fitting using a previous scan of corresponding dentition, such as a tooth surface prepared for the restoration.

[00136] Although not shown in Fig. 1, it will be appreciated that a number of supplemental lighting systems may be usefully employed during image capture. For example, environmental illumination may be enhanced with one or more spotlights illuminating the subject 104 to speed image acquisition and improve depth of field (or spatial resolution depth). The scanner 102 may also, or instead, include a strobe, flash, or other light source to supplement illumination of the subject 104 during image acquisition.

[00137] The subject 104 may be any object, collection of objects, portion of an object, or other subject matter. More particularly with respect to the dental fabrication techniques discussed herein, the object 104 may include human dentition captured intraorally from a dental patient's mouth. A scan may capture a three-dimensional representation of some or all of the dentition according to particular purpose of the scan. Thus the scan may capture a digital model of a tooth, a quadrant of teeth, or a full collection of teeth including two opposing arches, as well as soft tissue or any other relevant intraoral and/or extraoral structures. In other embodiments where, for example, a completed fabrication is being virtually test fit to a surface preparation, the scan may include a dental restoration such as an inlay or a crown, or any other artificial dental object. The subject 104 may also, or instead, include a dental model, such as a plaster cast, wax-up, impression, or negative impression of a tooth, teeth, soft tissue, or some combination of these.

[00138] The computer 108 may be, for example, a personal computer or other processing device. In one embodiment, the computer 108 includes a personal computer with a dual 2.8GHz Opteron central processing unit, 2 gigabytes of random access memory, a TYAN Thunder K8WE motherboard, and a 250 gigabyte, 10,000 rpm hard drive. This system may be operated to capture approximately 1,500 points per image set in real time using the techniques described herein, and store an aggregated point cloud of over one million points. As used herein, the term "real time" means generally with no observable latency between processing and display. In a video-based scanning system, real time more specifically refers to processing within the time between frames of video data, which may vary according to specific video technologies between about fifteen frames per second and about thirty frames per second. More generally, processing capabilities of the computer 108 may vary according to the size of the subject 104, the speed of image acquisition, and the desired spatial resolution of three-dimensional points. The computer 108 may also include peripheral devices such as a keyboard 114, display 110, and mouse 112 for user interaction with the camera system 100. The display 110 may be a touch screen display capable of receiving user input through direct, physical interaction with the display 110.

[00139] Communications between the computer 108 and the scanner 102 may use any suitable communications link including, for example, a wired connection or a wireless connection based upon, for example, IEEE 802.11 (also known as wireless Ethernet), Bluetooth, or any other suitable wireless standard using, e.g., a radio frequency, infrared, or other wireless communication medium. In medical imaging or other sensitive applications, wireless image transmission from the scanner 102 to the computer 108 may be secured. The computer 108 may generate control signals to the scanner 102 which, in addition to image acquisition commands, may include conventional camera controls such as focus or

zoom. In addition, the computer 108 may include a network communications interface for connecting to a network such as the dental network described below.

[00140] In an example of general operation of a three-dimensional image capture system 100, the scanner 102 may acquire two-dimensional image sets at a video rate while the scanner 102 is passed over a surface of the subject. The two-dimensional image sets may be forwarded to the computer 108 for derivation of three-dimensional point clouds. The three-dimensional data for each newly acquired two-dimensional image set may be derived and fitted or "stitched" to existing three-dimensional data using a number of different techniques. Such a system employs camera motion estimation to avoid the need for independent tracking of the position of the scanner 102. One useful example of such a technique is described in commonly-owned U.S. App. No. 11/270,135, filed on November 9, 2005, the entire contents of which is incorporated herein by reference. However, it will be appreciated that this example is not limiting, and that the principles described herein may be applied to a wide range of three-dimensional image capture systems.

[00141] The display 110 may include any display suitable for video or other rate rendering at a level of detail corresponding to the acquired data. Suitable displays include cathode ray tube displays, liquid crystal displays, light emitting diode displays and the like. In addition, where three-dimensional visualization is desired, the display 110 may include a three-dimensional display using a wide variety of techniques including stereo pair imaging, holographic imaging, and multiplanar or volumetric imaging, each with a number of rendering modalities that may be usefully employed with the systems described herein.

[00142] In some embodiments, the display may include a touch screen interface using, for example capacitive, resistive, or surface acoustic wave (also referred to as dispersive signal) touch screen technologies, or any other suitable technology for sensing physical interaction with the display 110.

[00143] The touch screen may be usefully employed in a dental office or other context to provide keyboardless processing and manipulation of scanning and any resulting three-dimensional representations. For example, the touch screen may be employed to permit user manipulation of a displayed model, such as panning, zooming, and rotating, through direct physical interaction with the displayed model and any corresponding controls within a user interface. For example, a user may touch a "rotate" button on the display 110, after which placing a finger on the screen and dragging may cause three-dimensional rotation of the displayed model around a corresponding axis (typically perpendicular to the direction of finger motion).

[00144] The touch screen may also provide tools for manipulating the digital model. For example, a user may define or specify a cementation void or die spacer. A user may define, edit, or annotate a margin line, such as a computer-generated margin line. A user may define a die and/or ditch a die by recessing one or more regions below the margin line. A user may place arches of a digital dental model into a virtual articulator and articulate the arches. The touch screen may provide one or more tools for virtually designing a dental restoration fitted to a dental model, including fitting to a prepared surface, adjacent teeth, and/or teeth of an opposing arch.

[00145] The touch screen may also provide case management controls providing functions such as transmitting a digital model to a dental laboratory, evaluating quality of a digital model or performing other quality control functions as described below, or creating a dental prescription as described, for example, below with reference to Fig. 3.

[00146] The image capture system 100 may generally be adapted for real time acquisition and display, e.g., at a video rate, of three-dimensional data, which may be rendered, for example, as a point cloud superimposed on a video image from the scanner 102. For certain types of data acquisition, there may be a significant difference in the processing time required for resolution of a three-dimensional image adequate for two-dimensional perspective rendering (faster) and maximum or optimum resolution that might be achieved with post-processing. In such circumstances, the image capture system 100 may include two different operating modes. In a first operating mode, a relatively low-quality three-dimensional representation may be obtained and rendered in real time, such as within the display 110. In a second operating mode, a relatively high-quality three-dimensional representation may be generated for

the source scan data using any desired degree of processing. The second operating mode may recover, through additional post-processing steps, three-dimensional data having greater spatial resolution and/or accuracy. It will be understood that, while two different modes are described, it is not required that the two modes be mutually exclusive. For example, both modes may execute simultaneously on a computer as separate processes or threads, or the data from the first operating mode may be employed to seed the second operating mode with a model for refinement for post-processing. All such variations as would be apparent to one of ordinary skill in the art may be employed with the systems described herein. Either the high-quality representation or the low-quality representation, or both, may be transmitted to a dental laboratory for subsequent steps such as quality control and model fabrication, examples of which are provided below.

[00147] In another aspect, the system 100 may provide different levels of accuracy or spatial resolution, each associated with, for example, different degrees of post-processing, computing power, or rate of movement by the scanner 102 over a subject 104. Thus, for example, an entire dental arch may be scanned at a relatively low accuracy, while a surface preparation or other area of diagnostic or treatment significance may be scanned at a relatively higher accuracy which may, for example, require a slower scanning motion or additional post-processing delays. Similarly, certain areas such as the surface preparation may be designated for supplemental post-processing to achieve enhanced accuracy or spatial resolution.

[00148] The input or output device 116 may include a feedback device that provides warnings or indicators to an operator of the image capture system 100 with respect to scan quality or progress. The device 116 may include, for example, a buzzer, speaker, light emitting diode, an incandescent light, or any other acoustic, haptic, tactile, or visual signal to notify the operator of an event without requiring the operator to look at the display 110. For example, data quality may be continuously monitored by the system 100, and an alert may be generated when the data quality drops below a quantitative threshold, or data acquisition is lost completely (or different alerts may be provided for each of these events). The evaluation of data quality may depend, for example, on an ability of the system 100 to fit a new data set to existing three-dimensional data, or the ability to resolve two-dimensional image sets into three-dimensional data, or the density of acquired data, or any other objective criterion, either alone or in combination. The evaluation of data quality may also, or instead, be inferred from other parameters such as motion of the scanner 102 or distance from the subject 104. It will be understood that while a data quality indicator may be positioned on the scanner 102 as shown, the device 116 may also, or instead, be positioned at any other location suitable for alerting an operator, which may depend on the type of alert generated (i.e., a visual alert may have different positioning parameters than an audio alert or a tactile alert). In another aspect, the input or output device 116 may provide feedback when data quality is within an acceptable range. In another aspect, the input or output device 116 may provide both positive feedback (good data quality) and negative feedback (poor data quality) so that continuous feedback is available to the operator concerning an ongoing scan.

[00149] Fig. 2 shows entities participating in a digital dentistry network. As depicted, a network 200 may include a plurality of clients 202 and servers 204 connected via an internetwork 210. Any number of clients 202 and servers 204 may participate in such a system 200. The network 200 may include one or more local area networks ("LANs") 212 interconnecting clients 202 through a hub 214 (in, for example, a peer network such as a wired or wireless Ethernet network) or a local area network server 214 (in, for example, a client-server network). The LAN 212 may be connected to the internetwork 210 through a gateway 216, which provides security to the LAN 212 and ensures operating compatibility between the LAN 212 and the internetwork 210. Any data network may be used as the internetwork 210 and the LAN 212.

[00150] The internetwork 210 may include, for example, the Internet, with the World Wide Web providing a system for interconnecting clients 202 and servers 204 in a communicating relationship through the internetwork 210. The internetwork 210 may also, or instead, include a cable network, a satellite network, the Public Switched Telephone Network, a WiFi network, a WiMax network, cellular

networks, and any other public, private, and/or dedicated networks, either alone or combination, that might be used to interconnect devices for communications and transfer of data.

[00151] An exemplary client 202 may include a processor, a memory (e.g. RAM), a bus which couples the processor and the memory, a mass storage device (e.g. a magnetic hard disk or an optical storage disk) coupled to the processor and the memory through an I/O controller, and a network interface coupled to the processor and the memory, such as modem, digital subscriber line ("DSL") card, cable modem, network interface card, wireless network card, or other interface device capable of wired, fiber optic, or wireless data communications. One example of such a client 202 is a personal computer equipped with an operating system such as Microsoft Windows XP, UNIX, or Linux, along with software support for Internet and other communication protocols. The personal computer may also include a browser program, such as Microsoft Internet Explorer, Netscape Navigator, or FireFox to provide a user interface for access to the internetwork 210. Although the personal computer is a typical client 202, the client 202 may also be a workstation, mobile computer, Web phone, VOIP device, television set-top box, interactive kiosk, personal digital assistant, wireless electronic mail device, or other device capable of communicating over the Internet. As used herein, the term "client" is intended to refer to any of the above-described clients 202 or other client devices, and the term "browser" is intended to refer to any of the above browser programs or other software or firmware providing a user interface for navigating through an internetwork 210 such as the Internet. The client 202 may also include various communications capabilities such as instant messaging, electronic mail, syndication (such as RSS 2.0), Web-based conferencing, Web-based application sharing, Web-based videoconferencing, Voice over IP ("VoIP"), and any other standards-based, proprietary, or other communication technologies, either in hardware, software, or a combination of these, to enable communications with other clients 202 through the internetwork 210.

[00152] An exemplary server 204 includes a processor, a memory (e.g. RAM), a bus which couples the processor and the memory, a mass storage device (e.g. a magnetic or optical disk) coupled to the processor and the memory through an I/O controller, and a network interface coupled to the processor and the memory. Servers may be clustered together to handle more client traffic, and may include separate servers for different functions such as a database server, an application server, and a Web presentation server. Such servers may further include one or more mass storage devices 206 such as a disk farm or a redundant array of independent disk ("RAID") system for additional storage and data integrity. Read-only devices, such as compact disk drives and digital versatile disk drives, tape drives, and the like may also be connected to the servers. Suitable servers and mass storage devices are manufactured by, for example, IBM, and Sun Microsystems. Generally, a server 204 may operate as a source of content, a hub for interactions among various clients, and platform for any back-end processing, while a client 202 is a participant in the dental activities supported by the digital dentistry systems described herein. However, it should be appreciated that many of the devices described above may be configured to respond to remote requests, thus operating as a server, and the devices described as servers 204 may participate as a client in various digital dentistry applications.

[00153] Focusing now on the internetwork 210, one embodiment is the Internet. The structure of the Internet 210 is well known to those of ordinary skill in the art and includes a network backbone with networks branching from the backbone. These branches, in turn, have networks branching from them, and so on. The backbone and branches are connected by routers, bridges, switches, and other switching elements that operate to direct data through the internetwork 210. For a more detailed description of the structure and operation of the Internet 210, one may refer to "The Internet Complete Reference," by Harley Hahn and Rick Stout, published by McGraw-Hill, 1994. However, one may practice the present invention on a wide variety of communication networks. For example, the internetwork 210 can include interactive television networks, telephone networks, wireless voice or data transmission systems, two-way cable systems, customized computer networks, Asynchronous Transfer Mode networks, and so on. Clients 202 may access the internetwork 210 through an Internet Service Provider ("ISP", not shown) or through a dedicated DSL service, ISDN leased lines, T1 lines, OC3 lines, digital satellite service, cable modem service, or any other connection, or through an ISP providing same.

Further, the internetwork 210 may include a variety of network types including wide-area networks, local area networks, campus area networks, metropolitan area networks, and corporate area networks.

[00154] In an exemplary embodiment, a browser, executing on one of the clients 202, retrieves a Web document at an address from one of the servers 204 via the internetwork 210, and displays the Web document on a viewing device, e.g., a screen. A user can retrieve and view the Web document by entering, or selecting a link to, a URL in the browser. The browser then sends an http request to the server 204 that has the Web document associated with the URL. The server 204 responds to the http request by sending the requested Web document to the client 202. The Web document is an HTTP object that includes plain text (ASCII) conforming to the HyperText Markup Language ("HTML"). Other markup languages are known and may be used on appropriately enabled browsers and servers, including the Dynamic HyperText Markup Language ("DHTML"), the Extensible Markup Language ("XML"), the Extensible Hypertext Markup Language ("XHTML"), and the Standard Generalized Markup Language ("SGML").

[00155] Each Web document usually contains hyperlinks to other Web documents. The browser displays the Web document on the screen for the user and the hyperlinks to other Web documents are emphasized in some fashion such that the user can identify and select each hyperlink. To enhance functionality, a server 204 may execute programs associated with Web documents using programming or scripting languages, such as Perl, C, C++, C#, or Java, or a Common Gateway Interface ("CGI") script to access applications on the server. A server 204 may also use server-side scripting languages such as ColdFusion from MacroMedia or PHP. These programs and languages may perform "back-end" functions such as order processing, database management, and content searching. A Web document may also contain, or include references to, small client-side applications, or applets, that are transferred from the server 204 to the client 202 along with a Web document and executed locally by the client 202. Java is one popular example of a programming language used for applets. The text within a Web document may further include (non-displayed) scripts that are executable by an appropriately enabled browser, using a scripting language such as JavaScript or Visual Basic Script. Browsers may further be enhanced with a variety of helper applications to interpret various media including still image formats such as JPEG and GIF, document formats such as PS and PDF, motion picture formats such as AVI and MPEG, animated media such as Flash media, and sound formats such as MP3 and MIDI. These media formats, along with a growing variety of proprietary media formats, may be used to enrich a user's interactive and audio-visual experience as each Web document is presented through the browser. In addition, user interaction may be supplemented with technologies such as RSS (for syndication), OPML (for outlining), AJAX (for dynamic control of a web page), and so forth. The term "page" as used herein is intended to refer to the Web document described above, as well as any of the above-described functional or multimedia content associated with the Web document. A page may be employed to provide a user interface to the digital dentistry systems described herein. In addition, one or more applications running on a client 202 may provide a user interface for local and/or networked digital dentistry functions as described herein.

[00156] In Fig. 2, each client 202 represents a computing device coupled to the internetwork 210. It will be understood that a client 202 may be present at a location associated with digital dentistry such as a dental laboratory, a rapid manufacturing facility, a dental office, and/or a dental data center. Each of these potential participants in a digital dentistry system will now be described in greater detail.

[00157] One of the clients 202 may reside at a dental office. The dental office may include any office or other physical facility that provides dental care including individual dentist offices, dental group offices, retail dental centers, university dental schools, and the like. A dental patient may visit the dental office for a routine check up or cleaning, or for a visit scheduled due to oral discomfort, dental injury, or the like.

[00158] During the dental visit, a dentist may examine the dental patient and provide a dental assessment, such as the need for a restoration, tooth extraction, or the like. The dental office may include a three-dimensional scanner, such as any of the scanners described above, which the dentist may use to capture a three-dimensional digital representation of the dental patient's dentition including scans both

before and after one or more tooth surfaces have been prepared for a dental object such as a restoration or the like. While a scan may be performed in the context of a specific dental issue, such as a planned restoration, the dentist may also capture scans during routine visits so that a dental history for the dental patient is accumulated over time. Using the client 202, which may include the image capture system 100 described above, the dentist may obtain one or more three-dimensional representations and, after discussing treatment with the dental patient, input any relevant dental prescription information. The dentist may then electronically transmit the three-dimensional representations, along with the prescription, to a dental laboratory or other fabrication facility using a network such as the internetwork 210 described above. In general, an electronic dental prescription, as used herein, includes a dental prescription in electronic form along with any three-dimensional data such as tooth surfaces before and after surface preparation, teeth in occlusion, and so forth. Additional data, such as x-ray, digital radiographic, or photograph data may be incorporated into the electronic dental prescription, or otherwise used with the systems and methods described herein. In certain instances, an electronic dental prescription may instead refer exclusively to the prescription data. In general, the meaning should be clear from the context, however, in the absence of explicit guidance, the broadest possible meaning is intended.

[00159] As a significant advantage, a practicing dentist may maintain a history of three-dimensional representations of dentition and surrounding soft tissue for each dental patient. Where a new procedure, such as a restoration, is scheduled for the patient, the dentist may pre-fabricate a temporary restoration using historic dental data. The temporary restoration may be fabricated for example, at the dental office where the procedure is scheduled using a three-dimensional printer and/or a copy milling machine, or at a remote facility such as the dental laboratory or rapid manufacturing facility described below. In one aspect, a scan may be obtained of a prepared surface during the scheduled visit, and the temporary restoration (or a final restoration) may be fabricated, such as at the dental office during the visit, by combining historical three-dimensional data with a three-dimensional representation of the prepared surface. In another embodiment, a treating dentist may shape the surface preparation to receive a pre-fabricated temporary restoration.

[00160] More generally, the client 202 at the dental office may be coupled in a communicating relationship with a client 202 at one or more of a dental laboratory, another dental office, a rapid manufacturing facility, and/or a dental data center for communication of three-dimensional representations of dental subject matter and related information. This dental network may be usefully employed in diagnosis, case planning, consultation, evaluation, and the like. Participation may include, for example, consultation, online or distance collaboration, approval, payment authorization, or any other collaborative or unilateral participation, examples of which are provided throughout this description. Thus there is disclosed herein methods and systems for sharing digital dental data, such as digital dental impressions captured using the techniques described above. This may permit a wide array of collaborative communications using a shared view of dentition or related digital models. For example, a dentist may collaborate with another dentist, a dental technician at a dental laboratory, an oral surgeon, a technician at a rapid manufacturing facility, or any other participant in a dental network at a remote location using a shared view of a patient's dentition. Various dental specialists may participate from remote (or local) locations, such as a periodontist, a prosthodontist, a pedodontist, an orthodontic specialist, an oral and maxillofacial surgery specialist, an oral and maxillofacial radiology specialist, an endodontist, and/or an oral and maxillofacial pathologist. Tools may be provided, such as collaborative tools, for sharing control of model manipulation, sectioning, rearranging, marking, and visualizing or simulating proposed clinical procedures. Each participant may view a rendering of the three-dimensional representation of dentition from a common or shared point of view. Control of the view and any modeling tools may be passed among participants, as well as a cursor or command prompt shared by participants within a user interface. In one aspect, this system forms a collaborative dental environment in which a three-dimensional representation of a dental patient's dentition is shared among participants. Communications among participants may include any network-supported communications protocol

including electronic mail, instant messaging, Internet Relay Chat, Voice-over-IP, and the like, as well as conventional teleconferencing.

[00161] Turning next to the dental laboratory, a dental laboratory may provide a fabrication resource for dental practitioners. A conventional dental laboratory may have a number of production departments specializing in various dental objects such as complete dentures, partial dentures, crowns and bridges, ceramics, and orthodontic appliances. A dental laboratory may employ trained technicians to perform various tasks associated with filling a dental prescription such as preparing dental models, dies, articulated models, and the like from impressions and occlusal registrations received from dentists. Typically, a dentist submits an order with specific instructions (a prescription) to a dental laboratory, and the laboratory fabricates the corresponding dental object(s) for use by the dentist. A client 202 at a dental laboratory may be coupled in a communicating relationship with a client 202 at one or more of a dental office, another dental laboratory, a rapid manufacturing facility, and/or a dental data center for communication of three-dimensional representations of dental subject matter and related information. This dental network may be usefully employed in diagnosis, case planning, consultation, evaluation, and the like.

[00162] Dental laboratories may for example create restorative products such as crowns and bridges. A traditional crown formed of gold, other metal alloys, or ceramic may replace all visible areas of a tooth. An onlay is a partial crown that does not fully cover the visible tooth. Crowns may include a precision attachment incorporated into the design that may receive and connect a removable partial denture. Inlays are restorations fabricated to fit a prepared tooth cavity and then cemented into place. A bridge is a restoration of one or more missing teeth, such as a fixed partial, a three unit bridge, or the like. A bridge may be permanently attached to the natural teeth or attached to custom-made or prefabricated posts and cores that are first cemented into the roots.

[00163] Another major area of dental objects includes reconstructive products, most typically dentures. Partial dentures are a removable dental prosthesis that replaces missing teeth and associated structures. Full dentures substitute for the total loss of teeth and associated structures. Some dental labs also make precision attachments that connect a crown to an artificial prosthesis. Implants are fixtures anchored securely in the bone of the mouth to which an abutment, crown or other dental object can be attached using screws, clips, or the like. This may include, for example, a titanium root replacement integrated with the bone, an abutment or transfer coping, and an implant secured to the abutment. Implant procedures also typically involve a healing abutment to assist with healing of affected soft tissue and to maintain positioning of teeth while the root replacement attaches to the bone (which may take several months). An additional impression may be taken of the implant using an impression coping or abutment after it has attached to the bone for preparation of a final restoration.

[00164] A dental laboratory may also manufacture cosmetic products such as ceramic or composite resin veneers and crowns. Veneers are thin coverings cemented to the front of the tooth for aesthetic affect. Crowns are designed to cover the entire tooth preparation and will resemble natural teeth. Composite or ceramic inlays and onlays may be manufactured to replace amalgams and give teeth a more natural appearance. Orthodontic appliances move existing teeth to enhance function and/or appearance.

[00165] In general, the procedures described above involve transfer of a dental impression to a laboratory for fabrication of the final dental object. In some cases, such as implants, a number of impressions may be taken over the course of treatment. Using a scanner such as that described above, a dentist may capture an accurate three-dimensional representation of dentition and surrounding tissue and transmit this digital version of the dental impression to a dental laboratory using a network such as the internetwork 210 described above. The dental laboratory may receive the data and proceed with any appropriate fabrication. In various procedures, the three-dimensional representation may include data from two or more scans, such as an initial three-dimensional representation of dentition prior to any dental work, and a prepared three-dimensional representation of the dentition after one or more tooth surfaces have been prepared for the dental object(s). The surface preparation may provide guidance to the laboratory concerning fit of the restoration or other dental object to the tooth surface, and the initial scan may provide valuable information concerning the appropriate dimensions for the final dental object and

its relationship to surrounding teeth. A dentist may also optionally specify a number of parameters for the dental laboratory as described in various examples below.

[00166] Where a particular dental object is temporary, or will be covered by another dental object at a subsequent dental visit, the object may be fabricated with one or more characteristics that improve scanning of any exposed surfaces once the object is placed within a dental patient's mouth. For example, an object such as an impression coping, fixture, or healing abutment may be fabricated with scanning-optimized surfaces such as an optical or textured finish. An optical finish may, for example, include randomly (or pseudo-randomly) distributed coloration such as black or other high-contrast dots. A textured finish may, for example, include a pseudo-random texture or one or more discrete landmarks.

[00167] It will be appreciated that in certain embodiments the dental laboratory may be an in-office dental laboratory physically located within or near a dental office where a dental patient is receiving treatment. In various embodiments, the in-office dental laboratory may provide facilities for a subset of dental objects described above, such as those most commonly used by a particular dentist.

[00168] Rapid manufacturing facilities may also be employed with the systems described herein. A rapid manufacturing facility may include equipment for designing and/or fabricating dental objects for use in dental procedures. A client 202 at a rapid manufacturing facility may be coupled in a communicating relationship with a client 202 at one or more of a dental office, another dental laboratory, a rapid manufacturing facility, and/or a dental data center for communication of three-dimensional representations of dental subject matter and related information. This dental network may be usefully employed in diagnosis, case planning, consultation, evaluation, and the like.

[00169] Rapid manufacturing facilities may include, for example one or more stereo lithography apparatuses, three-dimensional printers, computerized milling machines, or other three-dimensional rapid prototyping facilities or similar resources. A particular facility may include one or more of a number of different types of machines which may be scheduled for various fabrication jobs received through the internetwork 210. In one embodiment, a single facility may provide a large number of machines along with suitably trained technical personal to provide a centralized fabrication facility. In another embodiment, machines may be distributed at various locations, including one or more machines within dental offices and dental laboratories. Where copings, crowns, or the like are to be finished at the rapid manufacturing facility rather than, for example, a dental laboratory, the rapid manufacturing facility may also include machinery such as pressing machines and electroplating machines.

[00170] More generally, a dental fabrication facility may include one or more of the rapid manufacturing facilities, dental laboratory facilities, or in-office dental laboratories described above, either alone or in combination.

[00171] A dental data center may provide a hub for a digital dentistry network. A server 204 at a dental laboratory may be coupled in a communicating relationship with a client 202 at one or more of a dental office, a dental laboratory, a rapid manufacturing facility, and/or another dental data center for communication of three-dimensional representations of dental subject matter and related information. This dental network may be usefully employed in diagnosis, case planning, consultation, evaluation, and the like. The dental data center may, for example operate as an intermediary between dentists, laboratories, and fabrication facilities to provide a common repository for new dental jobs from a dental office, which may be distributed to available resources at one or more dental laboratories and/or rapid fabrication facilities. In addition to scheduling and workload allocation, the dental data center may provide various value-added services such as quality control for incoming three-dimensional representation, financial transaction management, insurance authorization and payment, and the like.

[00172] The dental data center may coordinate a number of transactions within a digital dentistry network. For example, the dental data center may engage in continuous bidding for fabrication work in order to ensure competitive pricing for fabrication facility and dental laboratory work sourced from the dental data center. As another example, the dental data center may provide status updates concerning a fabrication job to a dentist or other participant, including up-to-date information such as job received, job at fabrication facility, job at dental laboratory, model completed, waxing completed, investing completed, casting completed, porcelain build-up completed, restoration completed, finishing,

shipping, and so forth. The dental data center may provide a web-based work-in-progress interface through which a dentist may monitor progress. Other known systems, such as electronic mail alerts or RSS updates, may be used to provide status updates to dentists or other interested parties. While a dental data center may be usefully employed with the digital dentistry systems described herein, it will also be understood that various dental networks may operate independently between parties, such as between a dental office and a dental laboratory or between a dental laboratory and a rapid manufacturing facility, or between a number of dental offices and a rapid manufacturing facility, without a centralized server at a dental data center. All such embodiments are intended to fall within the scope of this disclosure. Further, it will be understood that a wide array of software platforms, communications protocols, security protocols, user interfaces, and the like are known, and may be suitably adapted to a web-based, web-services based, or other dental data center as described herein.

[00173] A digital dentistry network may include other participants, such as a consulting dentist, and oral surgeon, an insurer, a federal or state regulator or oversight entity, or any other dental entity. Each of these participants may communicate with other participants in the digital dentistry network through use of a client 202. Through this digital dentistry network, various methods and systems may be deployed. For example, in one aspect a three-dimensional representation and a dental prescription may be electronically transmitted to an insurer through the network, and the insurer may respond with authorization to perform the specified dental procedure (or a denial, which may include any reasons for the denial), including fabrication of any related dental objects. The insurer may maintain an electronic copy of three-dimensional representations relevant to the authorization, such as an image of the tooth surface prepared for the procedure. The insurer may also render payment, or authorize payment, to a treating dentist. The insurer may also, or instead, render payment to related entities, such as a dental laboratory or rapid manufacturing facility, for fabrication services provided. In one common practice, the insurer makes a single payment to the treating dentist who may in turn contract desired vendors for fabrication services. However, the insurer may render payments separately to one or more parties involved including a dentist, a dental patient, a dental laboratory, a rapid manufacturing facility, and so on.

[00174] In one aspect, dental laboratory procedures may be improved by fabricating a kit of components for use by a dental laboratory in subsequent fabrication of a final restoration, prosthesis, or the like. For example, a kit may include one or more of a die, a quad model, an opposing quad model, a full arch model, an opposing arch model, a base, a pre-articulated base, a waxup, and so forth. More generally, the kit may include one or more pre-cut components, pre-indexed components, and pre-articulated components for assembly into a dental model, such as a model adapted for use with an articulator. The kit may also, or instead, include various interim components of dental manufacture, such as required or commonly used components for particular procedures, e.g., the PFM crown kit, the bridge kit, and so on. All or some of these components may be automatically fabricated as a kit by a production facility specializing in high-throughput such as the rapid manufacturing facility described above, and the kit may be forwarded to a dental laboratory specializing in creation of final restorations and the like. This approach leverages the relative expertise of these two participants in a digital dentistry network, and may achieve significant decreases in cost and time to a final restoration or other dental object. Alternatively, a dentist may determine and directly fabricate any required kit components using, for example, an in-house three-dimensional printer. In one aspect, a group of different kits may be established for different dental work, so that a dental prescription automatically triggers fabrication of the corresponding kit.

[00175] Fig. 3 shows a user interface that may be used in a digital dental system. The user interface may be presented, for example, as a Web page viewed using a Web browser, or as an application executing on one of the clients 202 described above, or as a remotely hosted application, or as a combination of these.

[00176] The interface 300 may include navigation features such as a home control 302, a name directory control 304, a toolbox control 306, and a security control 308. Each of these features may direct the interface 300 to a different functional area. For example, the home control 302 may access a top level menu that provides access to, for example, system login, data source selection, hardware/software

configuration, administrative tools, and so forth. The name directory control 304 may access a directory of patients, physicians, dental laboratories, rapid manufacturing facilities and like, and permit searching, data input, and so forth. The directory may, for example, provide access to patient dental records and history, contact information, and the like. The toolbox control 306 may provide access to tools for scanning, case planning and management, scheduling, and the like. The security control 308 may provide access to account management, communications configuration, and other security-oriented features and functions of a digital dentistry system.

[00177] Within each main area of top-level navigation, the interface 300 may provide a number of tabs, such as the scanning tab 310, the prescription tab 312, and the status tab 314 depicted in Fig. 3. The scanning tab 310 may, for example, invoke an interface for controlling operation of an image capture system 100 such as that described above in reference to Fig. 1. The prescription tab 312 may, for example, invoke an interface that permits specification of a restoration or other dental object, including a specification of teeth being treated, treatment type, manufacturer, and details of the dental object including color, material, texture, and so forth. The interface of the prescription tab 312 may also include tools for transmitting a prescription, along with any three-dimensional data obtained from scans of a patient, to a dental laboratory, dental data center, rapid manufacturing facility, or the like. The status tab 314 may, for example, invoke an interface for obtaining or updating status information on a case such as the fabrication status of a prescription (e.g., prescription and scan received, scan evaluated and approved, models complete, object fabricated, object shipped to dentist, and so forth).

[00178] Fig. 3 depicts in more detail a prescription window of the interface 300, as accessed by selecting the prescription tab 312. This window may show current data for a prescription within a text window 320. A scroll bar 322 or other control may be provided for selecting options relating to a prescription. In operation, and by way of example only, a feature of the prescription, such as the material or manufacturer, may be highlighted within the text window 320, and options for that feature may be selected from the scroll bar 322. The window may also include additional navigational or process controls such as a next button 324, a back button 326, and a finish button 328, which may be used to navigate through one or more different windows of a prescription and/or case planning interface. This may include, for example, input of patient data, selection of a dental laboratory, scheduling of dental visits, and the like. It will be understood that the above interface 300 is an example only and that other hierarchical arrangements of functions, and/or arrangements of data and controls within a particular interface, are possible and may be employed with a digital dental system as described herein. For example, the interface may control scanning, marking or annotation of scanned models, case planning, access to databases of patient records and dental data, preparation of prescriptions, analysis of dentition, scheduling, management of patient data, communications with remote fabrication facilities, and so forth. Any user interface or combination of user interfaces and user interface technologies suitable for a digital dental system as described herein may be employed without departing from the scope of this disclosure. As such, a user interface 300 should be understood more generally with reference to the systems and methods described herein, and not by specific reference to the example interface shown in Fig. 3.

[00179] Having described a number of aspects of a digital dentistry system and network, along with various participants in such a network, specific uses of the system will now be discussed in greater detail.

[00180] Fig. 4 depicts a quality control procedure for use in a digital dental system. The process 400 may start 402 by obtaining a digital model, such as a three-dimensional representation of dental subject matter as described generally above.

[00181] The digital model may include a single model, such as a digital model of dentition prior to any dental work, such as for archival or comparison purposes. This may also, or instead, be a digital model of dentition including one or more prepared surfaces, such as a single tooth surface prepared for a crown, or a number of tooth surfaces prepared for a multi-unit bridge. This may also include a scan of bite registration. For example, a scan may be obtained of the teeth of a dental patient in centric relation, centric occlusion, or with maximum intercuspation, in protrusion (e.g., for sleep apnea guards), in lateral excursions, or in any other static orientation useful for any of the dental procedures described herein. As

a significant advantage, the upper and lower arches may be treated as rigid bodies, thus permitting relative three-dimensional orientation for a full bite registration to be obtained from a scan of a relatively small region of the upper and lower arches while in occlusion, such as centric occlusion. Thus for example, a three-dimensional scan that spans the two arches, such as a scan of the exterior surfaces of one or two teeth in a buccal or labial area, may be used to register bite. In addition, the digital model may include motion information describing the relative motion of, e.g., an upper and lower jaw throughout one or more jaw motions such as opening and closing the mouth or simulated chewing. Such motion data may, for example, be obtained through a variety of techniques suitable for tracking three-dimensional motion, which may include extrapolation from video data, use of transmitters on the moving jaws, mechanical or electromechanical sensors and/or transmitters, and so forth. Motion data may also be inferred by capturing orientation data for the jaws in a variety of positions. Motion data may be employed, for example, to derive the position of TMJ condyle paths of rotation and translation, or to provide input to a virtual or conventional dental articulator.

[00182] More generally, any digital model or other data useful in dental procedures, restorations, and the like as described herein may be obtained in step 404.

[00183] Once a digital model (or models) is obtained in step 404, the process 400 may proceed to one or more quality control steps as depicted in steps 406-410.

[00184] This may include automated quality control, as shown in step 406, which may be simple quantitative analysis such as measures of accuracy, variability, or density of three-dimensional surface data for a digital model. This may also, or instead, include more sophisticated, automated analyses such as adequacy and/or suitability of margins and prepared surfaces for an anticipated restoration. For example, an automated quality control tool may examine a prepared tooth surface to ensure that a margin line is present all the way around a preparation, or examine the prepared surface to ensure that adequate material has been removed to accommodate a restoration. Similarly, an automated process may locate areas of potential problems, such as occlusal high spots, occlusal clearance, occlusal irregularities, areas of poor margin preparation, areas of inadequate tooth removal, improper taper, improper draw path or removal path for a multiple unit preparation, inappropriate contour, and so forth.

[00185] In one aspect, quality control may include real time feedback during a scan, or between successive scans. The feedback may be rendered with suitable visualizations on a display to permit immediate observation and correction by a dentist. Thus it will be appreciated that, while depicted in Fig. 4 as a post-scanning operation, quality control may be implemented at any time in a digital dentistry process, or throughout the entire process. Real time feedback may include for example, textual annotations identifying teeth as they are recognized within a scan, and providing one or more dimensions of a tooth, or an analysis of contour, clearance relative to adjacent teeth, or a position of the tooth relative to other teeth or relative to a global coordinate system. By providing this information in real time within the context of a single dental visit, treatment may be generally improved by reducing or eliminating a need for follow up scans.

[00186] In another aspect, quality control may include an evaluation of suitability of a surface preparation, or a restoration or other dental object prepared for the restoration, for manufacturing using one or more techniques, including three-dimensional printing, milling, stereo lithography, and or conventional dental fabrication, or various combinations of these.

[00187] Although not depicted in Fig. 4, it will be appreciated that quality control may be semi-automated. Thus, for example, a user interface may provide a number interactive, three-dimensional tools such as markup tools that a dentist or other dental professional may use to measure, mark, annotate, or otherwise manipulate a digital model to evaluate suitability for subsequent processing and the creation of a physical dental object such as a restoration.

[00188] As shown in step 408, quality control may include manual quality control. For example, a dentist may inspect a scan in an interactive, three-dimensional environment to visually identify, e.g., holes or areas of incomplete scan needed for an intended dental procedure. The dentist may employ various features, such as rotation, zooming, and panning to inspect various surfaces of the three-dimensional digital representation from a scan.

[00189] As shown in step 410, quality control may include remote quality control. For example, after completing a scan, a dental office may transmit a digital model to a dental laboratory or a fabrication facility for evaluation of adequacy of the scan. As a significant advantage, the recipient, such as a dental laboratory may provide immediate feedback to a dentist while a dental patient is still in the dental office, or still in a dentist's chair at a dental office, thus avoiding a need to schedule repeat visits for additional surface scanning or surface preparation. A dental laboratory may inspect a prepared surface to ensure that a restoration can be fit to the prepared surface, or that there is adequate space (especially thickness) for a restoration or other dental object. The dental laboratory may also evaluate color and suggest shade matching for a dentist. The dental laboratory may request manual marking of a margin by a dentist where the margin is not visible on a prepared tooth surface. The dental laboratory may also apply separate standards for data quality (density, accuracy, surface continuity, feature detail, etc.), and may request additional or new scan data consistent with its own specifications. The dental office may transmit a case plan prior to (or during) transmission of a scan, which may permit more detailed analysis of the scan data by the recipient. Thus, for example, a dental laboratory may evaluate suitability of the scan and/or surface preparation for a type of restoration and any prescribed components (e.g., full ceramic, porcelain-fused-to-metal, etc.). Where the dental laboratory can quickly generate an accurate or rough model for a restoration or other dental object according to any fabrication or end use constraints, the rough model may, in digital form, be virtually fit to the prepared surface, and feedback may be provided to a dentist such as an identification of regions requiring further reduction.

[00190] Quality control, whether automated or manual, and whether local or remote, may include a variety of different dental evaluations. For example, a prepared tooth in an arch that will receive a restoration may be evaluated to determine whether there is adequate space for cement to bond the restoration to the prepared tooth surface. As another example, a dentist may visually confirm accuracy of a scan by inspection for gross errors or omissions such as holes, gaps, distortions, twists, and the like. The dentist may also visually inspect margin lines on surface preparations, and may annotate margins for identification by a dental laboratory or other fabrication facility. Similarly, a dental laboratory may, during a quality control evaluation, request that the dentist identify the margins on a surface preparation where the margin lines are not self-evident.

[00191] Feedback from a quality control step, whether automated or manual, and whether remote or local, may include various forms of feedback. For example, an evaluation may conclude with an identification of regions of a prepared tooth surface requiring additional preparation or reduction, or regions of a digital model requiring additional or supplemental scanning due to incomplete, erroneous, or potentially erroneous data, which may be identified, for example, by comparison to models of expected shape for dentition, surface preparations, and the like. An evaluation from a dental laboratory may request new data, or additional shaping of a prepared surface. An evaluation from a dental laboratory may include a request for an oral consultation. In addition other dental professionals such as a consulting dentist, an oral surgeon, a dental specialist, or a laboratory technician may be called upon for evaluation, approval, and/or recommendations. Feedback may be presented to a dentist in a number of forms. For example, the feedback may include text or audible narrative concerning additional scanning, additional surface preparation, or requests for confirmation. The feedback may be graphical feedback provided by highlighting questionable or erroneous areas of a preparation within a rendered display of scan data. The feedback may identify corrective action on a scan or a surface preparation. The feedback may identify a margin line which may be displayed on a two-dimensional rendering of a three-dimensional representation, and a user interface may permit the margin line to be edited or confirmed. The feedback may include a visual display with regions of inadequate margin highlighted, such as through use of color, texture, or explicit annotations, arrows, callouts, or the like, and any combination of these.

[00192] It will be understood that the quality control steps indicated in Fig. 4 are not mutually exclusive. That is each of the quality control steps 406-410 may be performed during the process 400, such as in sequence or in parallel (as where a dentist and a laboratory evaluate a scan simultaneously), and all such variations are intended to fall within the scope of this disclosure.

[00193] Any of the quality control steps above may advantageously be performed while a dental patient is still present at a dental office, or while the patient is still in a dental chair, thus reducing or eliminating the need for follow up dental visits for additional scanning.

[00194] After one or more quality control steps 406-410, a determination may be made as to whether a scan and/or surface preparations are satisfactory. If the data is not satisfactory, the process 400 may proceed to step 414 where the digital model may be supplemented or replaced with new scan data. This may include, for example, new scanning to replace apparently erroneous or inadequate scan data, or a new scan of the dental subject matter following, e.g., additional surface preparation consistent with errors identified during quality control. The process 400 may then return to step 404 where a new digital model is obtained.

[00195] If it is determined in step 412 that the data is satisfactory, the process 400 may proceed to step 416 where a dentist may prepare a prescription. The prescription may include, for example, a dental patient identification, an identification of one or more teeth being treated, a type of treatment (e.g., for a restoration, one or more of a bridge, a crown, an inlay, a laminate veneer, an onlay, or a temporary), an identification of missing teeth (if appropriate), a material or fabrication technology (e.g., full ceramic, cast metal, PFM, etc.), an alloy type (e.g., for a PFM crown), a manufacturer (e.g., Cercon, Cerec, Empress, Everest, Lava, Procera, etc.), limited occlusal clearance (e.g., enamelplasty, reduction coping, etc.), a shade guide (e.g., Vita 3D Master, Vita Classical, etc.), a surface texture, a surface glaze, an opacity, an occlusal staining, dental notes, and any other information relevant to identification or preparation of the dental object. For example, for a crown the specification may include a material type, a design (such as metal band, 360-degree facial butt porcelain shoulder, facial butt porcelain shoulder, metal occlusal surface, or no metal showing), a return (e.g., biscuit bake, finish, metal try-in, etc.). Each specification may include subspecifications. For example, a metal band crown may be specified as having the metal band located at a buccal location, a lingual location, or 360-degree.

[00196] As shown in step 418, once the prescription has been completed, the digital model and prescription may be uploaded to a dental laboratory or other fabrication facility using, for example, the dental network described above. The process 400 may then end, as shown in step 420.

[00197] It will be understood that numerous variations and modifications to the above process 400 may be used. For example, the prescription may be prepared at a different point in the process, such as before scanning so that the prescription data may be used to evaluate sufficiency of the scan data. As another example, each digital model (e.g., native tooth surfaces, bit registration, prepared tooth surfaces) may be separately presented to one or more quality control steps, or the entire digital model may be obtained prior to any quality control analysis. All such variations and modifications are intended to fall within the scope of the methods and systems described herein.

[00198] Fig. 5 shows a dental laboratory procedure using a digital dental model. While described as a dental laboratory procedure, it will be understood that the fabrication and quality control procedures described with reference to Fig. 5 may be performed by any fabrication facility including a dental fabrication facility such as a dental laboratory equipped to receive digital dental data, a model production laboratory (such as a rapid fabrication facility, milling facility, and the like), an in-office dental laboratory at a dental office, or any other dental fabrication facility. The fabrication facility may include a remote facility accessible through the dental network, and digital dental data may be communicated to the fabrication facility directly or through a hub for dental data such as the dental data center described above.

[00199] As shown in step 504, the process 500 may start 502 by receiving a digital model from a dentist or other source. This may include, for example, a digital model, such as a digital surface representation obtained using the image capture system 100 described above, of a surface prepared for a restoration such as a crown, or any other dental object.

[00200] As shown in step 506, the dental laboratory may design and/or fabricate a restoration or other dental object based upon the digital model received in step 504. This may include a variety of fabrication techniques, including working from a physical cast of a dental impression created using conventional dentistry techniques, or three-dimensional printing or other fabrication techniques to

manufacture various interim components of dental manufacture such as dies, casts, and the like, or direct fabrication of a virtually designed restoration, such as through computerized milling of the restoration from ceramic.

[00201] In one aspect, designing the restoration may include a step of virtually adding a die spacer to a digital model. It is known in dentistry to employ a die spacer – a thin layer painted onto regions of dental models – to improve the final fit between a prepared tooth surface in a dental patient's mouth and a restoration or other dental object. The die spacer may for example provide a small void between a cast of the prepared surface and a restoration constructed for the cast which may provide a void for cement used with the final fitting, or to account for size changes in the restoration fabrication process. The die spacer may be virtually added to a digital model of a prepared surface to achieve a similar effect with a restoration that is to be directly fabricated from the digital model, or an interim component such as a fabricated cast of a dental impression used to create the restoration. Similarly, where a cast dental model is to be fabricated from a digital model, the die spacer may be added to appropriate regions of the prepared surface and any other suitable surfaces to remove or reduce the need for use of die spacers in subsequent fabrication steps. More generally, a virtual die spacer may be added to a digital model of a conventional dental model, a die, a waxup, or any other interim component of dental manufacture to account for a cementation void or other physical variations in the design of a final restoration. This cementation void or virtual die spacer may be fabricated directly into a die, waxup, or other interim component that may be three-dimensionally printed or otherwise manufactured from the digital model.

[00202] Thus in one aspect, disclosed herein is a virtual die spacer. In fabricating a dental restoration, a virtual die spacer or cementation void may be specified, either by an originating dental office or a dental laboratory, and this void may be automatically or manually added to appropriate regions of a digital model to provide a corresponding cementation void in a final restoration. As a significant advantage, the thickness of the virtual die spacer may be explicitly specified, and may be adjusted according to, for example, a dentist's preference or according to a type of cement to be used with the restoration. Dentist preferences concerning die spacer thickness may also be stored for reuse, and dentist feedback (e.g., "too tight" or "inadequate void") may be recorded to provide sizing for a final restoration or other dental object that more closely meets and individual dentist's expectations.

[00203] In another aspect, designing the restoration may include virtually ditching a die for a restoration. In conventional dentistry, a material may be cut away from a die below the margin line (which would otherwise include bone, soft tissue, and the like) prior to use as a restoration model. This operation may be performed virtually within a user interface that includes interactive tools for manipulating a three-dimensional representation of dentition. Initially, this may include an automated, semi-automated, or manual step of defining a die in three-dimensional space by identifying a plane, a point, or a line used to separate a die from a model in an operation analogous to physically cutting a die from a conventional dental model. This may be followed by additional steps such as separate steps of explicitly identifying a margin line with a first tool and then manipulating the digital model "below" the margin line, i.e., away from the tooth surface fitted to a restoration, with a second tool to remove unwanted or unneeded areas from a volume bounded by the digital surface representation. This process may be semi-automated or automated, such as by automatic identification of the margin line and removal of a predetermined amount of sub-margin volume. The ditched die may then be directly fabricated using techniques described above.

[00204] Regardless of the interim modeling and fabrication steps, this step may result in a restoration in physical form, such as a crown, bridge, inlay, onlay, or other dental object intended for use by a dental patient.

[00205] As shown in step 508, the restoration may be scanned using, for example, an image capture system 100 such as the system described above with reference to Fig. 1, to obtain a scanned restoration.

[00206] As shown in step 510, the scanned restoration may be test fit to the digital model received in step 504, such as by virtually superimposing the scanned restoration to the digital model. This may permit evaluation of a variety of fit criteria prior to an attempt to fit the physical restoration to a

prepared surface in the dental patient's mouth. This includes, for example, an evaluation of margin fit, an evaluation of void space for cement used to affix the restoration to the prepared surface, and any other evaluation relating the prepared surface directly to the restoration or abutting tooth surfaces. This may also include an evaluation of bite, occlusions, lateral excursions and any other evaluation relating to jaw motion or the mating of lower and upper arches with the restoration in place.

[00207] In another aspect, test fitting may include measuring dimensional accuracy of the scanned restoration. For example, the restoration in this context may include a prosthesis, an implant, an appliance, a restorative component, an abutment, a fixture, or any other dental object. The scanned restoration may be measured for fit between adjacent teeth, or for evaluation of contact points with teeth of an opposing arch when the restoration is fitted to a prepared surface (or more specifically, when the scanned restoration is virtually fitted to a scan of the prepared surface), or a fit to the prepared surface, possibly including an allowance for die spacing on one or more surfaces. A dentist may specify a desired tightness of fit, which may be quantified objectively (e.g., in millimeters or microns) or subjectively (e.g., loose, average, tight, etc.).

[00208] In one aspect, feedback from specific dentists may be monitored, so that subsequent restorations may more closely meet each dentist's expectations for a desired tightness of fit.

[00209] In another aspect, measuring dimensional accuracy may include evaluating a quality of margin fit between a scanned restoration and a scanned surface preparation, in order to avoid fitting difficulties at the time of fitting the physical restoration to a patient's dentition.

[00210] As shown in step 512, the test fit of step 510 may be followed by a determination of whether the physical restoration is satisfactory. If the physical restoration is not satisfactory, the process 500 may proceed to step 514 where the physical restoration is reworked, or a new restoration prepared. If the physical restoration is satisfactory, the physical model may be sent to a dental office for a final fitting procedure in the dental patient's mouth. It may also be advantageous to also forward the scan of the restoration to the originating dental office in order to begin preparation for the final fitting procedure. The process 500 may then end 518.

[00211] It will be understood that numerous variations and modifications to the above process 500 may be used. For example, although not depicted in Fig. 5, in certain instances where it appears that a physical restoration cannot be properly fabricated to fit the restoration site, e.g., the prepare surface and surrounding dentition, the dental laboratory may contact the originating dental office to request additional preparation of the target surface. All such variations and modifications are intended to fall within the scope of the methods and systems described herein.

[00212] It will further be appreciated that, even in a system where the digital surface representation is used directly to fabricate a cast dental model to which subsequent, conventional dental laboratory techniques are applied, significant advantages may be realized through elimination or mitigation of physical handling and shipping of a dental impression. Thus in one aspect, there is disclosed herein a technique for acquiring a digital model, such as a digital surface representation, of a prepared surface and/or surrounding dentition, and transmitting the digital model to a dental laboratory or rapid manufacturing facility for preparation of a restoration or other dental object.

[00213] Fig. 6 illustrates a scan path that may be used with a three-dimensional image capture system. In a system that operates to continuously acquire three-dimensional data in real time, and fits or registers incremental three-dimensional data to an aggregate three-dimensional model, it may be advantageous to scan in a manner that increases registration to the aggregate model. Thus, for example, a scan path that runs adjacent to edges of the aggregate model may provide additional registration or fit information and improve overall accuracy, particularly over large surfaces. With respect to scans of human dentition, this general approach suggests an s-shaped scan that traces from interior to exterior (or exterior to interior) surfaces of one tooth, and then reverses direction to trace an exterior-to-interior path immediately adjacent to the initial path, which may reduce overall spatial error between extremities of the arch. Without loss of generality, a more detailed example of this approach is set out below.

[00214] A scan path 600 for obtaining three-dimensional data from a dental arch 602 using a scanner such as the scanner 102 described above with reference to Fig. 1 may begin at a first lingual point

604. The scan path may then traverse laterally over an occlusal point 606 or surface of a molar to a first buccal point 608, translate to a second buccal point 610 by moving forward along the gum line, and then traverse laterally over a second occlusal point to a second lingual point. The scan path may then translate forward once again to a third lingual point, traverse laterally over a third occlusal point to a third buccal point, and once again translate forward. By scanning in this s-shaped manner, each successive pass over occlusal surfaces may be fit to data from an adjacent pass over the occlusal surfaces, as well as to one or more immediately prior frames of data. While the remainder of a scan path is not illustrated in Fig. 6, it will be understood that the scan may continue along the entire arch in this manner, finally reaching a molar 612 at the opposite extremity of the arch.

[00215] It will be understood that the spacing of adjacent passes may be greater or less than illustrated. For example, a buccal-to-lingual pass may cover a portion of a tooth, an entire tooth, or a number of teeth depending upon, for example, the field of view for data acquisition with the scanner. It will also be understood that the starting and ending points of the generally s-shaped scan are somewhat arbitrary. A scan may begin, for example at a lingual point, at an occlusal point, or at a buccal point. Further, the scan may begin at a molar, or the scan may begin at an incisor, with two consecutive scans performed from this central location to each molar extremity of the arch. All such variations are intended to fall within the scope of the scan path described herein. In general, regardless of the starting point, a generally s-shaped scan may move along adjacent buccal-to-lingual passes in the manner described above. In one aspect, real-time feedback may be provided to a user by displaying on a display a next appropriate direction of motion for a scan that follows the generally s-shaped path.

[00216] Figs. 7A and 7B show a modeling environment for creating alignment guides for orthodontic hardware. A three-dimensional representation 702 of dentition and surrounding soft tissue may be acquired from a dental patient as described generally above, and rendered within a user interface 704 on a computer such as the image capture system 100 described above, or more generally, the client 202 described above. In various embodiments, orthodontic hardware may be virtually placed on the three-dimensional representation 702, which may be used to determine appropriate positions for one or more alignment guides, or brackets may themselves be virtually positioned on the three-dimensional representation 702 with corresponding alignment guides being generated by computer, or the alignment guides may be directly positioned on the three-dimensional representation 702. The user interface may include interactive tools for virtually positioning orthodontic hardware and/or brackets for orthodontic hardware and/or alignment guides onto the three-dimensional representation 702 within the user interface 704. The design of orthodontic hardware and any corresponding positioning of brackets or the like, may be performed by a dentist at a dental office and transmitted to a dental laboratory or other fabrication facility, or the unmodified three-dimensional representation may be transmitted to the dental laboratory along with a prescription for orthodontic hardware.

[00217] Fig. 7A shows a three-dimensional representation 702 with visual markings 706 that serve as alignment guides. This marked three-dimensional representation 702, or digital dental model, may serve as a basis for subsequent fabrication of custom orthodontic hardware. The markings 706 may be fabricated directly into a physical realization of the digital dental model, such as using pigmented printing techniques, or the markings 706 may be added to the physical realization after fabrication using additional computerized or manual marking techniques.

[00218] Fig. 7B shows a three-dimensional representation 702 with supports 708 that serve as a physical alignment guide. This three-dimensional representation 702, or digital dental model, may serve as a basis for subsequent fabrication of custom orthodontic hardware. As depicted, each support 708 may include a horizontal top surface or shelf for supporting an orthodontic fixture or other hardware. However, it will be understood that any physical form capable of supporting or engaging the intended hardware may suitably be employed, and fabricated into a physical model. The supports 708 may be fabricated directly into a physical realization of the digital dental model using techniques such as three-dimensional printing, stereo lithography, or computerized milling.

[00219] The alignment guides may serve to guide positioning of an orthodontic fixture onto the physical realization of the digital dental model to assist in fabricating custom orthodontic hardware. In an

additional processing step, once the corresponding orthodontic hardware, such as brackets, is positioned onto the physical model, the position of a number of brackets may be captured in a physical template such as a foam, a vacuum-formed appliance, or the like, for direct transfer to an arch within a dental patient's mouth. The appliance may, for example, be formed of a soft, clear material for easy handling by a dentist and/or greater comfort for a dental patient. In such a process, a treating dentist may perform an additional scan of the patient's dentition immediately prior to affixing the brackets to ensure that the natural dentition still corresponds closely to the model used for virtual bracket positioning.

[00220] In another embodiment, additional modeling may be employed to create a virtual bracket carrier model – a device to carry brackets in a specific relative orientation – that can be physically realized as a bracket positioning appliance through direct fabrication using any of the techniques described above. The bracket carrier model may include one or more alignment guides for brackets such as those described generally above. Brackets may then be attached to the bracket positioning appliance for transfer to an arch within a dental patient's mouth. The treating dentist may perform an additional scan of the patient's dentition immediately prior to affixing the brackets to ensure that the natural dentition still corresponds closely to the model used to create the bracket positioning appliance.

[00221] It will be appreciated that the processes and methods disclosed herein may be realized in hardware, software, or any combination of these suitable for the three-dimensional imaging and modeling techniques described herein. This includes realization in one or more microprocessors, microcontrollers, embedded microcontrollers, programmable digital signal processors or other programmable device, along with internal and/or external memory. They may also, or instead, include one or more application specific integrated circuits, programmable gate arrays, programmable array logic components, or any other device or devices that may be configured to process electronic signals. It will further be appreciated that a realization may include computer executable code created using a structured programming language such as C, an object oriented programming language such as C++, or any other high-level or low-level programming language (including assembly languages, hardware description languages, and database programming languages and technologies) that may be stored, compiled or interpreted to run on one of the above devices, as well as heterogeneous combinations of processors, processor architectures, or combinations of different hardware and software. At the same time, processing may be distributed across devices such as a camera and/or computer in a number of ways or all of the functionality may be integrated into a dedicated, standalone image capture device. All such permutations and combinations are intended to fall within the scope of the present disclosure.

[00222] It will also be appreciated that means for performing the steps associated with the processes described above may include any suitable components of the image capture system 100 described above with reference to Fig. 1, along with any software and/or hardware suitable for controlling operation of same. The user interfaces described herein may, for example, be rendered within the display 110 of the image capture system 100 of Fig. 1.

[00223] While the invention has been disclosed in connection with certain preferred embodiments, other embodiments will be recognized by those of ordinary skill in the art, and all such variations, modifications, and substitutions are intended to fall within the scope of this disclosure. Thus, the invention is to be understood with reference to the following claims, which are to be interpreted in the broadest sense allowable by law.

CLAIMS:

What is claimed is:

1. A method comprising:
acquiring a three-dimensional representation of one or more intraoral structures of a dental patient using an intraoral scanner; and
providing the three-dimensional representation to a dental fabrication facility.
2. The method of claim 1, further comprising fabricating a dental restoration at the dental fabrication facility using the three-dimensional representation.
3. The method of claim 1, wherein the dental fabrication facility includes a dental laboratory.
4. The method of claim 1, wherein the one or more intraoral structures include at least one dental implant.
5. The method of claim 1, wherein the one or more intraoral structures include at least one tooth.
6. The method of claim 1, wherein the one or more intraoral structures include at least one tooth surface prepared for a dental restoration.
7. The method of claim 1, wherein the one or more intraoral structures include at least one area of soft tissue.
8. The method of claim 1, wherein the one or more intraoral structures include at least one previously restored tooth.
9. The method of claim 1, further comprising fabricating a dental prosthesis at the dental fabrication facility using the three-dimensional representation.
10. The method of claim 1, further comprising transmitting the three-dimensional representation to a dental laboratory and, in response, receiving an assessment of quality for the three-dimensional representation from the dental laboratory.
11. The method of claim 10, wherein the assessment of quality is received before the dental patient leaves a dentist's office.
12. The method of claim 10, wherein the assessment of quality includes an assessment of acceptability of the three-dimensional representation.
13. The method of claim 6, further comprising transmitting the three-dimensional representation to a dental laboratory and, in response, receiving an assessment of quality of the at least one prepared tooth surface.
14. The method of claim 1, wherein providing the three-dimensional representation to a dental fabrication facility includes transmitting to a remote dental laboratory for fabrication of a dental restoration for the one or more intraoral structures.
15. The method of claim 14, further comprising transmitting the three-dimensional representation to a dental data hub.

16. The method of claim 14, further comprising transmitting a prescription for the dental restoration with the three-dimensional representation.
17. The method of claim 14, further comprising transmitting the three-dimensional representation to a model production laboratory.
18. The method of claim 17, wherein the model production laboratory is a milling facility.
19. The method of claim 17, wherein the model production laboratory is a manufacturing facility.
20. The method of claim 17, wherein the model production laboratory is a three-dimensional rapid prototyping facility.
21. The method of claim 1, wherein providing the three-dimensional representation to a dental fabrication facility includes providing the three-dimensional representation to an in-office dental laboratory for fabrication of a dental restoration for the one or more intraoral structures.
22. A computer program product comprising computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of:
 - acquiring one or more images of one or more intraoral structures of a dental patient from an intraoral scanner;
 - converting the one or more images into a three-dimensional representation of the one or more intraoral structures; and
 - transmitting the three-dimensional representation to a dental fabrication facility.
23. The computer program product of claim 22, further comprising computer code that performs the step of comparing quality of the three-dimensional representation to predefined quality criteria.
24. The computer program product of claim 23, wherein the predefined quality criteria includes acceptability of the three-dimensional representation for fabrication.
25. The computer program product of claim 22, further comprising computer code that performs the steps of:
 - retrieving a prescription for at least one of a prosthesis or an appliance prepared by a dentist; and
 - combining the prescription with the three-dimensional representation prior to transmitting the three-dimensional representation.
26. The computer program product of claim 22, wherein the one or more intraoral structures include at least one dental implant.
27. The computer program product of claim 22, wherein the one or more intraoral structures include at least one tooth.
28. The computer program product of claim 22, wherein the one or more intraoral structures include at least one tooth surface prepared for a dental restoration.
29. The computer program product of claim 28, further comprising computer code that performs the step of comparing quality of the at least one prepared tooth surface to predefined quality criteria.

30. The computer program product of claim 22, wherein the one or more intraoral structures include at least one area of soft tissue.
31. A system comprising:
an intraoral scanner for acquiring a three-dimensional representation of one or more intraoral structures of a dental patient; and
a transmission means for transmitting the three-dimensional representation to a dental fabrication facility.
32. The system of claim 31, further comprising a first fabrication means for fabricating a dental restoration at the dental fabrication facility using the three-dimensional representation.
33. The system of claim 31, wherein the one or more intraoral structures include at least one dental implant.
34. The system of claim 31, wherein the one or more intraoral structures include at least one tooth.
35. The system of claim 31, wherein the one or more intraoral structures include at least one tooth surface prepared for a dental restoration.
36. The system of claim 31, wherein the one or more intraoral structures include at least one area of soft tissue.
37. The system of claim 31, further comprising a second fabrication means for fabricating a dental prosthesis at the dental fabrication facility using the three-dimensional representation.
38. The system of claim 31, further comprising a quality assessment means for assessing quality of the three-dimensional representation.
39. The system of claim 38, wherein the quality assessment means includes a means for determining acceptability of the three-dimensional representation for use with the first fabrication means.
40. The system of claim 38, wherein the quality assessment means includes a means for determining acceptability of the three-dimensional representation for use with the second fabrication means.
41. The system of claim 38, wherein the one or more intraoral structures include at least one tooth surface prepared for a dental restoration, and wherein the quality assessment means includes a means for determining quality of the at least one prepared tooth surface.
42. A method comprising:
receiving a three-dimensional representation of a tooth, the tooth prepared for a dental restoration;
specifying a cementation void between the tooth surface and the dental restoration; and
fabricating the dental restoration such that the dental restoration, when mated to the tooth surface, defines an empty space corresponding to the cementation void.
43. The method of claim 42, further comprising adjusting the cementation void.
44. The method of claim 43, wherein adjusting the cementation void includes adjusting the cementation void according to a dentist's preferences.
45. The method of claim 43, wherein adjusting the cementation void includes:

specifying a type of cement to be used in the cementation void; and
adjusting the cementation void according to the type of cement to be used in the cementation
void.

46. The method of claim 42, wherein the cementation void is specified by a dentist.
47. The method of claim 46, wherein the dentist sends the specification of the cementation void to a dental laboratory.
48. The method of claim 47, wherein the cementation void is specified by a dental laboratory.
49. The method of claim 42, further comprising three-dimensionally printing a die including the cementation void.
50. The method of claim 42, further comprising fabricating a die including the cementation void using a stereo lithography apparatus.
51. The method of claim 42, further comprising three-dimensionally printing a wax-up including the cementation void.
52. The method of claim 42, further comprising milling a die including the cementation void.
53. The method of claim 42, further comprising integrating the cementation void into a digital surface representation of the tooth.
54. The method of claim 42, further comprising integrating the cementation void into a dental model.
55. The method of claim 42, wherein the three-dimensional representation includes a digital surface representation of the tooth.
56. The method of claim 42, wherein fabricating the dental restoration includes fabricating the dental restoration in an in-house laboratory in a dentist's office.
57. The method of claim 42, further comprising fabricating an opposing arch for an arch including the tooth, the opposing arch including a die spacer having a predetermined thickness.
58. A computer program product comprising computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of:
 - acquiring one or more images of a tooth of a dental patient from an intraoral scanner, the tooth including a tooth surface prepared for a dental restoration;
 - converting the one or more images into a three-dimensional representation of the tooth;
 - specifying a cementation void between the tooth surface and the dental restoration;
 - combining the specification for the cementation void with the three-dimensional representation into a fabrication specification; and
 - transmitting the fabrication specification to a dental fabrication facility.
59. The computer program product of claim 58, wherein a dentist specifies the cementation void.
60. The computer program product of claim 58, further comprising computer code that performs the step of receiving a specification of the cementation void from the dental fabrication facility.

61. The computer program product of claim 58 further comprising code for three-dimensionally printing the cementation void to a die.
62. The computer program product of claim 58 further comprising code for three-dimensionally printing the cementation void to a wax up.
63. The computer program product of claim 58, further comprising computer code that performs the step of integrating the cementation void into a digital surface representation of the tooth.
64. A system comprising:
a first means for three-dimensionally representing a tooth, the tooth prepared for a dental restoration;
a second means for specifying a cementation void, the cementation void representing an empty space between the tooth surface and the dental restoration; and
a fabrication means for fabricating the dental restoration such that the dental restoration, when mated to the tooth surface, defines an empty space corresponding to the cementation void.
65. The system of claim 64, further comprising an adjustment means for adjusting the cementation void.
66. The system of claim 65, wherein the adjustment means includes means for incorporating a dentist's preferences.
67. The system of claim 65, wherein the adjustment means includes means for adjusting the cementation void according to a type of cement.
68. The system of claim 64, further comprising a first printing means for three-dimensionally printing a die including the cementation void.
69. The system of claim 64, further comprising a second printing means for three-dimensionally printing a wax-up including the cementation void.
70. The system of claim 64, further comprising a milling means for milling a die including the cementation void.
71. The system of claim 64, further comprising a milling means for milling an investment chamber for casting including the cementation void.
72. The system of claim 64, further comprising a model means for integrating the cementation void into a model of a dental impression.
73. The system of claim 64, wherein the three-dimensional representation of a tooth includes a digital surface representation of the tooth.
74. A method comprising:
fabricating a dental object;
acquiring a first three-dimensional representation of the dental object; and
measuring a dimensional accuracy of the first three-dimensional representation.
75. The method of claim 74, wherein the first three-dimensional representation includes a digital surface representation.

76. The method of claim 74, wherein the dental object includes a dental prosthesis.
77. The method of claim 74, wherein the dental object includes a dental implant.
78. The method of claim 74, wherein the dental object includes a dental appliance.
79. The method of claim 74, wherein the dental object includes a restorative component.
80. The method of claim 74, wherein the dental object includes a dental restoration.
81. The method of claim 74, wherein the dental object includes an abutment.
82. The method of claim 74, further comprising acquiring a second three-dimensional representation of one or more teeth including at least one tooth surface prepared for the dental object, wherein measuring a dimensional accuracy includes evaluating a fit between the item of the first three-dimensional representation and the at least one tooth surface of the second three-dimensional representation.
83. The method of claim 74, further comprising acquiring a second three-dimensional representation of one or more teeth including at least one tooth surface prepared for the dental object, wherein measuring a dimensional accuracy includes evaluating one or more contact points between the item of the first three-dimensional representation and the one or more teeth of the second three-dimensional representation when the item is virtually affixed to the at least one tooth surface.
84. The method of claim 74, further comprising acquiring a second three-dimensional representation of one or more teeth including at least one tooth surface prepared for the dental object and at least one opposing tooth, wherein measuring a dimensional accuracy includes evaluating one or more contact points between the item of the first three-dimensional representation and the at least one opposing tooth of the second three-dimensional representation when the item is virtually affixed to the at least one tooth surface.
85. The method of claim 74 wherein the second three-dimensional representation is acquired as a plurality of separate scans.
86. The method of claim 74 wherein the second three-dimensional representation is acquired as a continuous scan of the at least one tooth surface and the at least one opposing tooth in occlusion.
87. The method of claim 74, wherein a dentist specifies tightness of fit of the dental object.
88. The method of claim 74, wherein measuring a dimensional accuracy includes quantifying tightness of fit of the dental object.
89. The method of claim 74, wherein measuring a dimensional accuracy includes measuring quality of a margin.
90. A computer program product comprising computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of:
 - acquiring one or more images of a dental object;
 - converting the one or more images of the dental object into a first three-dimensional representation of the item; and
 - measuring a dimensional accuracy of the first three-dimensional representation.

91. The computer program product of claim 90, wherein the first three-dimensional representation includes a digital surface representation.
92. The computer program product of claim 90, wherein the dental object includes a dental prosthesis.
93. The computer program product of claim 90, wherein the dental object includes a dental implant.
94. The computer program product of claim 90, wherein the dental object includes a dental appliance.
95. The computer program product of claim 90, wherein the dental object includes a restorative component.
96. The computer program product of claim 90, wherein the dental object includes an abutment.
97. The computer program product of claim 90, wherein the dental object includes a restoration.
98. The computer program product of claim 90, further comprising computer code that performs the steps of:
 acquiring one or more images of one or more teeth including at least one tooth surface prepared for the dental object; and
 converting the one or more images of the one or more teeth into a second three-dimensional representation of the one or more teeth, wherein measuring a dimensional accuracy includes evaluating a fit between the item of the first three-dimensional representation and the at least one tooth surface of the second three-dimensional representation.
99. The computer program product of claim 90, further comprising computer code that performs the steps of:
 acquiring one or more images of one or more teeth including at least one tooth surface prepared for the dental object;
 converting the one or more images of the one or more teeth into a second three-dimensional representation of the one or more teeth; and
 generating one or more contact points between the item of the first three-dimensional representation and the one or more teeth of the second three-dimensional representation by virtually affixing the item to the at least one tooth surface, wherein measuring includes evaluating one or more contact points.
100. The computer program product of claim 90, further comprising computer code that performs the steps of:
 acquiring one or more images of one or more teeth including at least one tooth surface prepared for the dental object and at least one opposing tooth;
 converting the one or more images of the one or more teeth and the at least one opposing tooth into a second three-dimensional representation of the one or more teeth and the at least one opposing tooth; and
 generating one or more contact points between the item of the first three-dimensional representation and the at least one opposing tooth of the second three-dimensional representation by virtually affixing the item to the at least one tooth surface, wherein measuring includes evaluating one or more contact points.

101. The computer program product of claim 90, wherein measuring a dimensional accuracy includes quantifying tightness of fit of the dental object.

102. The computer program product of claim 90, wherein measuring a dimensional accuracy includes measuring quality of a margin.

103. A system comprising:
a fabrication means for fabricating a dental object;
a first means for acquiring a first three-dimensional representation of the item; and
a measurement means for measuring a dimensional accuracy of the first three-dimensional representation.

104. The system of claim 103, wherein the first three-dimensional representation includes a digital surface representation.

105. The system of claim 103, wherein the dental object includes a dental prosthesis.

106. The system of claim 103, wherein the dental object includes a dental implant.

107. The system of claim 103, wherein the dental object includes a dental appliance.

108. The system of claim 103, wherein the dental object includes a restorative component.

109. The system of claim 103, wherein the dental object includes a dental restoration.

110. The system of claim 103, wherein the dental object includes an abutment.

111. The system of claim 103, further comprising a second means for acquiring a second three-dimensional representation of one or more teeth including at least one tooth surface prepared for the dental object, wherein measuring a dimensional accuracy includes evaluating a fit between the item of the first three-dimensional representation and the at least one tooth surface of the second three-dimensional representation.

112. The system of claim 103, further comprising a second means for acquiring a second three-dimensional representation of one or more teeth including at least one tooth surface prepared for the dental object, wherein measuring a dimensional accuracy includes evaluating one or more contact points between the item of the first three-dimensional representation and the one or more teeth of the second three-dimensional representation when the item is virtually affixed to the at least one tooth surface.

113. The system of claim 103, further comprising a second means for acquiring a second three-dimensional representation of one or more teeth including at least one tooth surface prepared for the dental object and at least one opposing tooth, wherein measuring a dimensional accuracy includes evaluating one or more contact points between the item of the first three-dimensional representation and the at least one opposing tooth of the second three-dimensional representation when the item is virtually affixed to the at least one tooth surface.

114. The system of claim 103, wherein a dentist specifies tightness of fit of the dental object.

115. The system of claim 103, wherein measuring a dimensional accuracy includes quantifying tightness of fit of the dental object.

116. The system of claim 103, wherein measuring a dimensional accuracy includes measuring quality of a margin.

117. A method comprising:
acquiring a three-dimensional representation including three-dimensional surface data for at least two independent dental structures; and
acquiring motion data characterizing a relative motion of the at least two independent dental structures with respect to one another within a mouth.

118. The method of claim 117, further comprising deriving TMJ condyle paths of rotation and translation from the motion data and the three-dimensional surface data.

119. The method of claim 117, further comprising providing input to a virtual dental articulator.

120. The method of claim 117, further comprising providing specifications for a physical dental articulator.

121. The method of claim 117, further comprising providing specifications for a disposable dental articulator.

122. The method of claim 117, wherein acquiring the three-dimensional representation includes acquiring the three-dimensional representation using an intraoral scanner.

123. The method of claim 117, wherein acquiring motion data includes acquiring motion data from a video source.

124. A computer program product comprising computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of:
acquiring one or more images of at least two independent dental structures of a dental patient from an intraoral scanner;
converting the one or more images into a three-dimensional representation of the at least two independent dental structures; and
acquiring motion data characterizing a relative motion of the at least two independent dental structures with respect to one another.

125. The computer program product of claim 124 further comprising code that performs the step of combining the three-dimensional representation with the motion data to derive TMJ condyle paths of rotation and translation.

126. The computer program product of claim 124, further comprising computer code that performs the steps of:
generating an image sequence of the combined three-dimensional representation and the motion data; and
generating a display signal of the image sequence.

127. The computer program product of claim 124, wherein acquiring motion data includes acquiring motion data from a video source.

128. A system comprising:
a first means for acquiring one or more images of at least two independent dental structures of a dental patient;

a conversion means for converting the one or more images into a three-dimensional representation of the at least two independent dental structures; and

a second means for acquiring motion data characterizing a relative motion of the at least two independent dental structures with respect to one another.

129. The system of claim 128, further comprising an analysis means for deriving TMJ condyle paths of rotation and translation using the three-dimensional representation and the motion data.

130. The system of claim 128, further comprising an action means for combining the three-dimensional representation and the motion data to generate an articulation input.

131. The system of claim 130, further comprising a first model means for virtually articulating the articulation input.

132. The system of claim 130, further comprising a second model means for physically articulating the articulation input.

133. The system of claim 130, further comprising a disposable model means for physically articulating the articulation input.

134. The system of claim 128, wherein the first means includes a means for acquiring the one or more images using an intraoral scanner.

135. The system of claim 128, wherein the second means includes a means for acquiring the motion data from a video source.

136. A method comprising:

receiving an electronic dental prescription including prescription data, a first three-dimensional representation of one or more intraoral structures including at least one tooth surface prepared for an artificial dental object, and a second three-dimensional representation of the at least one tooth surface prior to preparation for the artificial dental object; and

fabricating the artificial dental object for the one or more intraoral structures using the electronic dental prescription.

137. The method of claim 136, wherein an electronic dental prescription includes receiving a three-dimensional representation from a dental data hub.

138. The method of claim 136, wherein an electronic dental prescription includes receiving a three-dimensional representation from a dentist.

139. The method of claim 136, wherein the electronic dental prescription includes a prescription for a dental restoration for the tooth surface.

140. The method of claim 136, wherein at least one of the first and second three-dimensional representations includes a digital surface representation of a full arch.

141. The method of claim 136, wherein the electronic dental prescription includes a prescription for one or more of an appliance, a prosthesis, or an item of dental hardware.

142. The method of claim 136, wherein fabricating an artificial dental object includes fabricating a dental restoration in an in-house laboratory in a dentist's office.

143. A system comprising:
a communication means for receiving an electronic dental prescription including prescription data, a first three-dimensional representation of one or more intraoral structures including at least one tooth surface prepared for an artificial dental object, and a second three-dimensional representation of the at least one tooth surface prior to preparation for the artificial dental object; and
a fabrication means for fabricating an artificial dental object for the one or more intraoral structures using the three-dimensional representation.
144. The system of claim 143, wherein the communication means includes a means for receiving the electronic dental prescription from a dental data hub.
145. The system of claim 143, wherein the communication means includes a means for receiving the electronic dental prescription from a dentist.
146. The system of claim 143, wherein the electronic dental prescription includes a prescription for a dental restoration.
147. The system of claim 143, wherein the three-dimensional representation includes a digital surface representation of a full arch.
148. The system of claim 143, wherein the electronic dental prescription includes a prescription for one or more of an appliance, a prosthesis, and an item of dental hardware.
149. The system of claim 143, wherein the fabrication means includes an in-house laboratory in a dentist's office.
150. A method comprising, within a single dental visit, the steps of:
acquiring a three-dimensional representation of one or more intraoral structures from a dental patient, the intraoral structures including at least one tooth surface prepared for an artificial dental object; and
processing the three-dimensional representation to provide feedback to a dentist concerning the at least one tooth surface.
151. The method of claim 150, wherein the feedback identifies corrective action.
152. The method of claim 151, wherein the corrective action includes acquiring an additional three-dimensional representation of the one or more intraoral structures.
153. The method of claim 151, wherein the corrective action includes additional surface preparation of the at least one tooth.
154. The method of claim 150, wherein the feedback identifies a margin for fitting the dental restoration to the at least one tooth surface.
155. The method of claim 154, wherein the margin for fitting can be edited.
156. The method of claim 150, wherein the feedback includes a visual display of one or more regions of inadequate margin for fitting the dental restoration to the at least one tooth surface.

157. The method of claim 150, wherein the feedback includes a visual display recommending additional preparatory work required for the at least one tooth surface.

158. The method of claim 150, wherein the feedback includes a visual display recommending acquiring additional three-dimensional representations of one or more regions of the one or more intraoral structures.

159. The method of claim 150, wherein the feedback includes identifying an incomplete three-dimensional representation.

160. The method of claim 150, wherein the feedback includes identifying errors in the three-dimensional representation.

161. The method of claim 150, wherein the feedback includes visual highlighting of a margin line on a display of the three-dimensional representation.

162. A computer program product comprising computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of:
acquiring one or more images of one or more intraoral structures of a dental patient, the intraoral structures including at least one tooth surface prepared for an artificial dental object;
converting the one or more images into a three-dimensional representation of the one or more intraoral structures;
analyzing the at least one tooth surface within the three-dimensional representation;
generating a feedback signal, the feedback signal representative of the result of analyzing the at least one tooth surface; and
outputting the feedback signal to provide feedback to a dentist.

163. The computer program product of claim 162, wherein the feedback signal identifies corrective action.

164. The computer program product of claim 163, wherein the corrective action includes acquiring an additional one or more images of the one or more intraoral dental structures.

165. The computer program product of claim 163, wherein the corrective action includes additional surface preparation of the at least one tooth.

166. The computer program product of claim 162, wherein the feedback signal identifies a margin for fitting the dental restoration to the at least one tooth surface.

167. The computer program product of claim 162, wherein the margin for fitting can be edited.

168. A system comprising:
a scanning device configured to intraorally capture surface image data from a surface within a mouth of a dental patient, the scanning device adapted to provide real time feedback during a scan by superimposing surface image data onto a video image of the surface;
a computer coupled to the scanning device and receiving the surface image data therefrom, the computer configured to resolve the surface image data into a digital surface reconstruction, the computer further configured to generate a visualization of the digital surface reconstruction and provide the visualization as a display signal; and
a display coupled to the computer and receiving the display signal therefrom, the display converting the display signal into a viewable image of the visualization.

169. The system of claim 168, wherein the surface includes dentition.
170. The system of claim 168, further comprising a user interface controlled by the computer and rendered on the display, the user interface providing at least one tool for analyzing the surface.
171. The user interface of the system of claim 170, further comprising a tool that provides real time feedback to the user.
172. The user interface of the system of claim 171, wherein the real time feedback includes visual cues within the rendered image.
173. The system of claim 170, wherein the scanning device captures surface image data at a video frame rate.
174. The system of claim 170, wherein the at least one tool includes a distance measurement tool.
175. The system of claim 170, wherein the at least one tool includes a tool that evaluates adequacy of tooth structure removal from a dental restoration surface preparation.
176. The system of claim 170, wherein the at least one tool includes a tool that evaluates adequacy of margin preparations.
177. The system of claim 170, wherein the at least one tool includes a tool that evaluates taper.
178. The system of claim 170, wherein the at least one tool includes a tool that evaluates undercut.
179. The system of claim 170, wherein the at least one tool includes a tool that identifies scan deficiencies.
180. The system of claim 179, wherein the scan deficiencies include holes in the surface.
181. The system of claim 170, wherein the at least one tool includes a tool that evaluates adequacy of removal path in multiple unit preparation.
182. The system of claim 170, wherein the at least one tool includes a tool that identifies irregularities in one or more occlusal surfaces requiring further preparation.
183. The system of claim 170, wherein analyzing the surface includes an evaluation of suitability for three-dimensional printing.
184. The system of claim 170, wherein analyzing the surface includes an evaluation of suitability for milling.
185. The system of claim 170, wherein analyzing the surface includes an evaluation of suitability for manual fabrication.
186. The system of claim 168, wherein the computer is further configured to automatically annotate the visualization with a visual indication of an evaluation.

187. The system of claim 186, wherein the visual indication includes an evaluation of contour of a surface preparation.
188. The system of claim 186, wherein the surface image data includes at least two tooth surfaces in occlusion.
189. The system of claim 186, wherein the visual indication includes an evaluation of margin of a surface preparation.
190. The system of claim 186, wherein the visual indication includes an evaluation of occlusal clearance of a surface preparation.
191. The system of claim 186, wherein the surface includes at least one surface prepared for a dental prosthesis, the evaluation including an evaluation of an adequacy of the at least one surface for receiving the dental prosthesis.
192. The system of claim 186, wherein the visual indication includes display of a contour of an actual tooth and a computer-generated surface preparation.
193. The system of claim 192, wherein the computer-generated surface preparation is based upon intact configuration of the actual tooth prior to preparation.
194. A method comprising:
receiving a three-dimensional representation including three-dimensional surface data from an intraoral structure including at least one tooth having a tooth surface prepared for a dental restoration; and
presenting the three-dimensional representation in a user interface, the user interface including a first tool for identifying a margin line for the dental restoration on the at least one tooth and a second tool for recessing a region of the three-dimensional representation below the margin line.
195. The method of claim 194, wherein the first tool provides automated identification of the margin line.
196. The method of claim 194, further comprising removing a portion of the three-dimensional representation below the margin line with the second tool.
197. The method of claim 194, further comprising removing a portion of the three-dimensional representation below the margin line with the second tool to provide a virtual ditched die, and three-dimensionally printing the ditched die.
198. A system comprising:
a means for receiving a three-dimensional representation including three-dimensional surface data from an intraoral structure including at least one tooth having a tooth surface prepared for a dental restoration; and
a user interface means for presenting the three-dimensional representation to a user, the user interface means including a first tool means for identifying a margin line for the dental restoration on the at least one tooth and a second tool means for recessing a region of the three-dimensional representation below the margin line.
199. The system of claim 198, wherein the first tool means includes a means for providing automated identification of the margin line.

200. The system of claim 198, further comprising a means for removing a portion of the three-dimensional representation below the margin line.

201. The system of claim 198, further comprising a means for removing a portion of the three-dimensional representation below the margin line to provide a virtual ditched die, and a means for three-dimensionally printing the ditched die.

202. A method comprising:
acquiring a digital dental impression including three-dimensional surface data for at least two independent dental structures; and
acquiring orientation data defining a relative position of at least a portion of each of the at least two independent dental structures while in occlusion.

203. The method of claim 202, wherein the orientation data includes three-dimensional surface data that spans the at least two independent dental structures while in occlusion.

204. The method of claim 202, wherein the orientation data includes three-dimensional surface data from each of the at least two independent dental structures while in occlusion.

205. The method of claim 202, wherein the occlusion includes a centric occlusion.

206. The method of claim 202, further comprising applying the orientation data to position a virtual model of the at least two independent dental structures in a virtual articulator.

207. The method of claim 202, further comprising fabricating models of each of the at least two independent dental structures and applying the orientation data to position the models within a dental articulator.

208. The method of claim 202, wherein acquiring orientation data includes acquiring three-dimensional data of a buccal side of dentition.

209. The method of claim 202, wherein acquiring orientation data includes acquiring three-dimensional data of a labial side of dentition.

210. A system comprising:
a first acquisition means for acquiring a digital dental impression including three-dimensional surface data for at least two independent dental structures; and
a second acquisition means for acquiring orientation data defining a relative position of at least a portion of each of the at least two independent dental structures while in occlusion.

211. The system of claim 210, wherein the orientation data includes three-dimensional surface data that spans the at least two independent dental structures while in occlusion.

212. The system of claim 210, wherein the orientation data includes three-dimensional surface data from each of the at least two independent dental structures while in occlusion.

213. The system of claim 210, wherein the occlusion includes a centric occlusion.

214. The system of claim 210, further comprising a model means for virtually articulating the at least two independent dental structures.

215. The system of claim 210, further comprising:
a fabrication means for fabricating models of each of the at least two independent dental structures; and
a model means for physically articulating the fabricated models.
216. The system of claim 210, wherein the orientation data includes three-dimensional data of a buccal side of dentition.
217. The system of claim 210, wherein the orientation data includes three-dimensional data of a labial side of dentition.
218. A method comprising:
providing an intraoral three-dimensional scanning device; and
scanning a plurality of teeth in an arch with the device in a scan path that includes a motion that begins at a first lingual point, traverses laterally over a first occlusal point and a first buccal point, translates to a second buccal point adjacent to the first buccal point, and then traverses laterally over a second occlusal point adjacent to the first occlusal point and a second lingual point adjacent to the first lingual point.
219. The method of claim 218, further comprising scanning the plurality of teeth in the arch with the device using a motion that translates to a third lingual point, and then traverses laterally over a third occlusal point adjacent to the second occlusal point and a third buccal point adjacent to the second buccal point.
220. The method of claim 218, wherein the first lingual point and the second lingual point are spaced apart such that a field of view of the scanning device includes at least one overlapping portion of the plurality of teeth when the scanning device is positioned to image the first and second lingual points respectively.
221. The method of claim 218, wherein the scan path begins at a third buccal point.
222. The method of claim 218, wherein the scan path begins at a third palatal point.
223. The method of claim 218, wherein the scan path begins at a third labial point.
224. A method comprising, within a single dental visit, the steps of:
acquiring a three-dimensional representation of one or more intraoral structures including at least one tooth prepared for a dental restoration; and
processing the three-dimensional representation to provide feedback to a dentist concerning the at least one tooth.
225. The method of claim 224, wherein the feedback includes a physical dimension.
226. The method of claim 224, wherein the feedback includes a dimension of the at least one tooth prior to preparation for the dental restoration.
227. The method of claim 224, wherein the feedback includes a contour of the at least one tooth.
228. The method of claim 224, wherein the feedback includes a clearance relative to one or more adjacent teeth for a dental restoration associated with the at least one tooth.

229. The method of claim 224, wherein the feedback includes a clearance relative to one or more teeth in an opposing occluded arch.
230. The method of claim 224, wherein the feedback includes a position of the at least one tooth.
231. A computer program product comprising computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of:
acquiring a three-dimensional representation of one or more intraoral structures including at least one tooth prepared for a dental restoration;
analyzing the three-dimensional representation;
generating a feedback signal, the feedback signal representing the analysis of the three-dimensional representation; and
outputting the feedback signal to a dentist.
232. The computer program product of claim 231, wherein the feedback signal includes a physical dimension.
233. The computer program product of claim 231, wherein the feedback signal includes a dimension of the at least one tooth prior to preparation for the dental restoration.
234. The computer program product of claim 231, wherein the feedback signal includes a contour of the at least one tooth.
235. The computer program product of claim 231, wherein the feedback signal includes a clearance relative to one or more adjacent teeth for a dental restoration associated with the at least one tooth.
236. The computer program product of claim 231, wherein the feedback signal includes a clearance relative to one or more teeth of an opposing occluded arch.
237. The computer program product of claim 231, wherein the feedback signal includes a position of the at least one tooth.
238. A system comprising:
an acquisition means for acquiring a three-dimensional representation of one or more intraoral structures including at least one tooth prepared for a dental restoration;
an analysis means for analyzing the three-dimensional representation;
a means for generating a feedback signal, the feedback signal representing the analysis of the three-dimensional representation; and
a signal means for providing the feedback signal to a dentist.
239. The system of claim 238, wherein the feedback signal includes a physical dimension.
240. The system of claim 238, wherein the feedback signal includes a dimension of the at least one tooth prior to preparation for the dental restoration.
241. The system of claim 238, wherein the feedback signal includes a contour of the at least one tooth.
242. The system of claim 238, wherein the feedback signal includes a clearance relative to one or more adjacent teeth for a dental restoration associated with the at least one tooth.

243. The system of claim 238, wherein the feedback signal includes a clearance relative to one or more teeth in an opposing occluded arch.
244. The system of claim 238, wherein the feedback signal includes a position of the at least one tooth.
245. A method comprising:
acquiring a three-dimensional representation from a dental patient including a digital surface representation of one or more intraoral structures; and
providing a visual display of the three-dimensional representation in real time.
246. The method of claim 245, wherein the visual display of the three-dimensional representation is superimposed on a real time two-dimensional video image of the one or more intraoral structures.
247. The method of claim 245, wherein the one or more intraoral structures include at least one tooth.
248. The method of claim 245, wherein the one or more intraoral structures include at least one tooth surface prepared for a dental restoration.
249. The method of claim 245, wherein the one or more intraoral structures include at least one restored tooth.
250. The method of claim 245, wherein the one or more intraoral structures include at least one implant.
251. The method of claim 245, wherein one or more intraoral structures include at least one area of soft tissue.
252. The method of claim 245, further comprising processing the three-dimensional representation to generate user feedback concerning the one or more intraoral structures, and providing a visual display of the user feedback.
253. The method of claim 252 wherein the feedback includes highlighting areas in the three-dimensional representation requiring additional attention.
254. A computer program product comprising computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of:
acquiring one or more images of one or more intraoral structures;
processing the one or more images into a three-dimensional representation including a digital surface representation of the one or more intraoral structures; and
generating a first visual display signal of the three-dimensional representation in real time.
255. The computer program product of claim 254, further comprising computer code that performs the step of generating a second visual display signal wherein the three-dimensional representation is superimposed on a real time two-dimensional video image of the one or more intraoral structures.
256. The computer program product of claim 254, wherein the one or more intraoral structures include at least one tooth.
257. The computer program product of claim 254, wherein the one or more intraoral structures include at least one tooth surface prepared for a dental restoration.

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

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

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

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

- analyzing the three-dimensional representation;
- generating a feedback signal representative of the analysis of the three-dimensional representation; and
- generating a third visual display signal including the feedback signal.

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

263. A system comprising:

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

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

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

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

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

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

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

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

270. The system of claim 263, further comprising:

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

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

272. A handheld imaging device for a three-dimensional imaging system comprising:
an elongated body including a first end, a second end, and a central axis;
a video rate three-dimensional scanning device within the elongated body, the video rate three-dimensional scanning device having an optical axis for receiving images, the optical axis substantially perpendicular to the central axis at a position near the first end of the elongated body; and
the second end adapted for gripping by a human hand, and the second end including a user input responsive to user manipulation to generate control signals for transmission to a processor associated with the imaging system.

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

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

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

276. A handheld imaging device for a three-dimensional imaging system comprising:
an elongated body including a central axis, a first end, and a second end, the second end adapted for gripping by a human hand and a central axis;
a video rate three-dimensional scanning device within the elongated body, the video rate three-dimensional scanning device having an optical axis for receiving images, the optical axis substantially perpendicular to the central axis at a position near the first end of the elongated body; and
a physical offset shaped and sized to maintain a desired distance of the first end from an imaging subject along the optical axis.

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

278. A method comprising:
acquiring a three-dimensional representation from a dental patient including a digital surface representation of one or more intraoral structures, the intraoral structures including a dental arch;
processing the three-dimensional representation to provide a digital dental model including one or more alignment guides to aid in positioning an orthodontic fixture; and
fabricating a physical model from the digital dental model.

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

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

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

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

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

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

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

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

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

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

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

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

291. A method comprising:
acquiring a three-dimensional representation from a dental patient including a digital surface representation of one or more intraoral structures, the intraoral structures including a dental arch;
adding a plurality of virtual brackets to the three-dimensional representation to provide a bracket model;
processing the bracket model to generate a bracket guide model, the bracket guide model adapted to maintain a physical realization of the plurality of virtual brackets in a fixed orientation with respect to one another, the fixed orientation corresponding to a desired orientation of the physical realization on the dental arch;
fabricating a bracket guide from the bracket guide model; and
attaching the physical realization of the plurality of virtual brackets to the bracket guide model.

292. A computer program product comprising computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of:
acquiring one or more images of one or more intraoral structures, the intraoral structures including a dental arch;
processing the one or more images into a three-dimensional representation of the one or more intraoral structures;
transforming the three-dimensional representation into a digital dental model, the digital dental model including one or more orthodontic fixture alignment guides; and
generating a virtual orthodontic fixture using the alignment guides.

293. The computer program product of claim 292, further comprising computer code that performs the step of constructing a support for the virtual orthodontic fixture on the digital dental model.
294. The computer program product of claim 292, wherein the alignment guides include visual markings.
295. The computer program product of claim 292, wherein the alignment guides include at least one substantially horizontal shelf for the virtual orthodontic fixture.
296. The computer program product of claim 292, wherein transforming includes virtually placing a plurality of orthodontic brackets onto the dental arch of the three-dimensional representation, and adding a plurality of bracket supports to the digital dental model.
297. The computer program product of claim 292, further comprising computer code that performs the step of transmitting the digital dental model to a remote dental laboratory.
298. A system comprising:
an acquisition means for acquiring a three-dimensional representation from a dental patient including a digital surface representation of one or more intraoral structures, the intraoral structures including a dental arch;
a processing means for processing the three-dimensional representation to provide a digital dental model including one or more alignment guides to aid in positioning an orthodontic fixture; and
a first fabrication means for fabricating a physical model from the digital dental model.
299. The system of claim 298, further comprising a means for constructing the orthodontic fixture on the physical model using the alignment guides.
300. The system of claim 298, wherein the processing means includes a means for constructing a support for the orthodontic fixture on the digital dental model.
301. The system of claim 298, wherein the alignment guides include visual markings.
302. The system of claim 298, wherein the alignment guides include at least one substantially horizontal shelf for the orthodontic fixture.
303. The system of claim 298, wherein the processing means includes a means for virtually placing a plurality of orthodontic brackets onto the three-dimensional representation, and adding a plurality of bracket supports to the digital dental model to support a physical realization of the plurality of orthodontic brackets on the physical model.
304. The system of claim 303, further comprising a second fabrication means for fabricating the physical realization of the plurality of orthodontic brackets, a positioning means for positioning each one of the plurality of orthodontic brackets onto the physical model, and a forming means for vacuum forming an appliance over the plurality of orthodontic brackets, the appliance maintaining the plurality of orthodontic brackets in fixed relation to one another.
305. The system of claim 304, further comprising a means for applying the appliance with the plurality of orthodontic brackets to the dental arch.
306. The system of claim 304, wherein the appliance is formed of a soft, clear material.

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

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

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

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

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

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

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

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

315. A system comprising:
a scanning device configured to intraorally capture surface image data from a surface within a mouth of a dental patient;
a computer coupled to the scanning device and receiving the surface image data therefrom, the computer configured to resolve the surface image data into a three-dimensional representation, the computer further configured to generate a visualization of the three-dimensional representation and to provide the visualization as a display signal; and
a display coupled to the computer and receiving the display signal therefrom, the display converting the display signal into a viewable image, the display being a touch-screen display adapted to receive a user input through direct contact with a surface of the display, wherein the user input is interpreted by the computer to affect manipulation of the three-dimensional representation.

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

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

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

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

320. The system of claim 317, wherein the user controls include case management controls.
321. The system of claim 320, wherein the case management controls include a control to transmit the three-dimensional representation to a dental lab.
322. The system of claim 320, wherein the case management controls include a control to evaluate quality of the three-dimensional representation.
323. The system of claim 320, wherein the case management controls include a tool to edit the three-dimensional representation.
324. The system of claim 320, wherein the case management controls include a control to create a dental prescription.
325. The system of claim 317, wherein the user controls include a control to define a cementation void.
326. The system of claim 317, wherein the user controls include a control to define a margin line.
327. The system of claim 317, wherein the user controls include a control to infer a margin line from the three-dimensional representation.
328. The system of claim 317, wherein the user controls include a control to recess a region of the three-dimensional representation below a margin line
329. The system of claim 317, wherein the user controls include a control to virtually fit a dental restoration to a prepared tooth surface.
330. The system of claim 317, wherein the user controls include a virtual dental articulator.
331. The system of claim 317, wherein the user controls include a tool to design a dental restoration fitted to the surface within the mouth of the dental patient.
332. The system of claim 315, wherein the three-dimensional model includes two arches; the display including an area for one or more user controls accessible through the touch-screen display to permit positioning the two arches within a virtual articulator.
333. The system of claim 315, further comprising a user interface displayed on the display and controlled by the computer.
334. The system of claim 333, wherein the user interface is accessible through the touch-screen.
335. A system comprising:
a digital dental impression including three-dimensional digital surface data for one or more intraoral structures, the digital dental impression captured using a three-dimensional intraoral scanning device and stored in a computer readable medium;
a first computer configured to render the digital dental impression from a point of view; and
a second computer at a remote location configured to simultaneously render the digital dental impression from the point of view.

336. The system of claim 335, further including a control for passing control of the point of view between the first computer and the second computer.
337. The system of claim 335, further including the first computer and the second computer including a collaborative tool for manipulating the model.
338. The system of claim 335, further including the first computer and the second computer including a collaborative tool for sectioning the model.
339. The system of claim 335, further including the first computer and the second computer including a collaborative tool for rearranging one or more sections of the model.
340. The system of claim 335, further including the first computer and the second computer including a collaborative cursor control tool.
341. The system of claim 335, further including the first computer and the second computer connected by a communication channel.
342. The system of claim 341, wherein the communication channel includes one or more of VoIP, IRC, video conferencing, or instant messaging.
343. The system of claim 335, wherein the second computer is operated by a consulting dentist.
344. The system of claim 335, wherein the second computer is operated by a dental technician.
345. The system of claim 335, wherein the second computer is operated in a dental laboratory.
346. The system of claim 335, wherein the second computer is operated by an oral surgeon.
347. The system of claim 335, wherein the second computer is operated by a dental specialist including one or more of a periodontist, a prosthodontist, a pedodontist, an orthodontic specialist, an oral and maxillofacial surgery specialist, an oral and maxillofacial radiology specialist, an endodontist, and an oral and maxillofacial pathologist.
348. A method comprising:
seating a dental patient in a clinical office;
acquiring a digital dental impression including three-dimensional digital surface data for one or more intraoral structures from an intraoral scan of the dental patient;
transmitting the digital dental impression to a dental laboratory before the patient leaves the office;
receiving an evaluation of the digital dental impression from the dental laboratory before the patient leaves the office; and
if the evaluation is unfavorable, repeating the step of acquiring the digital dental impression.
349. The method of claim 348, wherein the evaluation includes an identification of at least one region of the one or more intraoral structures requiring additional preparation, the method including preparing the one or more intraoral structures according to the evaluation.
350. The method of claim 348, wherein the evaluation includes an evaluation of surface continuity.
351. The method of claim 348, wherein the evaluation includes an evaluation of data density.

352. The method of claim 348, wherein the evaluation includes an evaluation of feature detail.
353. The method of claim 348, wherein one or more intraoral structures includes a tooth surface prepared for a dental restoration.
354. The method of claim 353, wherein the digital dental impression includes a case plan for the restoration.
355. The method of claim 354, wherein the case plan includes a type of restoration.
356. The method of claim 354, wherein the case plan includes a design of restoration.
357. The method of claim 354, wherein the case plan includes a list of restoration components.
358. The method of claim 357, wherein the list of restoration components includes a full ceramic component.
359. The method of claim 357, wherein the list of restoration components includes a PFM component.
360. The method of claim 354, wherein the case plan includes a specification of one or more restoration materials.
361. The method of claim 348 wherein the evaluation includes an evaluation of a margin around a tooth prepared for a restoration.
362. A system comprising:
a means for acquiring a digital dental impression, the digital dental impression including three-dimensional digital surface data for one or more intraoral structures from an intraoral scan of a dental patient seated in a clinical office;
a request means for transmitting the digital dental impression to a dental laboratory before the patient leaves the office;
an evaluation means for determining if the digital dental impression must be reacquired before the patient leaves the office; and
a response means for transmitting the determination to the clinical office.
363. The system of claim 362, wherein the evaluation means includes a means for evaluating surface continuity.
364. The system of claim 362, wherein the evaluation means includes a means for evaluating data density.
365. The system of claim 362, wherein the evaluation means includes a means for evaluating feature detail.
366. The system of claim 362, wherein one or more intraoral structures includes a tooth surface prepared for a dental restoration.
367. The system of claim 366, wherein the digital dental impression includes a case plan for the restoration.

368. The system of claim 367, wherein the case plan includes a type of restoration.
369. The system of claim 367, wherein the case plan includes a design of restoration.
370. The system of claim 367, wherein the case plan includes a list of restoration components.
371. The system of claim 370, wherein the list of restoration components includes a full ceramic component.
372. The system of claim 370, wherein the list of restoration components includes a PFM component.
373. The system of claim 367, wherein the case plan includes a specification of one or more restoration materials.
374. A system comprising:
a scanning device for real time capture of three-dimensional surface data;
a monitor that renders the three-dimensional surface data in real time;
a processor configured to evaluate quality of the three-dimensional surface data, and to generate a signal representative of a data quality during a scan; and
a feedback device responsive to the signal to produce a user alert concerning the data quality when the data quality degrades below a predetermined threshold.
375. The system of claim 374, wherein the scanning device resolves the three-dimensional surface data from a plurality of two-dimensional image sets, and wherein the evaluation of quality includes evaluation of ability to determine spatial relationships from the plurality of two-dimensional image sets.
376. The system of claim 374, wherein the evaluation of quality includes evaluation of point cloud density.
377. The system of claim 374, wherein the evaluation of quality includes evaluation of scanning device motion.
378. The system of claim 374, wherein the feedback device includes an LED.
379. The system of claim 374, wherein the feedback device includes a speaker.
380. The system of claim 374, wherein the feedback device includes a buzzer.
381. The system of claim 374, wherein the feedback device includes a vibrator.
382. The system of claim 374, wherein the scanning device includes a wand, the feedback device positioned on the wand.
383. The system of claim 374, wherein the feedback device is further responsive to the signal to produce a second user alert when the data quality is within an acceptable range.
384. A method comprising:
scheduling a preparation visit for a dental restoration for a patient;
obtaining a digital surface representation of one or more intraoral structures of the patient, including at least one tooth associated with the dental restoration; and
fabricating a temporary restoration based upon the digital surface representation.

385. The method of claim 384, wherein fabricating a temporary restoration includes transmitting the digital surface representation to a dental laboratory.
386. The method of claim 384, wherein fabricating a temporary restoration includes applying the digital surface representation to prepare a design for the temporary restoration and transmitting the design to a dental laboratory.
387. The method of claim 384, further including three-dimensionally printing the temporary restoration.
388. The method of claim 384, further including three-dimensionally printing the temporary restoration at a dentist's office where the preparation visit is scheduled.
389. The method of claim 384, further including milling the temporary restoration.
390. The method of claim 384, further including milling the temporary restoration at a dental office where the preparation visit is scheduled.
391. The method of claim 384, wherein obtaining a digital surface representation includes three-dimensionally scanning the one or more intraoral structures on a day of the preparation visit.
392. The method of claim 384, wherein obtaining a digital surface representation includes retrieving the digital surface representation from prior dental data for the patient.
393. The method of claim 384, wherein fabricating the temporary restoration includes fabricating the temporary restoration prior to the preparation visit, the temporary restoration including one or more characteristics of the at least one tooth.
394. The method of claim 393, further comprising, on the day of the preparation visit adapting a surface of the at least one tooth to receive the temporary restoration.
395. The method of claim 393, further comprising, on the day of the preparation visit, adapting the temporary restoration to fit a prepared surface of the at least one tooth.
396. The method of claim 384, wherein the step of fabricating is performed at an in-house dental laboratory at a dentist's office.
397. A method comprising:
acquiring a digital dental impression including three-dimensional digital surface data for one or more intraoral structures, the intraoral structures including at least one tooth surface prepared for an artificial dental object; and
acquiring additional three-dimensional data with greater spatial resolution around the at least one tooth surface prepared for the artificial dental object.
398. The method of claim 397, wherein acquiring additional three-dimensional data includes acquiring additional data from the at least one tooth surface.
399. The method of claim 397, wherein acquiring additional three-dimensional data includes post-processing source data for the digital dental impression.

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

401. A computer program product comprising computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of:
acquiring one or more images of one or more intraoral structures, the intraoral structures including at least one tooth surface prepared for an artificial dental object; and
generating a digital dental impression including three-dimensional digital surface data from the one or more images.

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

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

404. A system comprising:
a first means for acquiring a digital dental impression including three-dimensional digital surface data for one or more intraoral structures, the intraoral structures including at least one tooth surface prepared for an artificial dental object; and
a second means for acquiring additional three-dimensional data with greater spatial resolution around the at least one tooth surface prepared for the artificial dental object.

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

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

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

408. A method comprising:
acquiring a digital surface representation for one or more intraoral structures, the intraoral structures including at least one tooth surface prepared for a dental prosthesis;
fabricating a kit from the digital surface representation, the kit including two or more components suitable for use in fabrication of the dental prosthesis; and
sending the kit to a dental laboratory for fabrication of the dental prosthesis.

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

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

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

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

413. An artificial dental object including an exposed surface, the exposed surface having a texture integrated therein adapted to enhance acquisition of three dimensional image data from the exposed surface with a multi-aperture three-dimensional scanning device.
414. The artificial dental object of claim 413 wherein the texture includes pseudo-random three-dimensional noise.
415. The artificial dental object of claim 413 wherein the artificial dental object includes an impression coping.
416. The artificial dental object of claim 413 wherein the artificial dental object includes a fixture.
417. The artificial dental object of claim 413 wherein the artificial dental object includes a healing abutment.
418. The artificial dental object of claim 413 wherein the artificial dental object includes a temporary impression coping.
419. The artificial dental object of claim 413 wherein the artificial dental object includes a dental prosthesis.
420. The artificial dental object of claim 413 wherein the artificial dental object includes a dental appliance.
421. The artificial dental object of claim 413 wherein the artificial dental object includes an item of dental hardware.
422. The artificial dental object of claim 413 wherein the artificial dental object includes a dental restoration.
423. A method comprising:
acquiring a three-dimensional representation of one or more intraoral structures, the intraoral structures including at least one intraoral surface suitable for an artificial dental object;
transmitting the three-dimensional representation to a dental insurer; and
receiving authorization from the dental insurer to perform a dental procedure including the artificial dental object.
424. The method of claim 423, wherein the artificial dental object includes one or more of an implant, a crown, an impression coping, a bridge, a fixture, and an abutment.
425. The method of claim 423, wherein the intraoral surface includes at least one edentulous space.
426. The method of claim 423, wherein the intraoral surface includes at least one tooth surface.
427. A computer program product comprising computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of:
acquiring a three-dimensional representation of one or more intraoral structures, the intraoral structures including at least one intraoral surface suitable for an artificial dental object;
transmitting the three-dimensional representation to a dental insurer; and

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

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

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

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

431. A system comprising:
a means for acquiring a three-dimensional representation of one or more intraoral structures, the intraoral structures including at least one intraoral surface suitable for an artificial dental object;
a first communication means for transmitting the three-dimensional representation to a dental insurer; and
a second communication means for receiving authorization from the dental insurer to perform a dental procedure including the artificial dental object.

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

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

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

435. A method comprising:
acquiring a three-dimensional representation of one or more intraoral structures, the intraoral structures including at least one intraoral surface related to a dental procedure; and
transmitting the three-dimensional representation to a dental insurer as a record of the dental procedure.

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

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

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

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

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

441. A computer program product comprising computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of:
acquiring a three-dimensional representation of one or more intraoral structures, the intraoral structures including at one intraoral surface related to a dental procedure; and
transmitting the three-dimensional representation to a dental insurer as a record of the dental procedure.

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

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

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

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

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

447. A system comprising:
a means for acquiring a three-dimensional representation of one or more intraoral structures, the intraoral structures including at least one intraoral surface related to a dental procedure; and
a communication means for transmitting the three-dimensional representation to a dental insurer as a record of the dental procedure.

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

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

450. A method comprising:
receiving a three-dimensional representation of one or more intraoral structures from a dentist;
receiving a proposed dental procedure from the dentist;
determining whether the proposed dental procedure is appropriate for the one or more intraoral structures; and
transmitting a reply to the dentist.

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

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

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

454. A computer program product comprising computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of:
receiving a three-dimensional representation of one or more intraoral structures from a dentist;
receiving a proposed dental procedure from the dentist;
comparing the proposed dental procedure to a predetermined list of appropriate procedures for the one or more intraoral structures; and
transmitting a reply to the dentist.

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

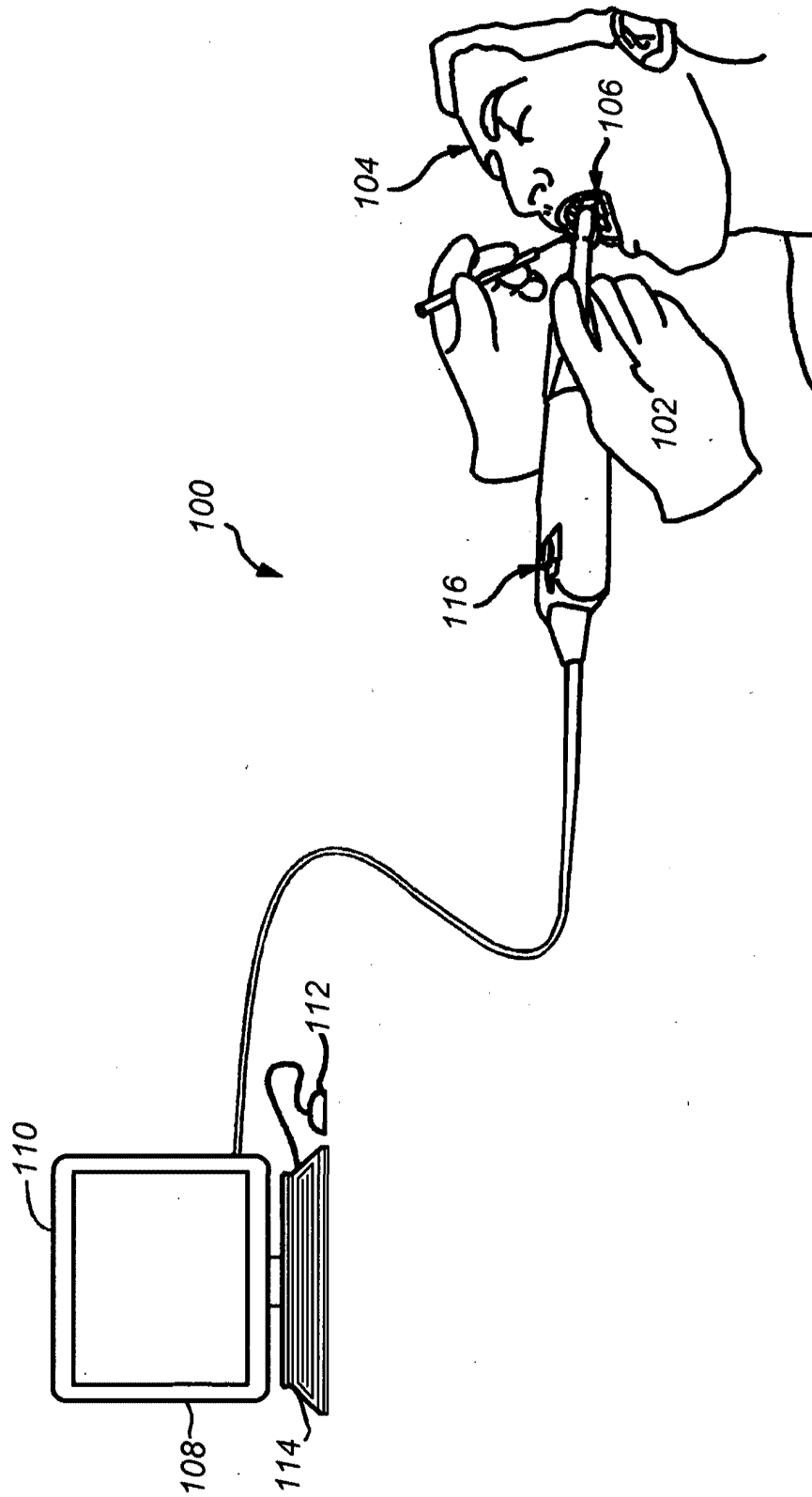
456. The computer program product of claim 454, wherein the reply includes a denial to perform the dental procedure.
457. The computer program product of claim 454, further comprising computer code that performs the step of authorizing payment for the dental procedure.
458. A system comprising:
a first means for receiving a three-dimensional representation of one or more intraoral structures from a dentist;
a second means for receiving a proposed dental procedure from the dentist;
an evaluation means for determining whether the proposed dental procedure is appropriate for the one or more intraoral structures; and
a reply means for transmitting a reply to the dentist.
459. The system of claim 458, wherein the reply includes an approval to perform the dental procedure.
460. The system of claim 458, wherein the reply includes a denial to perform the dental procedure.
461. The system of claim 458, further comprising a means for authorizing payment for the dental procedure.
462. A system comprising:
a dental data repository coupled to a communications network, the dental data repository adapted to receive dental data including three-dimensional representations of intraoral structures and prescriptions for dental procedures from a plurality of dentists.
463. The system of claim 462, wherein the dental data repository is adapted to transmit prescriptions and three-dimensional representations to a plurality of dental laboratories.
464. The system of claim 463, wherein at least one of the prescriptions identifies a specific one of the plurality of dental laboratories.
465. The system of claim 462, wherein the dental data repository is further adapted to communicate with one or more dental insurers for authorization of dental procedures.
466. The system of claim 462, wherein the dental data repository is further adapted to communicate with one or more dental insurers to coordinate payment for dental procedures.
467. The system of claim 462, further comprising a dental laboratory interface for the plurality of dental laboratories to provide status on work in progress.
468. The system of claim 462, further comprising a dental laboratory interface for the plurality of dental laboratories to receive work assignments.
469. The system of claim 462, further comprising a dentist interface for the plurality of dentists to monitor work in progress.
470. The system of claim 462, further comprising a dentist interface for the plurality of dentists to submit prescriptions and three-dimensional representations.

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

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

ABSTRACT

[00224] The systems and methods disclosed herein employ a scanning system for capturing highly detailed digital dental models. These models may be used within a dentist's office for a wide array of dental functions including quality control, restoration design, and fitting. These models may also, or instead, be transmitted to dental laboratories that may, alone or in collaboration with the originating dentist or other dental professionals, transform the digital model into a physical realization of a dental hardware item.



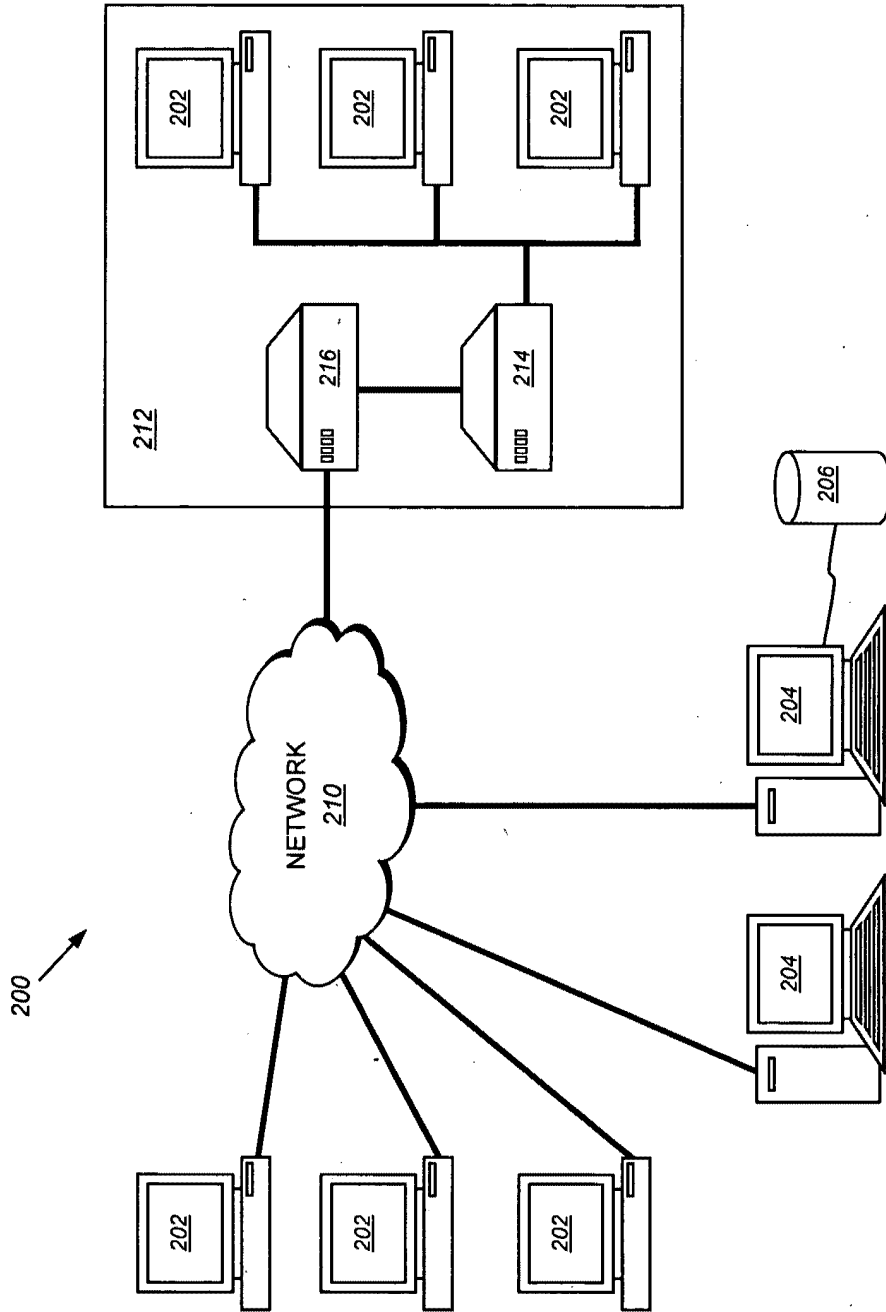


Fig. 2

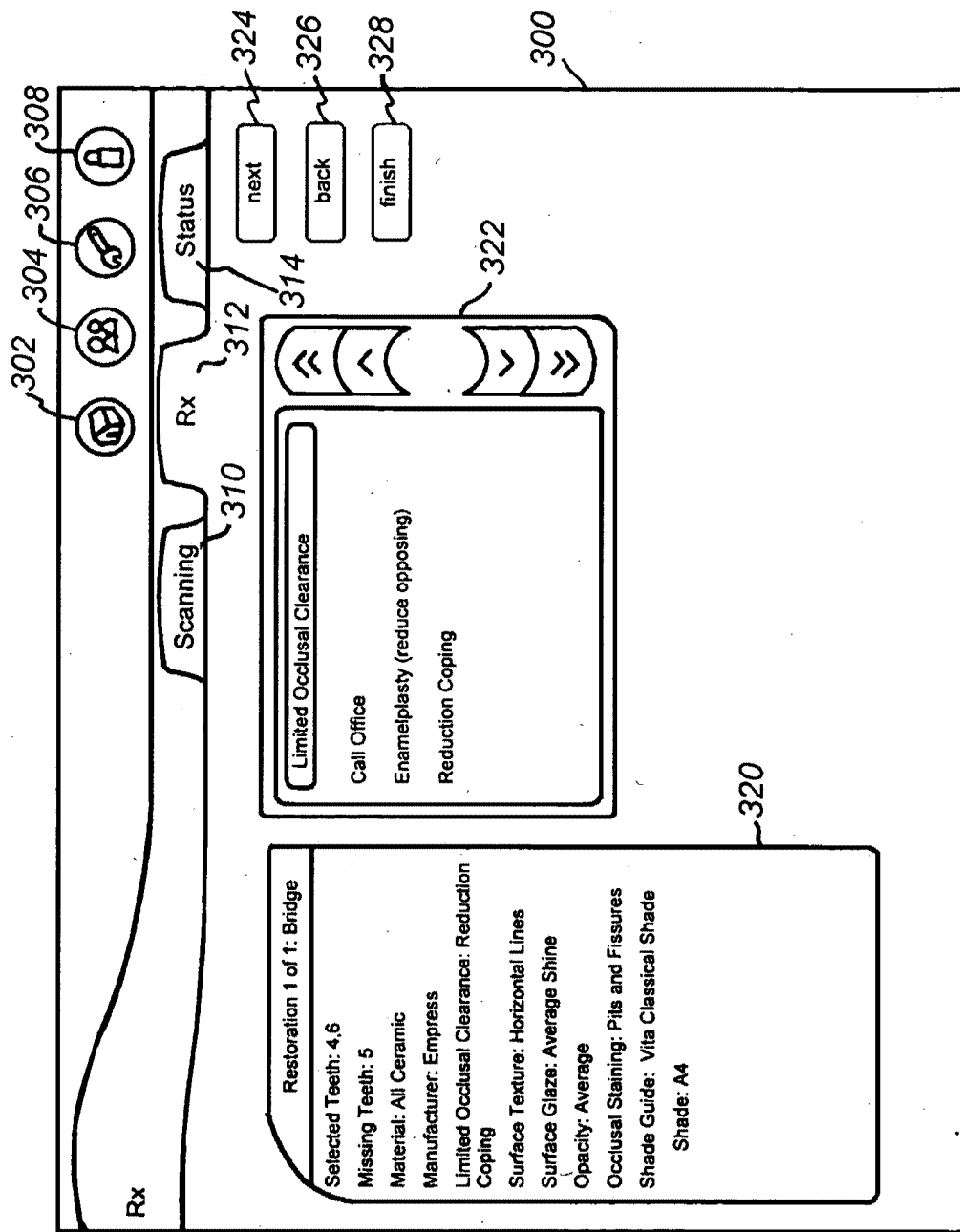


Fig. 3

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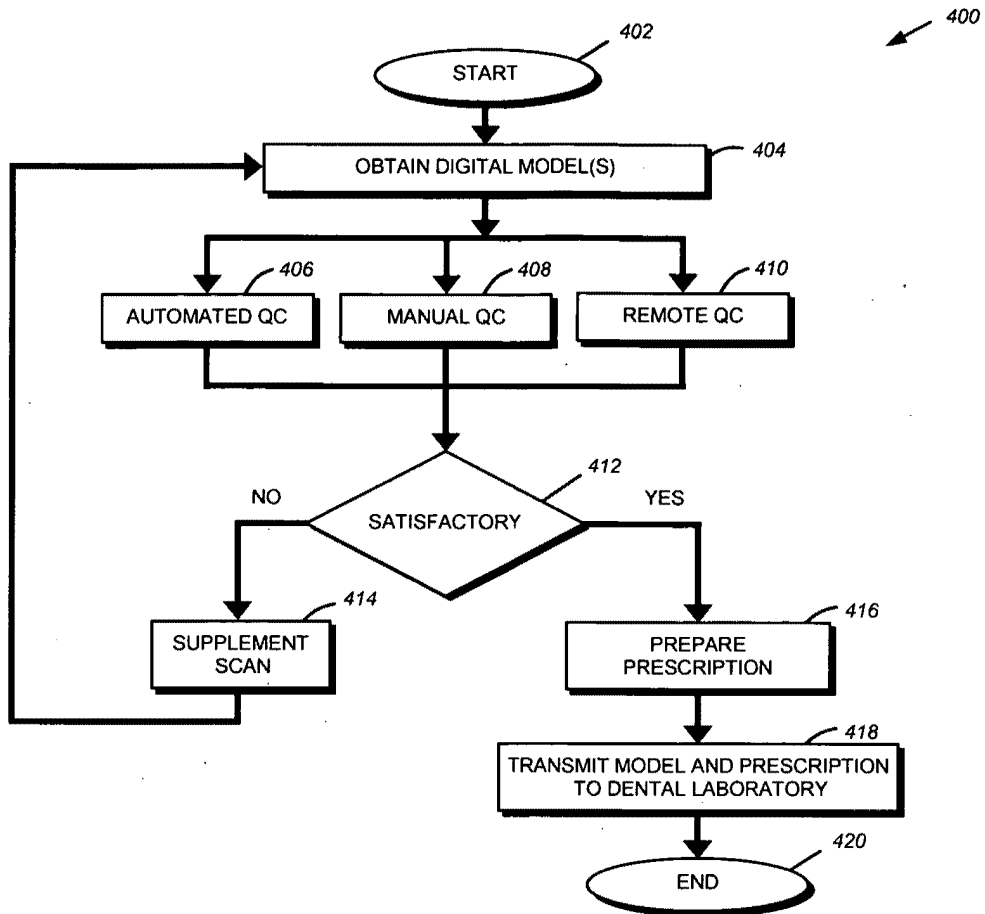


Fig. 4

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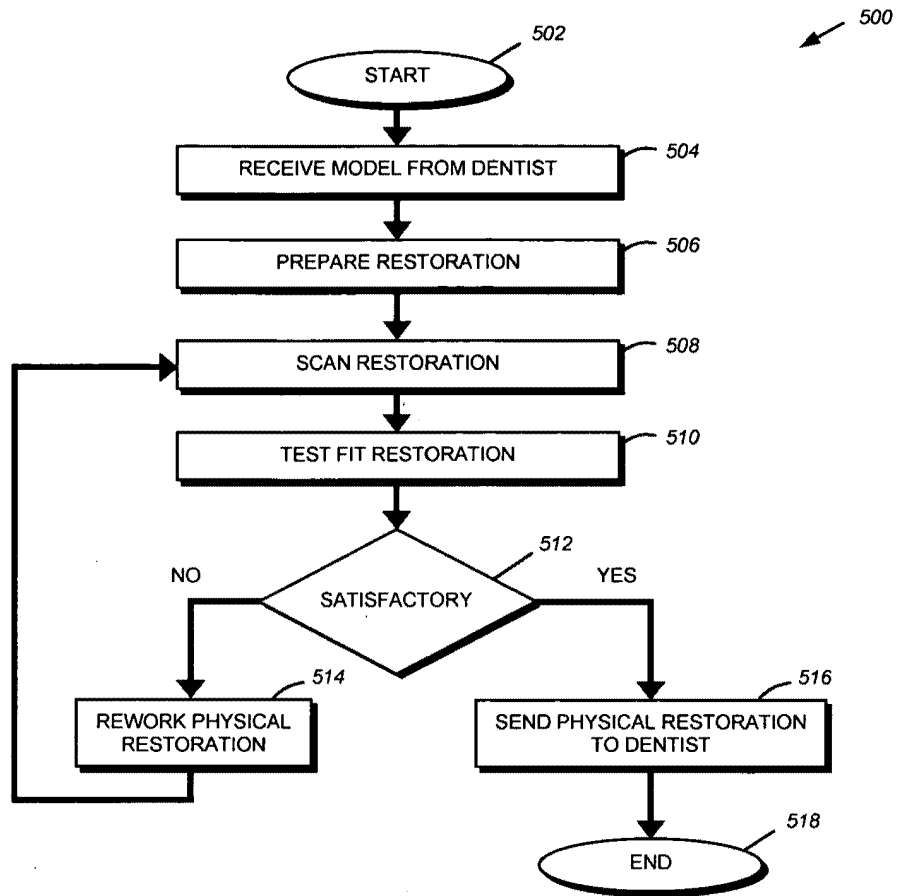
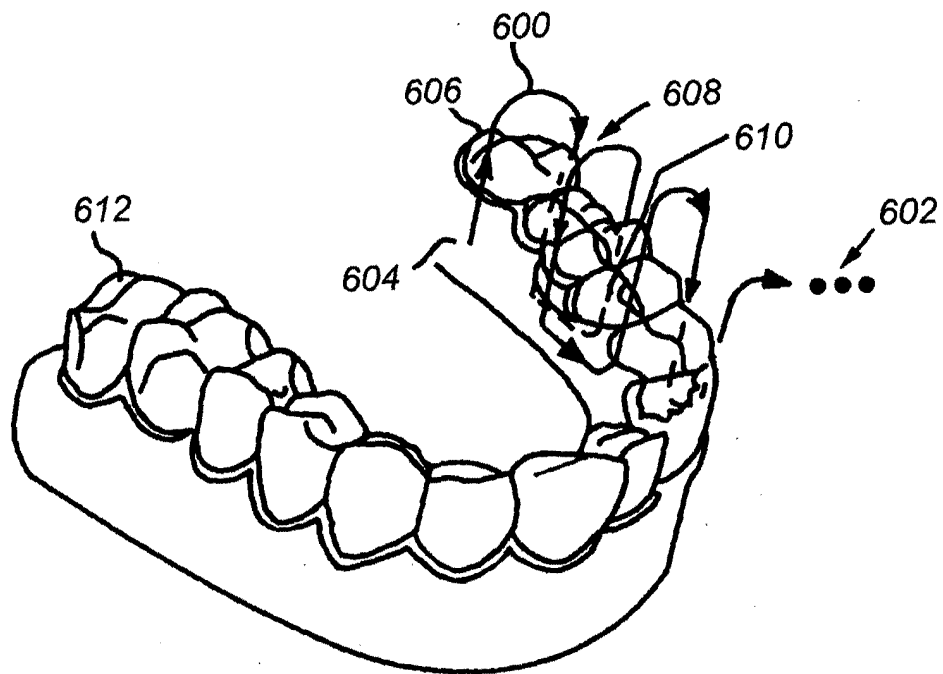


Fig. 5

**Fig. 6**

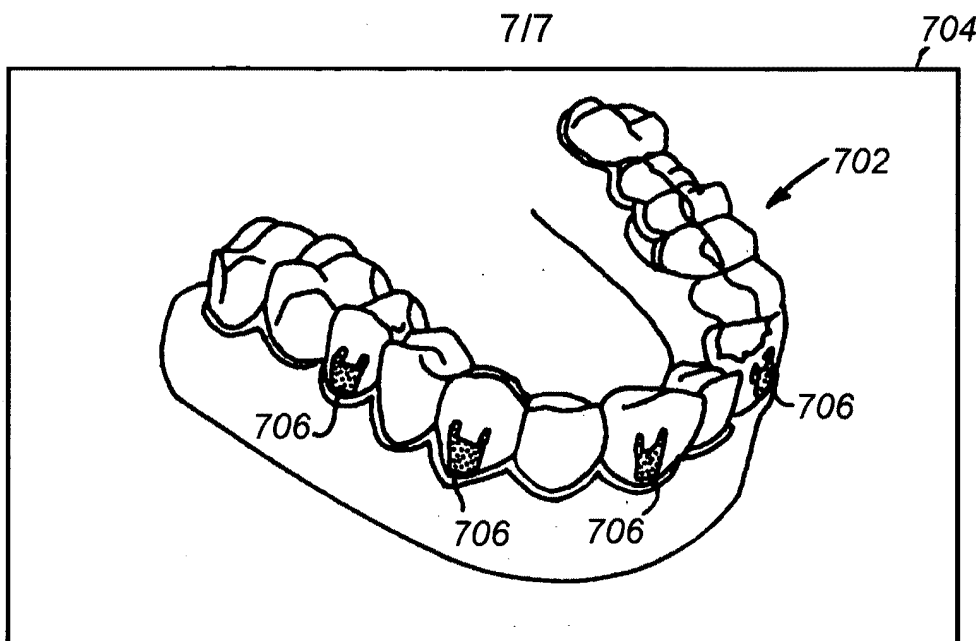


Fig. 7A

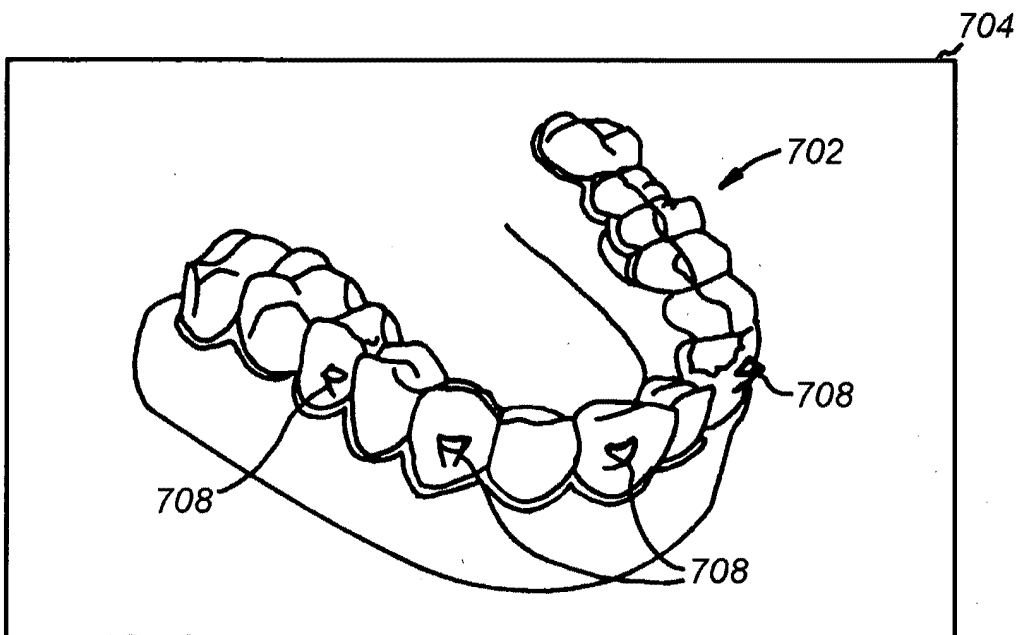


Fig. 7B

VISUALIZATION FOR THREE-DIMENSIONAL DATA ACQUISITION

BACKGROUND

1. Field of the Invention.

[0001] The invention relates to three-dimensional data acquisition and more particularly to visualization techniques to aid in capture and refinement of three-dimensional data.

2. Description of the Related Art.

[0002] A wide range of techniques exist for acquiring three-dimensional data from a subject. These techniques range from active techniques that actively control an imaging stimulus such as structured laser illumination, x-rays, ultrasound, or magnetic resonance) to passive techniques that operate directly on video data captured from one or more cameras. One broad category of techniques employs continuous scanning in which incremental three-dimensional data is acquired and assembled into a full three-dimensional model.

[0003] In this latter category, regardless of the particular sensing technology, a scanning process can be divided into abstract steps of incremental data capture, incremental derivation of three-dimensional data, and registration of the incremental data to a common coordinate system. The final registration step brings the incremental data together into a single three-dimensional model of a scan subject.

[0004] Current techniques generally separate acquisition from registration, with registration being performed in a post-processing step separate from data acquisition. While this permits relatively exhaustive processing, it poses a significant disadvantage because accuracy and completeness of the overall scan cannot be evaluated until after the scan has been completed. Unrecoverable errors or gaps in incremental data cannot be identified and fixed without initiating a new scan, possibly a full scan to completely replace the defective results. In commercial applications, where scheduling a common time and location for a scan subject and scanning hardware may pose logistical difficulties, this may increase the effective cost of scanning and inconvenience any parties involved.

[0005] In certain instances, this difficulty may be addressed by using robotics, independent references, or other techniques to determining the position of a scanning device within a global coordinate system. In addition to imposing further equipment costs, this approach can only be used to continue a previous scan if the subject of the scan has retained its position and orientation within the same global coordinate system.

[0006] There remains a need for real time visual feedback systems to support continuous three-dimensional scanning. There also remains a need for improved guidance and visual feedback systems for use with particular three-dimensional imaging applications, such as digital dentistry.

SUMMARY

[0007] The systems and methods disclosed herein employ a variety of visual feedback mechanisms to assist in acquisition and analysis of three-dimensional data. Some of these improvements are directed at guiding a user in a successful acquisition of a three-dimensional representation of a subject. Other improvements are directed toward rendering the three-dimensional representation with annotations or other visual cues to assist a user in understanding and analyzing the scanned subject matter. In a dental context, for example, highly detailed, accurate scans may be obtained and various analyses such as adequacy of a tooth surface preparation or suitability of a fabricated prosthetic for a particular patient may be performed in a virtual environment.

[0008] In one aspect, a method disclosed herein may include providing a dental model in digital form, the dental model may include a three-dimensional representation of one or more tooth surfaces of a first dental arch, the one or more tooth surfaces of the first dental arch may include a tooth prepared for a crown, and a three-dimensional representation of one or more tooth surfaces of a second dental arch, wherein the first dental arch and the second dental arch are in occlusion. The method may further include identifying one or more regions of the dental model requiring surface preparation to accommodate the crown, and displaying the dental model with a visual cue for the one or more regions.

[0009] In the method, the one or more regions may include a region of inadequate clearance for the crown, a region of inadequate surface preparation, or a region on a tooth that opposes the tooth prepared for the crown. The one or more regions may include a path of draw for the crown. The path of draw may include a suggested clearance from one or more adjacent teeth, a suggested shape of the tooth prepared for the crown, or a suggested size of the tooth prepared for the crown. The visual cue may include display of the path of draw superimposed on the dental model, display of the one or more regions in a different color than other regions of the dental model, display of the one or more regions with a different opacity than other regions of the dental model, or display of the one or more regions with a different level of detail than other regions of the dental model. The visual cue may include display of the one or more regions with a different surface treatment than other regions of the dental model, display of a trace around at least some portion of the one or more regions, display of an arrow pointing toward at least one of the one or more regions, or display of a callout associated with the one or more regions.

[0010] In another aspect, a computer program product herein disclosed may include processing a dental model in digital form, the dental model may include a three-dimensional representation of one or more tooth surfaces of a first dental arch, the one or more tooth surfaces of the first dental arch may include a tooth prepared for a crown, and a three-dimensional representation of one or more tooth surfaces of a second dental arch, wherein the first dental arch and the second dental arch are in occlusion. The computer program product may further include identifying one or more regions of the dental model requiring tooth removal to accommodate the crown, and rendering an image of the dental model with a visual cue for the one or more regions, the image being suitable for output to a display.

[0011] In the computer program product, the one or more regions may include a region of inadequate clearance for the crown, a region of inadequate surface preparation, a region on a tooth that opposes the tooth prepared for the crown, or a path of draw for the crown. The path of draw may include a suggested clearance from one or more adjacent teeth, a suggested shape of the tooth prepared for the crown, or a suggested size of the tooth prepared for the crown. The visual cue may include the path of draw, rendering the one or more regions in a different color than other regions of the dental model, or rendering the one or more regions with a different opacity than other regions of the dental model. The visual cue may further include rendering the one or more regions with a different level of detail than other regions of the dental model, or rendering the one or more regions with a different surface treatment than other regions of the dental model. The visual cue may include a trace around at least some portion of the one or more regions, an arrow pointing toward at least one of the one or more regions, or a callout associated with the one or more regions.

[0012] In another aspect, a system herein disclosed may include a model means for providing a dental model in digital form, the dental model may include a three-dimensional representation of one or more tooth surfaces of a first dental arch, the one or more tooth surfaces of the first dental arch may include a tooth prepared for a crown, and a three-dimensional representation of one or more tooth surfaces of a second dental arch, wherein the first dental arch and the second dental arch are in occlusion,

[0013] The system may further include an identification means for identifying one or more regions of the dental model requiring tooth removal to accommodate the crown, or a display means for displaying the dental model with a visual cue for the one or more regions. The one or more regions may include a region of inadequate clearance for the crown, or a region of inadequate surface preparation. The one or more regions may include a region on a tooth that opposes the tooth prepared for the crown, a path of draw for the crown, a suggested clearance from one or more adjacent teeth, a suggested shape of the tooth prepared for the crown, or a suggested size of the tooth prepared for the crown. The visual cue may include the path of draw superimposed on the dental model, a means for coloring the one or more regions in a different color than other regions of the dental model, a means for representing the one or more regions with a different opacity than other regions of the dental model, or a means for detailing the one or more regions with a different level of detail than other regions of the dental model. The visual cue may include a means for treating the one or more regions with a different surface treatment than other regions of the dental model, a means for tracing around at least some portion of the one or more regions, an arrow

pointing toward at least one of the one or more regions, or a callout associated with the one or more regions.

[0014] In another aspect, a method disclosed herein may provide a dental model in digital form, the dental model may include a three-dimensional representation of one or more tooth surfaces of a first dental arch and a three-dimensional representation of one or more tooth surfaces of a second dental arch, wherein the first dental arch and the second dental arch are in occlusion. The method may further include identifying one or more regions of diagnostic significance in the dental model between the one or more tooth surfaces of the first dental arch and the one or more tooth surfaces of the second dental arch, and may include displaying the dental model with a visual cue for the one or more regions of diagnostic significance.

[0015] In the method, the one or more tooth surfaces of the first dental arch may include at least one occlusal surface. The at least one occlusal surface may include an incisal surface of a front tooth, or a surface of a molar. The one or more tooth surfaces of the first dental arch may include a full dental arch, or a quadrant. Alternatively the one or more tooth surfaces of the second dental arch may include a full dental arch, or a quadrant. Identifying one or more regions of diagnostic significance may include identifying a region recommended for removal. The region recommended for removal may include one or more cusps, a region that contributes to unbalanced occlusion, a region of inadequate clearance for a dental prosthetic, a region requiring additional surface preparation, or a region on a tooth that opposes a surface preparation. Identifying one or more regions of diagnostic significance may include identifying a region requiring additional data acquisition, or a path of draw for a dental prosthetic. The path of draw may include a suggested clearance from one or more adjacent teeth, a suggested shape of surface preparation, or a suggested size of surface preparation. The visual cue may include display of the path of draw superimposed on the dental model, display of the one or more regions of diagnostic significance in a different color than other regions of the dental model, or display of the one or more regions of diagnostic significance with a different opacity than other regions of the dental model. The visual cue may include display of the one or more regions of diagnostic significance with a different level of detail than other regions of the dental model, display of the one or more regions of diagnostic significance with a different surface treatment than other regions of the dental model, display of a trace around at least some portion of the one or more regions, display of an arrow pointing toward at least one of the one or more regions, or display of a callout associated with the one or more regions.

[0016] In another aspect, a computer program product herein disclosed may include processing a dental model in digital form, the dental model may include a three-dimensional representation of one or more tooth surfaces of a first dental arch and a three-dimensional representation of one or more tooth surfaces of a second dental arch, wherein the first dental arch and the second dental arch are in occlusion. The computer program product may further include identifying one or more regions of diagnostic significance in the dental model between the one or more tooth surfaces of the first dental arch and the one or more tooth surfaces of the second dental arch, and generating an image of the dental model with a visual cue for the one or more regions of diagnostic significance, the image being suitable for output to a display.

[0017] In the computer program product, the one or more tooth surfaces of the first dental arch may include at least one occlusal surface. The at least one occlusal surface may include an incisal surface of a front tooth, or a surface of a molar. The one or more tooth surfaces of the first dental arch may include a full dental arch, or a quadrant. The one or more tooth surfaces of the second dental arch may include a full dental arch, or a quadrant. Identifying one or more regions of diagnostic significance may include identifying a region recommended for removal. The region recommended for removal may include one or more cusps, a region that contributes to unbalanced occlusion, or dental prosthetic. The region recommended for removal may include a region requiring additional surface preparation, which may also include a region on a tooth that opposes a surface preparation. Identifying one or more regions of diagnostic significance may include identifying a region requiring additional data acquisition, or identifying a path of draw for a dental prosthetic. The path of draw may include a suggested clearance from one or more adjacent teeth, a suggested shape of surface preparation, or a suggested size of surface

preparation. The visual cue may include display of the path of draw superimposed on the dental model. It may include rendering the one or more regions of diagnostic significance in a different color than other regions of the dental model, rendering the one or more regions of diagnostic significance with a different opacity than other regions of the dental model, rendering the one or more regions of diagnostic significance with a different level of detail than other regions of the dental model, or rendering the one or more regions of diagnostic significance with a different surface treatment than other regions of the dental model. The visual cue may include a trace around at least some portion of the one or more regions, an arrow pointing toward at least one of the one or more regions, or a callout associated with the one or more regions.

[0018] In another aspect, a system disclosed herein may include a model means for providing a dental model in digital form, the dental model may include a three-dimensional representation of one or more tooth surfaces of a first dental arch and a three-dimensional representation of one or more tooth surfaces of a second dental arch, wherein the first dental arch and the second dental arch are in occlusion. The system may include an identity means for identifying one or more regions of diagnostic significance in the dental model between the one or more tooth surfaces of the first dental arch and the one or more tooth surfaces of the second dental arch, and a display means for displaying the dental model with a visual cue for the one or more regions of diagnostic significance.

[0019] In the system, the one or more tooth surfaces of the first dental arch may include at least one occlusal surface. The at least one occlusal surface may include an incisal surface of a front tooth, a surface of a molar. The one or more tooth surfaces of the first dental arch may include a full dental arch, or a quadrant. The one or more tooth surfaces of the second dental arch may include a full dental arch, or a quadrant. Identifying one or more regions of diagnostic significance may include identifying a region recommended for removal. The region recommended for removal may include one or more cusps, a region that contributes to unbalanced occlusion, a region of inadequate clearance for a dental prosthetic, a region requiring additional surface preparation, or a region on a tooth that opposes a surface preparation. Identifying one or more regions of diagnostic significance may include identifying a region requiring additional data acquisition, or identifying a path of draw for a dental prosthetic. The path of draw may include a suggested clearance from one or more adjacent teeth, a suggested shape of surface preparation, or a suggested size of surface preparation. The visual cue may include display of the path of draw superimposed on the dental model, a means for coloring the one or more regions of diagnostic significance in a different color than other regions of the dental model, a means for representing the one or more regions of diagnostic significance with a different opacity than other regions of the dental model, a means for detailing the one or more regions of diagnostic significance with a different level of detail than other regions of the dental model, or a means for representing the one or more regions of diagnostic significance with a different surface treatment than other regions of the dental model.

[0020] The visual clue of the system may include a trace around at least some portion of the one or more regions, an arrow pointing toward at least one of the one or more regions, or a callout associated with the one or more regions.

[0021] In another aspect, a method disclosed herein may include acquiring a three-dimensional surface representation of an anatomic structure as a plurality of fitted three-dimensional surface scans, and superimposing the digital surface representation onto a two-dimensional video image of the anatomic structure in a display in real time while acquiring the three-dimensional surface representation. The method may further include identifying one or more regions of the anatomic structure requiring additional scanning.

[0022] In the method, one or more regions may include a region of inadequate point cloud density, or a region deviating substantially from an expected surface contour. The method may further include providing a visual indicator of the one or more regions within the display. The visual indicator may include a variation in color, a variation in point cloud density in the display, or a variation in surface texture. The three-dimensional surface representation may include a three-dimensional point cloud.

[0023] In another aspect, a computer program product herein disclosed may include generating a three-dimensional surface representation of an anatomic structure from a plurality of fitted

three-dimensional surface scans, and superimposing the digital surface representation onto a two-dimensional video image of the anatomic structure for display in real time while generating the three-dimensional surface representation.

[0024] The computer program product may further include computer code to perform the step of identifying one or more regions of the anatomic structure requiring additional scanning. The one or more regions may include a region of inadequate point cloud density, or a region deviating substantially from an expected surface contour. The computer program product may further include computer code to perform the step of providing a visual indicator of the one or more regions within the display. The visual indicator may include a variation in color, a variation in point cloud density in the display, or a variation in surface texture. The three-dimensional surface representation may include a three-dimensional point cloud.

[0025] In another aspect, a system disclosed herein may include an acquisition means for acquiring a three-dimensional surface representation of an anatomic structure as a plurality of fitted three-dimensional surface scans, and a display means for superimposing the digital surface representation onto a two-dimensional video image of the anatomic structure in a display in real time while acquiring the three-dimensional surface representation. The system may further include a means for identifying one or more regions of the anatomic structure requiring additional scanning. The one or more regions may include a region of inadequate point cloud density, or a region deviating substantially from an expected surface contour.

[0026] The system may further include an indication means for providing a visual indicator of the one or more regions within the display. The visual indicator may include a variation in color, a variation in point cloud density in the display, or a variation in surface texture. The three-dimensional surface representation may include a three-dimensional point cloud.

[0027] In another aspect, a method disclosed herein may include constructing a three-dimensional surface representation of an object from a plurality of image data sets, each image data set representing a portion of the object from a point of view, acquiring a new image data set from a new point of view of the object, updating the three-dimensional surface representation based upon the new image data set, acquiring a video image of the object from the new point of view, rendering the three-dimensional surface representation from the new point of view to provide a rendered surface representation, and superimposing the rendered surface representation on the video image in a display.

[0028] In the method, the three-dimensional surface representation may include a plurality of three-dimensional points. The plurality of image data sets may include two-dimensional image data, or three-dimensional surface data. The object may include a dental object, dentition in a mouth of a dental patient, a dental model, a dental prosthetic, dental hardware, a dental filling, a dental appliance, or an orthodontic fixture. The video image may include a two-dimensional video image. The display may include a two-dimensional display. Rendering may include rendering one or more discrete three-dimensional points of the digital surface representation, or it may include rendering in two dimensions. Alternatively, the new image data set may be acquired at a video rate. The method may further include displaying the rendered surface representation superimposed on the video image in real time.

[0029] In the method, the three-dimensional surface representation may include a region of incomplete scan. If the scan is incomplete, the method may include acquiring one or more supplemental image data sets from the region of incomplete scan, or it may include visually indicating the region of incomplete scan in the display. Visually indicating the region of incomplete scan may include rendering the digital surface representation as a plurality of discrete points having a rendered density corresponding to an actual density of points in the digital surface representation.

[0030] In another aspect, a computer program product herein disclosed may include constructing a three-dimensional surface representation of an object from a plurality of image data sets, each image data set representing a portion of the object from a point of view, selecting a new image data set from a new point of view of the object, updating the three-dimensional surface representation based upon the new image data set, selecting a video image of the object from the new point of view, rendering the three-dimensional surface representation from the new point of view to provide a rendered surface

representation, and superimposing the rendered surface representation on the video image to provide an image being suitable for output to a display.

[0031] In the computer program product, the three-dimensional surface representation may include a plurality of three-dimensional points. The plurality of image data sets may include two-dimensional image data, or three-dimensional surface data. The object may include a dental object, dentition in a mouth of a dental patient, a dental model, a dental prosthetic, dental hardware, a dental filling, a dental appliance, or an orthodontic fixture. The video image may include a two-dimensional video image. The image for display may include a two-dimensional image. Rendering may include rendering one or more discrete three-dimensional points of the digital surface representation, or it may include rendering in two dimensions. The new image data set may be acquired at a video rate. The computer program product may further include computer code to perform the step of displaying the rendered surface representation superimposed on the video image in real time. The three-dimensional surface representation may include a region of incomplete scan. If the scan is incomplete, the computer program product may include computer code to perform the step of receiving one or more supplemental image data sets of the region of incomplete scan from a scanner. Alternatively, the computer program product may perform the step of visually indicating the region of incomplete scan in the display image. Visually indicating the region of incomplete scan may include rendering the digital surface representation as a plurality of discrete points having a rendered density corresponding to an actual density of points in the digital surface representation.

[0032] In another aspect, a system disclosed herein may include a means for reconstructing a three-dimensional surface representation of an object from a plurality of image data sets, each image data set representing a portion of the object from a point of view, a means for acquiring a new image data set from a new point of view of the object, an update means for updating the three-dimensional surface representation based upon the new image data set a video acquisition means for acquiring a video image of the object from the new point of view, a drawing means for rendering the three-dimensional surface representation from the new point of view to provide a rendered surface representation, and a display means for superimposing the rendered surface representation on the video image in a display.

[0033] In the system, the three-dimensional surface representation may include a plurality of three-dimensional points. The plurality of image data sets may include two-dimensional image data, or three-dimensional surface data. The object may include a dental object, dentition in a mouth of a dental patient, a dental model, a dental prosthetic, dental hardware, a dental filling, a dental appliance, or an orthodontic fixture. The video image may include a two-dimensional video image, the display may include a two-dimensional display, and the drawing means may include a means for rendering one or more discrete three-dimensional points of the digital surface representation. The new image data set may be acquired at a video rate. The display means may include a means for rendering in two dimensions. The system may further include a real time display means for displaying the rendered surface representation superimposed on the video image in real time.

[0034] In the system, the three-dimensional surface representation may include a region of incomplete scan. If the scan is incomplete, the system may further a means for acquiring one or more supplemental image data sets from the region of incomplete scan, or a means for visually indicating the region of incomplete scan in the display. The means for visually indicating the region of incomplete scan may include a means for rendering the digital surface representation as a plurality of discrete points having a rendered density corresponding to an actual density of points in the digital surface representation.

[0035] In another aspect, a method disclosed herein may include displaying a digital surface representation of a dental object, and simulating within the display an internal illumination for the dental object wherein light is emitted from any holes in the digital surface representation. The method may further include acquiring additional surface scan data to fill any holes in the digital surface representation.

[0036] In the method, the holes may include regions of the digital surface representation having a point density below a predetermined threshold. The dental object may include dentition, a

restoration, a prosthetic, an appliance, an item of dental hardware, or an interim component of dental manufacture.

[0037] In another aspect, a computer program product herein disclosed may include rendering an image of a digital surface representation of a dental object, the image being suitable for output to a display, and simulating within the image an internal illumination for the dental object wherein light is emitted from any holes in the digital surface representation.

[0038] In the computer program product, the holes may include regions of the digital surface representation having a point density below a predetermined threshold. The dental object may include dentition, a restoration, a prosthetic, an appliance, an item of dental hardware, or an interim component of dental manufacture.

[0039] In another aspect, a system disclosed herein may include a display means for displaying a digital surface representation of a dental object, and a simulation means for simulating within the display an internal illumination for the dental object wherein light is emitted from any holes in the digital surface representation. The system may further include an acquisition means for acquiring additional surface scan data to fill any holes in the digital surface representation.

[0040] In the system, the holes may include regions of the digital surface representation having a point density below a predetermined threshold. The dental object may include dentition, a restoration, a prosthetic, an appliance, an item of dental hardware, or an interim component of dental manufacture.

[0041] In another aspect, a method disclosed herein may include acquiring data for a digital surface representation of an object with a scanner, the scanner having a point of view of the object, displaying the digital surface representation of the object on a display, and simulating within the display an external illumination of the digital surface representation of the object from the point of view of the scanner as an illuminated region of the digital surface representation.

[0042] In the method, the illuminated region may correspond to a field of view of the scanner. The external illumination localizes a position of the scanner with respect to the object. The illuminated region provides a user feedback identifying a current source of surface data for the scanner. The object may include a dental object.

[0043] In another aspect, a computer program product herein disclosed may include generating a digital surface representation of an object from data received from a scanner, the scanner having a point of view of the object, generating an image of the digital surface representation of the object, the image being suitable for output to a display, and simulating within the image an external illumination of the digital surface representation of the object from the point of view of the scanner as an illuminated region of the digital surface representation.

[0044] In the computer program product, the illuminated region may correspond to a field of view of the scanner. The external illumination localizes a position of the scanner with respect to the object. The illuminated region provides a user feedback identifying a current source of surface data for the scanner. The object may include a dental object.

[0045] In another aspect, a system disclosed herein may include an acquisition means for acquiring data for a digital surface representation of an object from a scanner, the scanner having a point of view of the object, a display means for displaying the digital surface representation of the object on a display, and a simulation means for simulating within the display an external illumination of the digital surface representation of the object from the point of view of the scanner as an illuminated region of the digital surface representation.

[0046] In the system, the illuminated region may correspond to a field of view of the scanner. The external illumination may include a means for localizing a position of the scanner with respect to the object. The illuminated region may include a means for providing a user feedback identifying a current source of surface data for the scanner. The object may include a dental object.

[0047] In another aspect, a method disclosed herein may include reconstructing a three-dimensional point cloud from a surface of an object using a plurality of image data sets, each image data set may include video data of a portion of the object from a point of view, acquiring a new image data set from a new point of view of the object, updating the three-dimensional point cloud in real time based

upon the new image data set, and rendering the three-dimensional point cloud in a display in real time to provide a rendered digital surface representation. Real time updating of the three-dimensional point cloud may include updating at the video rate for acquiring the new image data set. The method may further include superimposing a video image of the object from the new point of view in the display.

[0048] In the method, rendering may include rendering from a point of view that remains fixed, or it may include rendering from the new point of view of the object. The method may further include superimposing a video image of the object and the digital surface representation in the display from a common point of view.

[0049] In another aspect, a computer program product herein disclosed may include constructing a three-dimensional point cloud from a surface of an object using a plurality of image data sets, each image data set may include video data of a portion of the object from a point of view, detecting a new image data set from a new point of view of the object, updating the three-dimensional point cloud in real time based upon the new image data set, and rendering the three-dimensional point cloud in real time to provide a rendered digital surface representation suitable for output to a display. Real time updating of the three-dimensional point cloud may include updating at the video rate by which each new image data set is detected.

[0050] In the computer program product, rendering may include superimposing a video image of the object from the new point of view on the rendered digital surface representation. Rendering may alternatively include rendering from a point of view that remains fixed, or rendering from the new point of view of the object. Rendering may include superimposing a video image of the object on the rendered digital surface representation, the video image and the rendered digital surface representation being rendered from a common point of view.

[0051] In another aspect, a system disclosed herein may include a means for constructing a three-dimensional point cloud from a surface of an object using a plurality of image data sets, each image data set may include video data of a portion of the object from a point of view, an acquisition means for acquiring a new image data set from a new point of view of the object, an update means for updating the three-dimensional point cloud in real time based upon the new image data set, and a display means for rendering the three-dimensional point cloud in a display in real time to provide a rendered digital surface representation. Real time update of the three-dimensional image may include updating at the video rate at which the acquisition means acquires the new image data set.

[0052] In the system, the display means may include a means for superimposing a video image of the object from the new point of view in the display. The display means may include a means for rendering from a point of view that remains fixed, or it may a means for rendering from the new point of view of the object. The display means may include a means for superimposing a video image of the object and the digital surface representation in the display from a common point of view

[0053] In another aspect, a method disclosed herein may include providing a dental surface may include a visually distinguishable feature on the dental surface, acquiring one or more two-dimensional images of the dental surface, and resolving the one or more two-dimensional images into a three-dimensional point cloud of the dental surface in real time using the visually distinguishable feature.

[0054] In the method, the visually distinguishable feature may include an intrinsic feature of the dental surface, or it may include an artificial feature added to the dental surface.

[0055] In another aspect, a computer program product herein disclosed may include detecting a visually distinguishable feature on a dental surface from one or more two-dimensional images of the dental surface, and resolving the one or more two-dimensional images into a three-dimensional point cloud of the dental surface in real time using the visually distinguishable feature.

[0056] The visually distinguishable feature may include an intrinsic feature of the dental surface or it may include an artificial feature added to the dental surface.

[0057] In another aspect, a system disclosed herein may include a means for providing a dental surface may include a visually distinguishable feature on the dental surface, an acquisition means for acquiring one or more two-dimensional images of the dental surface, and a resolution means for resolving

the one or more two-dimensional images into a three-dimensional point cloud of the dental surface in real time using the visually distinguishable feature.

[0058] In the system, the visually distinguishable feature may include an intrinsic feature of the dental surface, or an artificial feature added to the dental surface.

[0059] In another aspect, a method disclosed herein for operating a scanning system including a scanning device and a display, the scanning device adapted for continuous acquisition of surface data, the scanning device having one or more scanning parameters, and the display adapted for displaying a digital surface reconstruction containing a plurality of three-dimensional points recovered from the surface data may include rendering the digital surface reconstruction in the display from a current point of view of the scanning device, and providing a visual cue that relates to the one or more scanning parameters.

[0060] The method may further include superimposing a video image of the object from the current point of view onto the digital surface reconstruction in the display. Rendering the digital surface reconstruction may include rendering the digital surface reconstruction in real time. The one or more scanning parameters may include an optimal distance from the scanning device to a subject. Alternatively the one or more scanning parameters may include a range of distances for data capture and a field of view for data capture, the visual cue may include a three-dimensional box bounding the range of distances and the field of view within the display. The one or more scanning parameters may include a range of distances for data capture, providing a visual cue may include color coding a plurality of rendered points of the digital surface reconstruction according to a current distance of each one of the plurality of rendered points relative to the range of distances for data capture. Color coding may include rendering points more distant than the range of distances in a first color, rendering points nearer than the range of distances in a second color, or rendering points within the range of distances in a third color. The visual cue may include a dynamic object within the display, the dynamic object adapted to convey information relating to a distance between the scanning device and a subject of the surface data. The dynamic object may include a dynamic bulls eye, it may relate to a most recent frame of surface data, or it may provide a relative distance indicator for visual feedback to a user concerning whether the scanning device is too close, too far, or properly distanced from the subject. The relative distance indicator may provide graduated feedback to assist a user in maintaining a proper scan distance. The distance between the scanning device and the subject may be calculated as a mean distance from a plurality of points within a field of view of the scanning device.

[0061] In another aspect, a computer program product herein disclosed may include processing surface data received from a scanning device adapted for continuous acquisition of the surface data, the scanning device having one or more scanning parameters, generating a digital surface reconstruction containing a plurality of three-dimensional points recovered from the surface data, generating a visual cue that relates to the one or more scanning parameters, and rendering an image of the visual clue and the digital surface reconstruction from a current point of view of the scanning device, the image being suitable for output to a display.

[0062] In the computer program product, rendering the image may include superimposing a video image of the object from the current point of view onto the image, or it may include rendering the image in real time. The one or more scanning parameters may include an optimal distance from the scanning device to a subject. Alternatively, the one or more scanning parameters may include a range of distances for data capture and a field of view for data capture, the visual cue may include a three-dimensional box bounding the range of distances and the field of view within the image. The one or more scanning parameters may alternatively include a range of distances for data capture, and providing a visual cue may include color coding a plurality of rendered points of the digital surface reconstruction according to a current distance of each one of the plurality of rendered points relative to the range of distances for data capture. Color coding may include rendering points more distant than the range of distances in a first color, rendering points nearer than the range of distances in a second color, or rendering points within the range of distances in a third color. The visual cue may include a dynamic object, the dynamic object adapted to convey information relating to a distance between the scanning

device and a subject of the surface data. The dynamic object may include a dynamic bulls eye, it may relate to a most recent frame of surface data, or it may include a relative distance indicator concerning whether the scanning device is too close, too far, or properly distanced from the subject. The relative distance indicator may include a graduated indication of distance to assist a user in maintaining a proper scan distance. The distance between the scanning device and the subject may be calculated as a mean distance from a plurality of points within a field of view of the scanning device.

[0063] In another aspect, a system disclosed may include a scanner for continuously acquiring surface data, the scanner having one or more scanning parameters, a processor for generating a digital surface reconstruction containing a plurality of three-dimensional points recovered from the surface data, a display means for displaying the digital surface reconstruction from a current point of view of the scanning device, and a means for providing a visual cue that relates to the one or more scanning parameters.

[0064] In the system, the display means may include a means for superimposing a video image of the object from the current point of view onto the digital surface reconstruction. The display means may include a means for displaying the digital surface reconstruction in real time, or it may include a means for incorporating the visual cue with the digital surface reconstruction. The one or more scanning parameters may include an optimal distance from the scanning device to a subject. In the system, the one or more scanning parameters may include a range of distances for data capture and a field of view for data capture, the visual cue may include a three-dimensional box bounding the range of distances and the field of view. The one or more scanning parameters may include a range of distances for data capture, the means for providing a visual cue further may include a means for color coding a plurality of rendered points of the digital surface reconstruction according to a current distance of each one of the plurality of rendered points relative to the range of distances for data capture. The means for color coding may include a means for rendering points more distant than the range of distances in a first color, a means for rendering points nearer than the range of distances in a second color, or a means for rendering points within the range of distances in a third color. The visual cue may include a dynamic object which may include a means for conveying information relating to a distance between the scanning device and a subject of the surface data. The dynamic object may include a dynamic bulls eye, it may relate to a most recent frame of surface data, or it may include a means for providing a relative distance indicator concerning whether the scanning device is too close, too far, or properly distanced from the subject. The relative distance indicator may include a means for providing graduated feedback to assist a user in maintaining a proper scan distance. The system may further include a means for calculating the distance between the scanning device and the subject as a mean distance from a plurality of points within a field of view of the scanning device.

BRIEF DESCRIPTION OF THE FIGURES

[0065] The invention and the following detailed description of certain embodiments thereof may be understood by reference to the following figures.

[0066] Fig. 1 shows a dental image capture system.

[0067] Fig. 2 depicts a view of a user interface for an image capture system.

[0068] Fig. 3 depicts a view of a user interface for an image capture system.

[0069] Fig. 4 depicts a view of a user interface for an image capture system during an acquisition of three-dimensional data.

[0070] Fig. 5 depicts a view of a user interface for an image capture system during an evaluation.

[0071] Fig. 6 depicts a dental model in digital form.

[0072] Fig. 7 depicts a cross-section of a digital dental model.

[0073] Fig. 8 depicts a visualization technique for locating holes in a digital surface representation of dental subject matter.

[0074] Fig. 9 depicts a visualization technique using a simulated external illumination.

DETAILED DESCRIPTION

[0075] Described are an array of visual feedback techniques to assist in acquiring and analyzing three-dimensional data. While the description emphasizes continuous scanning and dental applications, it will be appreciated that the inventive concepts disclosed herein are not limited to the specific embodiments disclosed. For example, the dental visualization systems described herein may be supported by any imaging technology capable of capturing three-dimensional dental data of suitable precision and detail. Similarly, the diagnostically oriented techniques disclosed herein, such as analysis of surface preparations or occlusion of arches, may be useful deployed in other contexts, including medical applications, three-dimensional animation modeling, custom, rapid manufacturing processes, and so forth. In addition, while numerous, combinations and variations of imaging technologies and dental applications are described, it will be appreciated that other combinations of the specific scanning, processing, and visualization techniques described herein may be used, and that such variations are intended to fall within the scope of this disclosure.

[0076] In the following description, the term “image” generally refers to a two-dimensional set of pixels forming a two-dimensional view of a subject within an image plane. The term “image set” generally refers to a set of related two dimensional images that might be resolved into three-dimensional data. The term “point cloud” generally refers to a three-dimensional set of points forming a three-dimensional view of the subject reconstructed from a number of two-dimensional views. In a three-dimensional image capture system, a number of such point clouds may also be registered and combined into an aggregate point cloud constructed from images captured by a moving camera. Thus it will be understood that pixels generally refer to two-dimensional data and points generally refer to three-dimensional data, unless another meaning is specifically indicated or clear from the context.

[0077] The terms “three-dimensional surface representation”, “digital surface representation”, “three-dimensional surface map”, and the like, as used herein, are intended to refer to any three-dimensional surface map of an object, such as a point cloud of surface data, a set of two-dimensional polygons, or any other data representing all or some of the surface of an object, as might be obtained through the capture and/or processing of three-dimensional scan data, unless a different meaning is explicitly provided or otherwise clear from the context.

[0078] A “three-dimensional representation” may include any of the three-dimensional surface representations described above, as well as volumetric and other representations, unless a different meaning is explicitly provided or otherwise clear from the context.

[0079] In general, the terms “render” or “rendering” refer to a two-dimensional visualization of a three-dimensional object, such as for display on a monitor. However, it will be understood that three-dimensional rendering technologies exist, and may be usefully employed with the systems and methods disclosed herein. As such, rendering should be interpreted broadly unless a narrower meaning is explicitly provided or otherwise clear from the context.

[0080] The term “dental object”, as used herein, is intended to refer broadly to subject matter specific to dentistry. This may include intraoral structures such as dentition, and more typically human dentition, such as individual teeth, quadrants, full arches, pairs of arches which may be separate or in occlusion of various types, soft tissue, and the like, as well bones and any other supporting or surrounding structures. As used herein, the term “intraoral structures” refers to both natural structures within a mouth as described above and artificial structures such as any of the dental objects described below that might be present in the mouth. Dental objects may include “restorations”, which may be generally understood to include components that restore the structure or function of existing dentition, such as crowns, bridges, veneers, inlays, onlays, amalgams, composites, and various substructures such as copings and the like, as well as temporary restorations for use while a permanent restoration is being fabricated. Dental objects may also include a “prosthesis” that replaces dentition with removable or permanent structures, such as dentures, partial dentures, implants, retained dentures, and the like. Dental objects may also include “appliances” used to correct, align, or otherwise temporarily or permanently adjust dentition, such as removable orthodontic appliances, surgical stents, bruxism appliances, snore guards, indirect bracket placement appliances, and the like. Dental objects may also include “hardware” affixed to dentition for

an extended period, such as implant fixtures, implant abutments, orthodontic brackets, and other orthodontic components. Dental objects may also include "interim components" of dental manufacture such as dental models (full and/or partial), wax-ups, investment molds, and the like, as well as trays, bases, dies, and other components employed in the fabrication of restorations, prostheses, and the like. Dental objects may also be categorized as natural dental objects such as the teeth, bone, and other intraoral structures described above or as artificial dental objects such as the restorations, prostheses, appliances, hardware, and interim components of dental manufacture as described above.

[0081] Terms such as "digital dental model", "digital dental impression" and the like, are intended to refer to three-dimensional representations of dental objects that may be used in various aspects of acquisition, analysis, prescription, and manufacture, unless a different meaning is otherwise provided or clear from the context. Terms such as "dental model" or "dental impression" are intended to refer to a physical model, such as a cast, printed, or otherwise fabricated physical instance of a dental object. Unless specified, the term "model", when used alone, may refer to either or both of a physical model and a digital model.

[0082] Fig. 1 shows an image capture system. In general, the system 100 may include a scanner 102 that captures images of a subject 104 within an image plane 106, and forwards the images to a computer 108, which may include a display 110 and one or more user input devices such as a mouse 112 or a keyboard 114.

[0083] The scanner 102 may include any camera or camera system suitable for capturing images from which a three-dimensional point cloud may be recovered. For example, the scanner 102 may employ a multi-aperture system as disclosed, for example, in U.S. Pat. Pub. No. 20040155975 to Hart et al., the entire contents of which is incorporated herein by reference. While Hart discloses one multi-aperture system, it will be appreciated that any multi-aperture system suitable for reconstructing a three-dimensional point cloud from a number of two-dimensional images may similarly be employed. In one multi-aperture embodiment, the scanner 102 may include a plurality of apertures including a center aperture positioned along a center optical axis of a lens and any associated imaging hardware. The scanner 102 may also, or instead, include a stereoscopic, triscopic or other multi-camera or other configuration in which a number of cameras or optical paths are maintained in fixed relation to one another to obtain two-dimensional images of an object from a number of slightly different perspectives. The scanner 102 may include suitable processing for deriving a three-dimensional point cloud from an image set or a number of image sets, or each two-dimensional image set may be transmitted to an external processor such as contained in the computer 108 described below. In other embodiments, the scanner 102 may employ structured light, laser scanning, direct ranging, or any other technology suitable for acquiring three-dimensional data, or two-dimensional data that can be resolved into three-dimensional data.

[0084] In one embodiment, the scanner 102 is a handheld, freely positionable probe having at least one user input device, such as a button, lever, dial, thumb wheel, switch, or the like, for user control of the image capture system 100 such as starting and stopping scans. In an embodiment, the scanner 102 may be shaped and sized for dental scanning. More particularly, the scanner may be shaped and sized for intraoral scanning and data capture, such as by insertion into a mouth of an imaging subject and passing the imaging plane 106 over one or more intraoral structures at a suitable distance to acquire surface data from teeth, gums, and so forth. The scanner 102 may, through such a continuous acquisition process, capture a point cloud of surface data having sufficient spatial resolution and accuracy to prepare dental objects such as prosthetics, hardware, appliances, and the like therefrom, either directly or through a variety of intermediate processing steps. In other embodiments, surface data may be acquired from a dental model such as a dental prosthetic, to ensure proper fitting using a previous scan of corresponding dentition, such as a tooth surface prepared for the prosthetic.

[0085] Although not shown in Fig. 1, it will be appreciated that a number of supplemental lighting systems may be usefully employed during image capture. For example, environmental illumination may be enhanced with one or more spotlights illuminating the subject 104 to speed image acquisition and improve depth of field (or spatial resolution depth). The scanner 102 may also, or instead,

include a strobe, flash, or other light source to supplement illumination of the subject 104 during image acquisition.

[0086] The subject 104 may be any object, collection of objects, portion of an object, or other subject matter. While illustrated in Fig. 1 as a simple geometric form, the subject 104 may include much more complex surfaces, and any number of separate elements. For example, in a dental imaging application, the subject 104 may include a tooth, a quadrant of teeth, or a full collection of teeth including two opposing arches from which a virtual dental impression is desired. The subject 104 may also, or instead, include a dental prosthesis such as an inlay, a crown, or any other dental prosthesis, implant, or the like. The subject 104 may include a dental model, such as a plaster cast, wax-up, impression, or negative impression of a tooth, teeth, soft tissue, or some combination of these. In certain instances, an optical or textured imaging agent may be applied to surfaces of the subject 104 to improve capture of three dimensional points. In other embodiments, the subject 104 may be a human head, or a portion thereof, from which a three-dimensional model is desired for custom fitting of a hearing aid, eyeglasses, goggles, or the like. In other embodiments, the subject 104 may be a physical model of an object for use in digital animation, such as a miniature, physical model for use in a three-dimensional digital animation process. From the preceding examples, it will be apparent that a system using the techniques described herein may be suitably adapted to a wide range of applications for relatively short range, high resolution three-dimensional image acquisition. However, one skilled in the art will appreciate that suitable adaptations to the image capture system 100 may be made for a variety of other three-dimensional imaging applications based upon multi-aperture or multi-camera systems, as well as other three-dimensional imaging systems and technologies, and all such variations are intended to fall within the scope of this disclosure.

[0087] The image plane 106 may include a two-dimensional field of view of the scanner 102. It will be appreciated that the term "image plane" as used in this paragraph, refers to a plane in the imaging environment rather than a plane within an optical sensor (such as film or sensors) where an image is captured. Though illustrated as a rectangle the image plane 106 may, for example, form a square, a circle, or any other geometry provided by the scanner 102. In general, the scanner 102 will have a depth of field or range of depth resolution for image acquisition within the image plane 106 determined by the physical construction of the scanner 102 and environmental conditions such as ambient light.

[0088] The computer 108 may be, for example, a personal computer or other processing device. In one embodiment, the computer 108 includes a personal computer with a dual 2.8GHz Opteron central processing unit, 2 gigabytes of random access memory, a TYAN Thunder K8WE motherboard, and a 250 gigabyte, 10,000 rpm hard drive. This system may be operated to capture approximately 1,500 points per image set in real time using the techniques described herein, and store an aggregated point cloud of over one million points. As used herein, the term "real time" means generally with no observable latency between processing and display. In a video-based scanning system, real time more specifically refers to processing within the time between frames of video data, which may vary according to specific video technologies between about fifteen frames per second and about thirty frames per second. More generally, processing capabilities of the computer 108 may vary according to the size of the subject 104, the speed of image acquisition, and the desired spatial resolution of three-dimensional points. The computer 108 may also include peripheral devices such as a keyboard 114, display 110, and mouse 112 for user interaction with the camera system 100. The display 110 may be a touch screen display capable of receiving user input through direct, physical interaction with the display 110.

[0089] Communications between the computer 108 and the scanner 102 may use any suitable communications link including, for example, a wired connection or a wireless connection based upon, for example, IEEE 802.11 (also known as wireless Ethernet), BlueTooth, or any other suitable wireless standard using, e.g., a radio frequency, infrared, or other wireless communication medium. In medical imaging or other sensitive applications, wireless image transmission from the scanner 102 to the computer 108 may be secured. The computer 108 may generate control signals to the scanner 102 which, in addition to image acquisition commands, may include conventional camera controls such as focus or zoom.

[0090] In an example of general operation of a three-dimensional image capture system 100, the scanner 102 may acquire two-dimensional image sets at a video rate while the scanner 102 is passed over a surface of the subject. The two-dimensional image sets may be forwarded to the computer 108 for derivation of three-dimensional point clouds. The three-dimensional data for each newly acquired two-dimensional image set may be derived and fitted or "stitched" to existing three-dimensional data using a number of different techniques. One useful example of such a technique is described in commonly-owned U.S. App. No. 11/270,135, filed on November 9, 2005, the entire contents of which is incorporated herein by reference. However, it will be appreciated that this example is not limiting, and that the principles described herein may be applied to a wide range of three-dimensional image capture systems.

[0091] It will be appreciated that the ability of certain systems, such as multiaperture camera systems, to derive three-dimensional data from two-dimensional video image sets may depend in part on an ability to establish correspondence of surface points between image pairs (or triplets, and so on). The process of establishing point correspondences may be improved by identifying, within the processing system, unique features of the surface upon which correspondence may be based. In certain aspects, distinguishing features of teeth at varying levels of detail may be employed to enhance this process. However, this process depends on an ability to locate such distinguishable features. The process of establishing point correspondences may also, or instead, be enhanced by the addition of optically detectable features thereto, which may be as simple as artificial black dots distributed over a white or relatively light surface. In a dental context, this may be achieved with a spray, powder, mouth rinse, or the like that distributes optically detectable matter across the dentition or other dental object to be scanned. By randomly distributing such small, distinguishable dots across the surface, the likelihood of locating distinguishable features in a particular image set may be significantly improved, thus improving the speed and accuracy of the overall three-dimensional data acquisition process.

[0092] From time to time in continuous or incremental data acquisition systems, the fitting or stitch may fail for reasons described in greater detail below. In such situations, a user may be notified through visual feedback that a recover mode has been entered. In the recover mode, the system 100 may seek to reacquire the previous scan by test fitting new scan data to previously acquired data, and providing visual feedback to a user to assist in navigating back to a scan location on the subject where the re-acquisition is being attempted. In a related landing mode, a user may attempt to initiate a new scan registered or connected to an existing three-dimensional model. Similar visual feedback tools may be provided to guide a user to an appropriate scan location, and notify a user when the scan has been reacquired. These techniques are described in greater detail in [Attorney Docket No. BRNT-0009-P02, filed on xx/xx/xx], incorporated herein by reference in its entirety. Other suitable techniques may be employed for navigation, controlling scan quality, analyzing scanned subject matter, and manipulating scanned models, various embodiments of which are described in greater detail below.

[0093] The display 110 may include any display suitable for video or other rate rendering at a level of detail corresponding to the acquired data. Suitable displays include cathode ray tube displays, liquid crystal displays, light emitting diode displays and the like. In some embodiments, the display may include a touch screen interface using, for example capacitive, resistive, or surface acoustic wave (also referred to as dispersive signal) touch screen technologies, or any other suitable technology for sensing physical interaction with the display 110. In addition, where three-dimensional visualization is desired, the display 110 may include a three-dimensional display using a wide variety of techniques including stereo pair imaging, holographic imaging, and multiplanar or volumetric imaging, each with a number of rendering modalities that may be usefully employed with the systems described herein.

[0094] Fig. 2 depicts a view of a user interface for an image capture system. The user interface 200 may include a window 202 rendered on a monitor such as the display 110 of Fig. 1. Within the window 202, a video image may be displayed including a field of view of a scanner, such as the image plane 106 of the scanner 102 of Fig. 1. Within the field of view, a video or other image of a subject such as the subject 104 of Fig. 1 may be displayed. However, as depicted in Fig. 2, no image acquisition steps

have been initiated, so the window 202 remains blank except for various controls which will be described below.

[0095] Scanning controls may include, for example, a scan control 204, a pause control 206, a stop control 208, a clear control 210, a save control 212, and a retrieve control 214. The scan control 204 may initiate a three-dimensional scan. The pause control 206 may temporarily discontinue a scan in a manner that permits subsequent reacquisition of a continuous scanning process. The paused scan may exhibit a number of visual properties. For example, the video image may be frozen, or the video image may continue to display current video information while a point cloud or other scan data remains frozen, or the screen may go entirely blank, or some combination of these, all according to user preferences or a particular implementation. In general, a paused scan may remain active so that a user may resume the scan. By contrast, if a user activates the stop control 208, the scan may be terminated, such that a user would have to retrieve the scan, such as using the retrieve control 214 in order to continue adding data thereto. The save control 212 may store a scan and any related data for subsequent use. These controls may operate as buttons that a user activates to perform the indicated function, such as through a mouse click or, where the display 110 is a touchscreen, by direct physical interaction with the display 110. It will be appreciated that activation of the control may create a pop-up window, or provide drop down lists, radio buttons, text input fields; and any other controls suitable for parameterizing the particular selection. Thus for example, where a user activates the save control 212, a text box may appear for a user to enter a filename for saving any related data. Numerous techniques for organizing user interfaces and providing controls within a user interface are known in the art, and may be suitably adapted to the interface 200 described herein.

[0096] A number of navigation controls may be provided, such as a zoom out control 216, a zoom in control 218, a zoom indicator 220, a rotate control 222, a pan control 224, and a reset control 226. These controls may be used to view an acquired three-dimensional representation after a scan has been completed or, where a pause/resume feature is provided, during a scan. The reset control 226 may, for example, restore a view of a three-dimensional representation to a global coordinate system, or to a most recent view from which data was acquired during a scan.

[0097] A number of range finding visualizations may also be included that provide visual cues related to one or more scanning parameters of an image capture system. These visualizations may be rendered in real time, e.g., at the video rate of the image capture system, to provide real time user feedback and guidance with respect to proper orientation and positioning of a scanner during a scan. The user feedback may improve the quality and speed of data acquisition, particularly during continuous scanning operations that acquire a full three-dimensional representation of a subject as a sequence of fitted three-dimensional surface samples. These visual cues may be particularly useful in continuous three-dimensional data acquisition systems based upon camera motion estimation or similar techniques. In such techniques, sequential frames of data are registered to one another using various processing techniques such as those described in commonly owned U.S. App. No. 11/270,135, filed on November 9, 2005. This works well provided three-dimensional data can be successfully resolved from each sequential frame of image data, and there is sufficiently small displacement of the scanner that the data from sequential frames overlaps in three-dimensional space. However, when this "stitching" of sequential frames is lost, such as due to an operator moving outside the proper scanning distance, it can be very difficult to recover the continuous acquisition. Visualization tools that guide a user toward maintaining proper scanning distance advantageously promote a continuous, uninterrupted acquisition of three-dimensional data for an entire surface of interest.

[0098] For example, within a window 230 that shows a current video image from the image plane 106 of the scanner 102 (which is blank in Fig. 2, as the system has not started a scan), a volume 232 of space, such as the box depicted in Fig. 2, for which quality scan data can be captured may be depicted in perspective. This volume 232 rendered within the imaging space may assist a user in positioning subject matter within the video image appropriately for data acquisition. In addition, sliders 234 may be animated along z-axis edges of the volume 232 to indicate a distance of points of three-dimensional data actually being acquired. This may be based on, for example, a mean distance of some or all of the points,

a distance of a central point, a range of distances for all or some of the points, or a distance of a point at each respective corner of the volume 232, such that the sliders 234 may move independently from one another during a scan. Distance calculations may be based on a current frame of image data, i.e., the most recently acquired data set, or an average of a predetermined number of immediately prior data sets, or upon all three-dimensional points of the three-dimensional surface representation falling within the volume 432 without regard to when they were acquired.

[0099] As another example, a dynamic object 236 such as a sphere or bullseye may be rendered in the center of the window 230. The dynamic object 236 may also, or instead, be positioned at another location within the window; however positioning the dynamic object 236 within the center of the window 230 advantageously permits a user to receive visual feedback from the dynamic object 236 without looking away from current video of the subject being scanned.

[00100] A number of useful animations may be provided by the dynamic object 236 to give user feedback to an operator of the image capture system 100. In one implementation, the dynamic object 236 may be an animated bullseye that is color-coded to provide distance information. The bullseye may, for example be rendered as concentric rings of different colors, such as red, white, and blue, with the central color filling the entire bullseye when a subject is properly distanced from the scanner. When the scanner moves too far from the subject, a red ring may form around the white circle filling a greater portion of the bullseye as the scanner moves further from a subject until the entire bullseye is completely red. Conversely, when the scanner moves too close to a subject, a blue circle may appear within the center of the white circle and grow in size as the scanner moves farther from the subject until the entire circle is blue. In this manner, a user may receive continuous feedback with respect to scan distance – a growing blue central circle as the scanner moves too close, and an engulfing red ring when as the scanner moves too far away – so that the scanner may maintain a proper distance from the subject for continuous acquisition of three-dimensional data in a three-dimensional representation of the subject.

[00101] In another possible animation, three concentric rings may be continuously displayed within the bullseye, with the radius of each ring independently controlled in proportion to the number of points that are too close, properly distanced, and too far. In another possible animation, the center ring (a circle) may move within the bullseye with an offset corresponding to an x-y displacement in the field of view of a region of the surface having the greatest density of points at a target, or desirable, scanning distance. Of course, it will be appreciated that the selection of colors for such animations is somewhat arbitrary, although significant contrast in hue or intensity may assist a user in recognizing deviations from an optimal scan distance.

[00102] Other visual cues and/or metaphors may also, or instead, be employed, such as a visualization of a plane passing through a sphere, active distance bars, animated text, or other visualizations, any of which may provide animated, visual feedback based on, for example, mean distance, center distance, or some other metric that can be derived from scanner output. More generally, visual cues may provide feedback concerning any scanning parameter such as depth of optimal data acquisition, width of field of view, rate of travel or yaw of the scanner 102, density of data acquisition, and so forth, as well as various combinations of these. These visual cues may provide graduated feedback to assist a user in maintaining proper scan distance, and to inform a user when a scan has been lost.

[00103] Fig. 3 depicts a view of a user interface for an image capture system. This abstracted drawing shows a window 302 of the user interface 300, which may be, for example, the window 230 of Fig. 2, without the visual cues described therein. The window 302 may include a video image from a point of view of a scanner such as the image plane 106 of the scanner 102 described above with reference to Fig. 1. Within the window 302, the video image may include a subject 304. As depicted in Fig. 3 (and not by way of limitation), the subject 304 is a slender cylinder extended from a near end 306 relatively close to the scanner to a distant end 308 relatively far from the scanner. During a continuous surface scan of the subject 304, three-dimensional surface data may have been acquired, as indicated generally by x's, o's, and encircled +s. Within the window 302, the three-dimensional surface scan may be rendered from the point of view of the scanner, along with shading or other visual effects to indicate shape and surface contours. The rendered three-dimensional surface scan may be superimposed in a registered fashion

directly over the video image. This superposition alone provides significant user information, such as what surface regions of the subject 304 have been scanned. In addition, the rendered three-dimensional surface scan may be color-coded or otherwise rendered to provide color information concerning, for example, what region is currently being scanned in the continuous data acquisition process, what regions are too close to acquire scan data from, what regions are at a proper distance for acquisition of surface data, and what regions are too far for surface data. For example, if points on or near the near end 306 of the subject 304 are too close to acquire scan data – these points are indicated in Fig. 3 as x's – they may be rendered in a first color. Points at an optimal scanning distance – indicated in Fig. 3 as o's – may be rendered in a second color. Points too distance for acquisition of three-dimensional data – indicated in Fig. 3 as encircled +s – may be rendered in a third color. Of course, this distance information may not be directly relevant because the rendered points have already been acquired in three-dimensional space. However, this color coding of the surface of the subject 304, as rendered through the acquired three-dimensional digital surface representation, may provide useful information to a user concerning the distance of the subject 304, particularly with respect to regions of the subject 304 that have not yet been scanned.

[00104] It will be appreciated that, while only a dozen or so points have been drawn in Fig. 3, a practical image capture system for use in dentistry and similar applications may require spatial resolution on the order of 100 microns or less for sufficient detail to fabricate properly fitting dental objects. As such, the actual point cloud acquired by the image capture system for a subject such as a dental arch may contain thousands, tens of thousands, hundreds of thousands, or millions of individual three-dimensional points, or more. While the small number of points in Fig. 3 may assist in demonstrating the nature of a point cloud distribution with reference to specific points, the larger number of points available in a typical scan can provide significantly improved visualization of surface contours and the like. It should also be appreciated that the points used to render the digital surface representation for display may include a subset of points in a full point cloud of acquired three-dimensional data, with the density of points selected according to any suitable design parameters including processing/rendering speed, need for contour visualization, and the like.

[00105] It will be appreciated that the capability of capturing highly detailed models of dental objects, and in particular, the capability of capturing highly detailed digital surface representations of dentition directly from an intraoral scan, enables an array of subsequent processing steps that may be useful to dentists, dental laboratory technicians, oral surgeons, and the like. A number of such applications are now described in greater detail.

[00106] The embodiments described in reference to Fig. 2 and Fig. 3 emphasize the use of an interface that displays a subject from a point of view of the scanner. However it will be understood that alternative models may be used, such as an interface that renders acquired data from a fixed point of view within a global coordinate system. In this approach, the generally visualization strategy may change, such as by providing continues feedback as to the position of the scanner relative to the subject. However, the visual cues described above may generally be adapted to such an environment, or other environments, in a number of ways as will be readily appreciated by one of skill in the art.

[00107] In general, a system as described herein may have a number of operating modes, such as a file management mode, a model editing mode, a model evaluation and/or analysis mode, a scanning mode, and so forth. Two such modes are described below with respect to Figs. 4-5 below, which show a scanning mode and an evaluation mode respectively.

[00108] Fig. 4 depicts a view of a user interface for an image capture system during an acquisition of three-dimensional data. The user interface 400 may include a window 402 including range-finding visual cues 404, 406, all as generally described above. Within the window 402, a video image may be displayed, such as a video image from a current point of view of a scanner, such as the scanner 102 described above. As depicted, the video image may include a plurality of teeth 410 and other intraoral structures visible during an intraoral scan. It will be noted that three-dimensional points acquired from the surface, i.e., the current digital surface representation, may be rendered within the user

interface 400, and more particularly, may be rendered from the point of view of the scanner and superimposed on the current video image.

[00109] In addition to permitting visual enhancements such as contour shading and feature emphasis, the rendering may provide specific feedback to a user concerning the current scan. For example, regions too close for capture of scan data may include previously acquired points, which may be rendered in the window 402 with a style or color that indicates their relative proximity to the scanner. Conversely, regions of the intraoral structures too far for capture may also, or instead, include previously acquired points, which may be rendered in the window 402 with a style or a color that indicates their relative distance from the scanner. As new surface data is acquired and added to the digital surface representation, the new point data may concurrently, or in real time or near real time, be added to the rendered view of the digital surface representation. In this manner, a user may receive immediate visual feedback, such as the density of rendered points, with respect to whether data is being successfully acquired from surfaces visible within the window 402. This information may indicate gaps in surface data so that a user can back up and rescan surfaces of the subject for which data has not been captured, or for which inadequate or defective data has been captured. This feedback may, in part flow directly from the process of rendering an increasing number of points within the window as new surface data is acquired. The visual feedback may also, or instead, be supplemented by rendering points with a density in the window 402 specifically selected to communicate to a user whether adequate data has been acquired from within the current view.

[00110] The visual metaphor may be one of spray painting the video image with a shaded surface map as points are acquired. The point cloud of the digital surface representation (or other representation) may be rendered as a growing constellation of points that forms over the video subject matter as data is acquired. Regions for which a target point density has been achieved may, for example appear as continuous surfaces, while regions with inadequate surface data may be rendered as discrete points having visible gaps therebetween, which gaps may be varied in size according to, e.g., the density of point data in the underlying digital surface representation. As another example, points may be rendered as uniformly spaced surface points, which may be color coded according to density of point data in the underlying digital surface representation.

[00111] In certain embodiments, the acquired digital model may be compared to a statistical, spatial, or other model of expected shapes relevant to dentistry (or other objects, for non-dental applications), using known machine vision and other techniques. This may include relatively subtle variations such as unexpected tooth contours, thicknesses, or the like, as well as gross deviations that are likely a result of user or equipment malfunction or loss of scan data. Where deviations from expectations are detected, these may be visually identified within the window 402 through use of color, shading, and other cues and annotations described generally above. Thus, algorithmically unexpected scan results may be immediately flagged during a scan for any suitable human intervention (which may, of course, be none where the unexpected feature is known by the operator to actually be present).

[00112] Fig. 5 depicts a view of a user interface for an image capture system during an evaluation. The window 500 may include a two-dimensionally rendered perspective view 502 of a stored digital surface representation, as well as a number of navigation controls 504 and other user controls for viewing, manipulating, and evaluating the digital surface representation. As depicted in Fig. 5, the digital surface representation includes a full arch, although it will be appreciated that any three-dimensional surface may be stored as a digital surface representation, including portions of teeth, one or more full teeth, soft tissue, quadrants, arches, dental objects such as hardware, appliances, prosthetics, and interim components of dental manufacture, as well as, in non-dental applications, any other object or objects.

[00113] In the window, gross errors in a digital model, such as a region 506 of omitted or missing scan data, may be intrinsically identified by the absence of visible point data. Other errors such as excessive variability of surface data may be intrinsically identified by fuzziness or excessive random texture. Visualization of scan quality may also, or instead, be augmented by explicit indicators, such as coloring, shading, surface texturing, or any of the other visual cues described above, which may visually

identify regions of incomplete scan data, inaccurate scan data, insufficient scan detail (such as where a restoration will be affixed) and the like.

[00114] Using the navigation controls 504, a user may rotate, pan, zoom in, or otherwise navigate around and within the digital model to more closely inspect areas of interest, or to view the model from a number of perspectives to visually inspect otherwise occluded features. One user control (not shown) may permit a user to return to data acquisition, e.g., the scanning mode of Fig. 4, to acquire additional data where a void or deviation is detected (either automatically or through human visual inspection). This control, or another control, may permit a user to select a specific point on the surface of the digital model (or the scan subject, although the distinction becomes trivial for highly detailed and accurate digital models) where the continuous scan is to be reacquired from the subject, as described for example in [attorney docket no. BRNT-0009-P01].

[00115] It will be appreciated that, while Fig. 5 depicts a two-dimensional rendering based upon a display of discrete surface points, other rendering techniques may be employed, such as a continuous surface map formed of polygons or other regular or irregular planar or non-planar surfaces.

[00116] Fig. 6 depicts a dental model in digital form, otherwise referred to herein as a digital surface representation, a three-dimensional representation, or the like. The dental model may be rendered, for example within a window 600 of the user interface described above with reference to Fig. 2 from a three-dimensional point cloud captured in a continuous intraoral scanning process as described above with reference to Fig. 1. The user interface may be adapted for use by a dentist (or dental laboratory) to review a surface preparation for a crown. It will be understood that in this mode, new data is not being acquired. Rather, a stored model may be processed through a combination of user interaction and automated analysis controlled through the user interface.

[00117] In operation, a dentist may prepare a tooth surface for a crown using suitable dental tools. The dentist or a dental technician may then acquire a scan from the dental patient's mouth including the prepared surface and any surrounding or opposing tooth structures. The dentist may then specify in the user interface a restoration type such as a crown, a bridge, a veneer, an inlay, an onlay, or the like. After receiving the dentist's specification of restoration type, an automated process may examine the surface preparation and surrounding dentition to ensure adequate physical clearance, taper, appropriate shape, and the like for the specific restoration type. The automated process, which may be performed, for example, by the computer 108 described above, may generate corresponding annotations which may be visual annotations for rendering with the model in a display, or textual annotations containing narrative description of conclusions, or a combination of these.

[00118] As depicted in Fig. 6, the three-dimensional representation of dentition may include including portions of two arches 602, 604 in occlusion (although the arches are in occlusion, there may be space between any pair of opposing teeth, as depicted in Fig. 4) and one surface 606 prepared for a crown. The portions of the arches 602, 604 may include single teeth, quadrants, full arches, or any other portions of one or more teeth or tooth surfaces useful for analyzing a crown surface preparation. It will also be understood that, while the arches are depicted in occlusion, the user interface may depict only one arch, or may depict the arches separated. Any automated analysis may be performed on the stored model, which may be manipulated to place the arches in occlusion, rather than the rendered model in the window, which may be in any configuration useful for display. After automated analysis, one or more regions may be highlighted with annotations or other visual cues such as an arrow 608 or surface effect 610 such as color, texturing, cross-hatching, or the like. For example, the arrow 608 may indicate a region of inadequate taper. As another example, the cross-hatched surface effect 610 may indicate an inadequate reduction of material at the butt joint margin. Other effects, such as use of different colors, different opacity or other surface treatment, different levels of surface detail or shading, highlighting, callouts, a trace or line around relevant regions, and so forth, may be similarly employed, either alone, or in combination with other effects. Within the interface, the annotations may be hyperlinked or otherwise active, so that a dentist may click on these annotations and receive narrative or other descriptive feedback. Where physical specifications for a particular restoration require additional removal, the regions to be removed may be depicted within the three-dimensional model using one or more visual cues for

identification by the dentist. In certain embodiments, regions recommended for removal may include a number of different possible regions for removal, such as the surface preparation and/or an opposing tooth surface.

[00119] A process of preparing a tooth surface, scanning, and analyzing may be applied iteratively to refine a surface preparation. In an iterative process, a dentist may repeat steps of tooth removal and scanning until a satisfactory surface preparation is achieved.

[00120] It will be understood that correct specifications for a particular restoration may vary from dentist to dentist, from laboratory to laboratory, from manufacturer to manufacturer, and from tooth to tooth (e.g., anterior v. posterior crowns). For example, occlusion and clearance for incisal tooth surfaces may be analyzed differently from occlusion and clearance for molar occlusal surfaces. As another example, different dentists may have different preferences for tightness of fit for a prosthetic to a prepared tooth surface. However, the types of features that might be specified may generally relate to features of the prepared surface such as taper (angling of prepared surfaces to accommodate placement of the prosthetic), draw path (taper, as well as physical clearance from neighboring dentition such as adjacent and opposing teeth), reduction of surfaces (to accommodate physical structure of prosthetic), clearance from opposing teeth, adequacy of margin, and so forth. Any features that can be objectively characterized, such as curvature, taper, clearance, and the like, can be tested for against an accurate three-dimensional representation of an actual surface preparation, with suitable visualizations generated to guide a dentist in improving or accepting a preparation. In certain cases, such as a bridge, multiple teeth must be prepared. The analysis described herein may include an analysis of draw path for the multi-tooth preparation that ensures a fit is physically possible. Thus, it will be appreciated that, more generally, analysis of a surface preparation may include a multi-tooth surface preparation for a single dental object.

[00121] While reviewing a crown surface preparation is one useful application of the analysis and visualization tool described above, it will be understood that the techniques above may be similarly applied to a variety of dental objects, including restorations, hardware, appliances, and the like, as well as any region of diagnostic or other significance that can be objectively characterized for automated analysis.

[00122] Fig. 7 depicts a cross-section of a digital dental model. The cross section 700 may be rendered within a window of a user interface, as described generally above. As a visualization tool, the user interface may permit a dentist to review a cross-section of the dental model to permit more accurate assessment of dimensions, orientation, and so forth. The user interface may also permit placement of a virtual prosthetic 702, in this case a posterior crown, onto the digital model 704. A collision 706 between the models, as depicted in Fig. 5 as an inadequate occlusal reduction under the deepest fossa pit 708 of the prosthetic 702, may be displayed in any manner, such as shading, coloring, or mixing of cross-hatching styles for overlapped models.

[00123] Fig. 8 depicts a visualization technique for locating holes in a digital surface representation of dental subject matter. A window 800 of a user interface, which may include any of the user interfaces described above, may include a two-dimensionally rendered perspective view 802 of a stored digital surface representation, as well as a number of navigation controls 804 and other user controls for viewing, manipulating, and evaluating the digital surface representation. As depicted in Fig. 8, the digital surface representation includes a full arch, although it will be appreciated that any three-dimensional surface may be stored as a digital surface representation, including portions of teeth, one or more full teeth, soft tissue, quadrants, arches, dental objects such as hardware, appliances, prosthetics, and interim components of dental manufacture, or various combinations of any of the foregoing, as well as, in non-dental applications, any other object or objects. The figure shows a visualization of gaps in surface data, which may be used, for example, in an analysis or evaluation mode of the image capture system.

[00124] As shown in Fig. 8, a hole 806 in the digital surface representation may be visualized by simulating an internal illumination of the digital model, with rays 808 of light passing through the hole. The visual effect may be, for example, a flashlight or other metaphor to simulate internal illumination. The rays 808 may be depicted literally as lines, as shown in the figure, or as a glow emanating from the hole 806, or as a corresponding illumination of a dark background for the view 802,

or as a combination of these. Other techniques for visualizing illumination may similarly be employed, such as shadows cast upon neighboring contours and surfaces of the digital model, and so forth. Any such techniques that simulate an internal illumination of the digital surface representation may be suitably employed to indicate the presence, size, and/or shape of holes in the surface data.

[00125] It will be appreciated that a hole is a relative term, particularly for a digital surface representation formed from a set of discrete three-dimensional points. Holes may be identified, for example, as regions of relatively low point density, or a point density below a predetermined threshold, such as a density adequate for fabricating physical dental models or for performing dental diagnosis or requesting fabrication of a prosthetic. The threshold or other parameters used to identify holes may be user selected, so that data density may be controlled according to, for example, user preferences, desired scan speed, or an intended end use of the digital model. In addition, the threshold or parameters may be varied over the surface of the digital model, such as by requiring greater point density around a region of a surface preparation for a dental prosthetic.

[00126] Using the navigation controls 804, a user may rotate, pan, zoom in, or otherwise navigate around and within the digital model to more closely inspect areas of interest, or to view the model from a number of perspectives to visually inspect otherwise occluded features. One user control (not shown) may permit a user to return to data acquisition, e.g., the scanning mode of Fig. 4, to acquire additional data where a void or deviation is detected (either automatically or through human visual inspection). This control, or another control, may permit a user to select a specific point on the surface of the digital model (or the scan subject, although the distinction becomes trivial for highly detailed and accurate digital models) where the continuous scan is to be reacquired from the subject, as described for example in [attorney docket no. BRNT-0009-P01].

[00127] Fig. 9 depicts a visualization technique using a simulated external illumination. A window 900 of a user interface, which may be any of the user interfaces described above, may include a two-dimensionally rendered perspective view 902 of a stored digital surface representation, as well as a number of navigation controls 904 and other user controls for viewing, manipulating, and evaluating the digital surface representation. As depicted in Fig. 9, the digital surface representation includes a full arch, although it will be appreciated that any three-dimensional surface may be stored as a digital surface representation, including portions of teeth, one or more full teeth, soft tissue, quadrants, arches, dental objects such as hardware, appliances, prosthetics, and interim components of dental manufacture, or various combinations of any of the foregoing, as well as, in non-dental applications, any other object or objects. The figure shows a visualization of external illumination of the model, which may be used, for example, in an analysis or evaluation mode of the image capture system.

[00128] As shown in Fig. 9, an illumination beam 910 may be visualized as emanating from a scanner 908 or other object within the window 900 and falling upon a region 906 of the view 902 of the digital model. An orientation and position of the scanner 908 may be controlled using the controls 904 within the window 900 of the user interface. The visual effect may be, for example, that of a flashlight or spotlight, or some other metaphor to simulate a beam of illumination external to the view 902 of the digital model. Rays 910 of illumination may be depicted literally as lines, as shown in the figure, or as a lighted beam emanating from the scanner 908, or as a corresponding illumination of a dark background for the view 902, or as a combination of these. Other techniques for visualizing illumination may similarly be employed, such as shadows cast upon the "illuminated" contours and surfaces of the digital model, and so forth. Any such techniques that simulate an internal illumination of the digital surface representation may be suitably employed.

[00129] The simulated external illumination beam may serve a number of purposes within the user interface. For example, in one scanning model where the view 902 remains fixed, the rays 910 of the illumination beam may serve to localize the scanner 908 with respect to the underlying physical model that is the subject of a scan. In this model, or other models, the illuminated region 906 of the surface may correspond to a region from which data is being acquired. The illuminated region 906 may correspond, for example, to a field of view of the scanner 908. In other embodiments, the illuminated region 906 may correspond to a location selected for reacquiring a paused scan. This localization information may permit

a selection of one or more corresponding frames of source scanner data to improve efficiency of a reacquisition process.

[00130] It will be appreciated that a hole is a relative term, particularly for a digital surface representation formed from a set of discrete three-dimensional points. Holes may be identified, for example, as regions of relatively low point density, or a point density below a predetermined threshold, such as a density adequate for fabricating physical dental models or for performing dental diagnosis or requesting fabrication of a prosthetic. The threshold or other parameters used to identify holes may be user selected, so that data density may be controlled according to, for example, user preferences, desired scan speed, or an intended end use of the digital model. In addition, the threshold or parameters may be varied over the surface of the digital model, such as by requiring greater point density around a region of a surface preparation for a dental prosthetic.

[00131] Using the navigation controls 804, a user may rotate, pan, zoom in, or otherwise navigate around and within the digital model to more closely inspect areas of interest, or to view the model from a number of perspectives to visually inspect otherwise occluded features. One user control (not shown) may permit a user to return to data acquisition, e.g., the scanning mode of Fig. 4, to acquire additional data where a void or deviation is detected (either automatically or through human visual inspection). This control, or another control, may permit a user to select a specific point on the surface of the digital model (or the scan subject, although the distinction becomes trivial for highly detailed and accurate digital models) where the continuous scan is to be reacquired from the subject, as described for example in [attorney docket no. BRNT-0009-P01].

[00132] It will be appreciated that the processes and methods disclosed above may be realized in hardware, software, or any combination of these suitable for the three-dimensional imaging and modeling techniques described herein. It will also be appreciated that the user interfaces, user interface controls, and methods of using same, as well as the visualizations, digital model processing and analysis, and rendering as described herein may similarly be expressed as methods or processes embodied in hardware, software, and various combinations thereof. This includes realization in one or more microprocessors, microcontrollers, embedded microcontrollers, programmable digital signal processors or other programmable devices, along with internal and/or external memory. The may also, or instead, include one or more application specific integrated circuits, programmable gate arrays, programmable array logic components, or any other device or devices that may be configured to process electronic signals. It will further be appreciated that a realization may include computer executable code created using a structured programming language such as C, an object oriented programming language such as C++, or any other high-level or low-level programming language (including assembly languages, hardware description languages, and database programming languages and technologies) that may be stored, compiled or interpreted to run on one of the above devices, as well as heterogeneous combinations of processors, processor architectures, or combinations of different hardware and software. At the same time, processing may be distributed across devices such as a camera and/or computer in a number of ways or all of the functionality may be integrated into a dedicated, standalone image capture device. All such permutations and combinations are intended to fall within the scope of the present disclosure.

[00133] It will also be appreciated that means for performing the steps associated with the processes described above may include any suitable components of the image capture system 100 described above with reference to Fig. 1, along with any software and/or hardware suitable for controlling operation of same. The user interfaces described herein may, for example, be rendered within the display 110 of the image capture system 100 of Fig. 1. All such realizations and means for performing the processes disclosed herein are intended to fall within the scope of this disclosure.

[00134] While the invention has been disclosed in connection with certain preferred embodiments, other embodiments will be recognized by those of ordinary skill in the art, and all such variations, modifications, and substitutions are intended to fall within the scope of this disclosure. Thus, the invention is to be understood with reference to the following claims, which are to be interpreted in the broadest sense allowable by law.

CLAIMS:

What is claimed is:

1. A method comprising:
 - providing a dental model in digital form, the dental model including a three-dimensional representation of one or more tooth surfaces of a first dental arch, the one or more tooth surfaces of the first dental arch including a tooth prepared for a crown, and a three-dimensional representation of one or more tooth surfaces of a second dental arch, wherein the first dental arch and the second dental arch are in occlusion;
 - identifying one or more regions of the dental model requiring surface preparation to accommodate the crown; and
 - displaying the dental model with a visual cue for the one or more regions.
2. The method of claim 1, wherein the one or more regions include a region of inadequate clearance for the crown.
3. The method of claim 1, wherein the one or more regions include a region of inadequate surface preparation.
4. The method of claim 1, wherein the one or more regions include a region on a tooth that opposes the tooth prepared for the crown.
5. The method of claim 1, wherein the one or more regions include a path of draw for the crown.
6. The method of claim 5, wherein the visual cue includes display of the path of draw superimposed on the dental model.
7. The method of claim 5, wherein the path of draw includes a suggested clearance from one or more adjacent teeth.
8. The method of claim 5, wherein the path of draw includes a suggested shape of the tooth prepared for the crown.
9. The method of claim 5, wherein the path of draw includes a suggested size of the tooth prepared for the crown.
10. The method of claim 1, wherein the visual cue includes display of the one or more regions in a different color than other regions of the dental model.
11. The method of claim 1, wherein the visual cue includes display of the one or more regions with a different opacity than other regions of the dental model.
12. The method of claim 1, wherein the visual cue includes display of the one or more regions with a different level of detail than other regions of the dental model.
13. The method of claim 1, wherein the visual cue includes display of the one or more regions with a different surface treatment than other regions of the dental model.
14. The method of claim 1, wherein the visual cue includes display of a trace around at least some portion of the one or more regions.

15. The method of claim 1, wherein the visual cue includes display of an arrow pointing toward at least one of the one or more regions.
16. The method of claim 1, wherein the visual cue includes display of a callout associated with the one or more regions.
17. A computer program product comprising computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of:
 processing a dental model in digital form, the dental model including a three-dimensional representation of one or more tooth surfaces of a first dental arch, the one or more tooth surfaces of the first dental arch including a tooth prepared for a crown, and a three-dimensional representation of one or more tooth surfaces of a second dental arch, wherein the first dental arch and the second dental arch are in occlusion;
 identifying one or more regions of the dental model requiring tooth removal to accommodate the crown; and
 rendering an image of the dental model with a visual cue for the one or more regions, the image suitable for output to a display.
18. The computer program product of claim 17, wherein the one or more regions include a region of inadequate clearance for the crown.
19. The computer program product of claim 17, wherein the one or more regions include a region of inadequate surface preparation.
20. The computer program product of claim 17, wherein the one or more regions include a region on a tooth that opposes the tooth prepared for the crown.
21. The computer program product of claim 17, wherein the one or more regions include a path of draw for the crown.
22. The computer program product of claim 21, wherein the visual cue includes the path of draw.
23. The computer program product of claim 21, wherein the path of draw includes a suggested clearance from one or more adjacent teeth.
24. The computer program product of claim 21, wherein the path of draw includes a suggested shape of the tooth prepared for the crown.
25. The computer program product of claim 21, wherein the path of draw includes a suggested size of the tooth prepared for the crown.
26. The computer program product of claim 17, wherein the visual cue includes rendering the one or more regions in a different color than other regions of the dental model.
27. The computer program product of claim 17, wherein the visual cue includes rendering the one or more regions with a different opacity than other regions of the dental model.
28. The computer program product of claim 17, wherein the visual cue includes rendering the one or more regions with a different level of detail than other regions of the dental model.

29. The computer program product of claim 17, wherein the visual cue includes rendering the one or more regions with a different surface treatment than other regions of the dental model.
30. The computer program product of claim 17, wherein the visual cue includes a trace around at least some portion of the one or more regions.
31. The computer program product of claim 17, wherein the visual cue includes an arrow pointing toward at least one of the one or more regions.
32. The computer program product of claim 17, wherein the visual cue includes a callout associated with the one or more regions.
33. A system comprising:
a model means for providing a dental model in digital form, the dental model including a three-dimensional representation of one or more tooth surfaces of a first dental arch, the one or more tooth surfaces of the first dental arch including a tooth prepared for a crown, and a three-dimensional representation of one or more tooth surfaces of a second dental arch, wherein the first dental arch and the second dental arch are in occlusion;
an identification means for identifying one or more regions of the dental model requiring tooth removal to accommodate the crown; and
a display means for displaying the dental model with a visual cue for the one or more regions.
34. The system of claim 33, wherein the one or more regions include a region of inadequate clearance for the crown.
35. The system of claim 33, wherein the one or more regions include a region of inadequate surface preparation.
36. The system of claim 33, wherein the one or more regions include a region on a tooth that opposes the tooth prepared for the crown.
37. The system of claim 33, wherein the one or more regions include a path of draw for the crown.
38. The system of claim 37, wherein the visual cue includes the path of draw superimposed on the dental model.
39. The system of claim 37, wherein the path of draw includes a suggested clearance from one or more adjacent teeth.
40. The system of claim 37, wherein the path of draw includes a suggested shape of the tooth prepared for the crown.
41. The system of claim 37, wherein the path of draw includes a suggested size of the tooth prepared for the crown.
42. The system of claim 33, wherein the visual cue includes a means for coloring the one or more regions in a different color than other regions of the dental model.
43. The system of claim 33, wherein the visual cue includes a means for representing the one or more regions with a different opacity than other regions of the dental model.

44. The system of claim 33, wherein the visual cue includes a means for detailing the one or more regions with a different level of detail than other regions of the dental model.
45. The system of claim 33, wherein the visual cue includes a means for treating the one or more regions with a different surface treatment than other regions of the dental model.
46. The system of claim 33, wherein the visual cue includes a means for tracing around at least some portion of the one or more regions.
47. The system of claim 33, wherein the visual cue includes an arrow pointing toward at least one of the one or more regions.
48. The system of claim 33, wherein the visual cue includes a callout associated with the one or more regions.
49. A method comprising:
 providing a dental model in digital form, the dental model including a three-dimensional representation of one or more tooth surfaces of a first dental arch and a three-dimensional representation of one or more tooth surfaces of a second dental arch, wherein the first dental arch and the second dental arch are in occlusion;
 identifying one or more regions of diagnostic significance in the dental model between the one or more tooth surfaces of the first dental arch and the one or more tooth surfaces of the second dental arch;
 and
 displaying the dental model with a visual cue for the one or more regions of diagnostic significance.
50. The method of claim 49, wherein the one or more tooth surfaces of the first dental arch include at least one occlusal surface.
51. The method of claim 50, wherein the at least one occlusal surface includes an incisal surface of a front tooth.
52. The method of claim 50, wherein the at least one occlusal surface includes a surface of a molar.
53. The method of claim 49, wherein the one or more tooth surfaces of the first dental arch include a full dental arch.
54. The method of claim 49, wherein the one or more tooth surfaces of the first dental arch include a quadrant.
55. The method of claim 49, wherein the one or more tooth surfaces of the second dental arch include a full dental arch.
56. The method of claim 49, wherein the one or more tooth surfaces of the second dental arch include a quadrant.
57. The method of claim 49, wherein identifying one or more regions of diagnostic significance includes identifying a region recommended for removal.
58. The method of claim 57, wherein the region recommended for removal includes one or more cusps.

59. The method of claim 57, wherein the region recommended for removal includes a region that contributes to unbalanced occlusion.
60. The method of claim 57, wherein the region recommended for removal includes a region of inadequate clearance for a dental prosthetic.
61. The method of claim 57, wherein the region recommended for removal includes a region requiring additional surface preparation.
62. The method of claim 57, wherein the region recommended for removal includes a region on a tooth that opposes a surface preparation.
63. The method of claim 49, wherein identifying one or more regions of diagnostic significance includes identifying a region requiring additional data acquisition.
64. The method of claim 49, wherein identifying one or more regions of diagnostic significance includes identifying a path of draw for a dental prosthetic.
65. The method of claim 64, wherein the visual cue includes display of the path of draw superimposed on the dental model.
66. The method of claim 64, wherein the path of draw includes suggested clearance from one or more adjacent teeth.
67. The method of claim 64, wherein the path of draw includes suggested shape of surface preparation.
68. The method of claim 64, wherein the path of draw includes suggested size of surface preparation.
69. The method of claim 49, wherein the visual cue includes display of the one or more regions of diagnostic significance in a different color than other regions of the dental model.
70. The method of claim 49, wherein the visual cue includes display of the one or more regions of diagnostic significance with a different opacity than other regions of the dental model.
71. The method of claim 49, wherein the visual cue includes display of the one or more regions of diagnostic significance with a different level of detail than other regions of the dental model.
72. The method of claim 49, wherein the visual cue includes display of the one or more regions of diagnostic significance with a different surface treatment than other regions of the dental model.
73. The method of claim 49, wherein the visual cue includes display of a trace around at least some portion of the one or more regions.
74. The method of claim 49, wherein the visual cue includes display of an arrow pointing toward at least one of the one or more regions.
75. The method of claim 49, wherein the visual cue includes display of a callout associated with the one or more regions.
76. A computer program product comprising computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of:

processing a dental model in digital form, the dental model including a three-dimensional representation of one or more tooth surfaces of a first dental arch and a three-dimensional representation of one or more tooth surfaces of a second dental arch, wherein the first dental arch and the second dental arch are in occlusion;

identifying one or more regions of diagnostic significance in the dental model between the one or more tooth surfaces of the first dental arch and the one or more tooth surfaces of the second dental arch; and

generating an image of the dental model with a visual cue for the one or more regions of diagnostic significance, the image suitable for output to a display.

77. The computer program product of claim 76, wherein the one or more tooth surfaces of the first dental arch include at least one occlusal surface.

78. The computer program product of claim 77, wherein the at least one occlusal surface includes an incisal surface of a front tooth.

79. The computer program product of claim 77, wherein the at least one occlusal surface includes a surface of a molar.

80. The computer program product of claim 76, wherein the one or more tooth surfaces of the first dental arch include a full dental arch.

81. The computer program product of claim 76, wherein the one or more tooth surfaces of the first dental arch include a quadrant.

82. The computer program product of claim 76, wherein the one or more tooth surfaces of the second dental arch include a full dental arch.

83. The computer program product of claim 76, wherein the one or more tooth surfaces of the second dental arch include a quadrant.

84. The computer program product of claim 76, wherein identifying one or more regions of diagnostic significance includes identifying a region recommended for removal.

85. The computer program product of claim 84, wherein the region recommended for removal includes one or more cusps.

86. The computer program product of claim 84, wherein the region recommended for removal includes a region that contributes to unbalanced occlusion.

87. The computer program product of claim 84, wherein the region recommended for removal includes a region of inadequate clearance for a dental prosthetic.

88. The computer program product of claim 84, wherein the region recommended for removal includes a region requiring additional surface preparation.

89. The computer program product of claim 84, wherein the region recommended for removal includes a region on a tooth that opposes a surface preparation.

90. The computer program product of claim 76, wherein identifying one or more regions of diagnostic significance includes identifying a region requiring additional data acquisition.

91. The computer program product of claim 76, wherein identifying one or more regions of diagnostic significance includes identifying a path of draw for a dental prosthetic.

92. The computer program product of claim 91, wherein the visual cue includes display of the path of draw superimposed on the dental model.

93. The computer program product of claim 91, wherein the path of draw includes suggested clearance from one or more adjacent teeth.

94. The computer program product of claim 91, wherein the path of draw includes suggested shape of surface preparation.

95. The computer program product of claim 91, wherein the path of draw includes suggested size of surface preparation.

96. The computer program product of claim 76, wherein the visual cue includes rendering the one or more regions of diagnostic significance in a different color than other regions of the dental model.

97. The computer program product of claim 76, wherein the visual cue includes rendering the one or more regions of diagnostic significance with a different opacity than other regions of the dental model.

98. The computer program product of claim 76, wherein the visual cue includes rendering the one or more regions of diagnostic significance with a different level of detail than other regions of the dental model.

99. The computer program product of claim 76, wherein the visual cue includes rendering the one or more regions of diagnostic significance with a different surface treatment than other regions of the dental model.

100. The computer program product of claim 76, wherein the visual cue includes a trace around at least some portion of the one or more regions.

101. The computer program product of claim 76, wherein the visual cue includes an arrow pointing toward at least one of the one or more regions.

102. The computer program product of claim 76, wherein the visual cue includes a callout associated with the one or more regions.

103. A system comprising:

a model means for providing a dental model in digital form, the dental model including a three-dimensional representation of one or more tooth surfaces of a first dental arch and a three-dimensional representation of one or more tooth surfaces of a second dental arch, wherein the first dental arch and the second dental arch are in occlusion;

an identity means for identifying one or more regions of diagnostic significance in the dental model between the one or more tooth surfaces of the first dental arch and the one or more tooth surfaces of the second dental arch; and

a display means for displaying the dental model with a visual cue for the one or more regions of diagnostic significance.

104. The system of claim 103, wherein the one or more tooth surfaces of the first dental arch include at least one occlusal surface.

105. The system of claim 104, wherein the at least one occlusal surface includes an incisal surface of a front tooth.

106. The system of claim 104, wherein the at least one occlusal surface includes a surface of a molar.

107. The system of claim 103, wherein the one or more tooth surfaces of the first dental arch include a full dental arch.

108. The system of claim 103, wherein the one or more tooth surfaces of the first dental arch include a quadrant.

109. The system of claim 103, wherein the one or more tooth surfaces of the second dental arch include a full dental arch.

110. The system of claim 103, wherein the one or more tooth surfaces of the second dental arch include a quadrant.

111. The system of claim 103, wherein identifying one or more regions of diagnostic significance includes identifying a region recommended for removal.

112. The system of claim 111, wherein the region recommended for removal includes one or more cusps.

113. The system of claim 111, wherein the region recommended for removal includes a region that contributes to unbalanced occlusion.

114. The system of claim 111, wherein the region recommended for removal includes a region of inadequate clearance for a dental prosthetic.

115. The system of claim 111, wherein the region recommended for removal includes a region requiring additional surface preparation.

116. The system of claim 111, wherein the region recommended for removal includes a region on a tooth that opposes a surface preparation.

117. The system of claim 103, wherein identifying one or more regions of diagnostic significance includes identifying a region requiring additional data acquisition.

118. The system of claim 103, wherein identifying one or more regions of diagnostic significance includes identifying a path of draw for a dental prosthetic.

119. The system of claim 118, wherein the visual cue includes display of the path of draw superimposed on the dental model.

120. The system of claim 118, wherein the path of draw includes suggested clearance from one or more adjacent teeth.

121. The system of claim 118, wherein the path of draw includes suggested shape of surface preparation.

122. The system of claim 118, wherein the path of draw includes suggested size of surface preparation.

123. The system of claim 103, wherein the visual cue includes a means for coloring the one or more regions of diagnostic significance in a different color than other regions of the dental model.

124. The system of claim 103, wherein the visual cue includes a means for representing the one or more regions of diagnostic significance with a different opacity than other regions of the dental model.

125. The system of claim 103, wherein the visual cue includes a means for detailing the one or more regions of diagnostic significance with a different level of detail than other regions of the dental model.

126. The system of claim 103, wherein the visual cue includes a means for representing the one or more regions of diagnostic significance with a different surface treatment than other regions of the dental model.

127. The system of claim 103, wherein the visual cue includes a trace around at least some portion of the one or more regions.

128. The system of claim 103, wherein the visual cue includes an arrow pointing toward at least one of the one or more regions.

129. The system of claim 103, wherein the visual cue includes a callout associated with the one or more regions.

130. A method comprising:
 acquiring a three-dimensional surface representation of an anatomic structure as a plurality of fitted three-dimensional surface scans; and
 superimposing the digital surface representation onto a two-dimensional video image of the anatomic structure in a display in real time while acquiring the three-dimensional surface representation.

131. The method of claim 130, further comprising identifying one or more regions of the anatomic structure requiring additional scanning.

132. The method of claim 131, wherein one or more regions include a region of inadequate point cloud density.

133. The method of claim 131, wherein one or more regions include a region deviating substantially from an expected surface contour.

134. The method of claim 131, further comprising providing a visual indicator of the one or more regions within the display.

135. The method of claim 134, wherein visual indicator includes a variation in color.

136. The method of claim 134, wherein visual indicator includes a variation in point cloud density in the display.

137. The method of claim 134, wherein visual indicator includes a variation in surface texture.

138. The method of claim 130, wherein the three-dimensional surface representation includes a three-dimensional point cloud.

139. A computer program product comprising computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of:
generating a three-dimensional surface representation of an anatomic structure from a plurality of fitted three-dimensional surface scans; and
superimposing the digital surface representation onto a two-dimensional video image of the anatomic structure for display in real time while generating the three-dimensional surface representation.
140. The computer program product of claim 139, further comprising computer code to perform the step of identifying one or more regions of the anatomic structure requiring additional scanning.
141. The computer program product of claim 140, wherein one or more regions include a region of inadequate point cloud density.
142. The computer program product of claim 140, wherein one or more regions include a region deviating substantially from an expected surface contour.
143. The computer program product of claim 140, further comprising computer code to perform the step of providing a visual indicator of the one or more regions within the display.
144. The computer program product of claim 143, wherein visual indicator includes a variation in color.
145. The computer program product of claim 143, wherein visual indicator includes a variation in point cloud density in the display.
146. The computer program product of claim 143, wherein visual indicator includes a variation in surface texture.
147. The computer program product of claim 139, wherein the three-dimensional surface representation includes a three-dimensional point cloud.
148. A system comprising:
an acquisition means for acquiring a three-dimensional surface representation of an anatomic structure as a plurality of fitted three-dimensional surface scans; and
a display means for superimposing the digital surface representation onto a two-dimensional video image of the anatomic structure in a display in real time while acquiring the three-dimensional surface representation.
149. The system of claim 148, further comprising a means for identifying one or more regions of the anatomic structure requiring additional scanning.
150. The system of claim 149, wherein one or more regions include a region of inadequate point cloud density.
151. The system of claim 149, wherein one or more regions include a region deviating substantially from an expected surface contour.
152. The system of claim 149, further comprising an indication means for providing a visual indicator of the one or more regions within the display.
153. The system of claim 152, wherein visual indicator includes a variation in color.

154. The system of claim 152, wherein visual indicator includes a variation in point cloud density in the display.

155. The system of claim 152, wherein visual indicator includes a variation in surface texture.

156. The system of claim 148, wherein the three-dimensional surface representation includes a three-dimensional point cloud.

157. A method comprising:

- constructing a three-dimensional surface representation of an object from a plurality of image data sets, each image data set representing a portion of the object from a point of view;
- acquiring a new image data set from a new point of view of the object;
- updating the three-dimensional surface representation based upon the new image data set;
- acquiring a video image of the object from the new point of view;
- rendering the three-dimensional surface representation from the new point of view to provide a rendered surface representation; and
- superimposing the rendered surface representation on the video image in a display.

158. The method of claim 157, wherein the three-dimensional surface representation includes a plurality of three-dimensional points.

159. The method of claim 157, wherein the plurality of image data sets includes two-dimensional image data.

160. The method of claim 157, wherein the plurality of image data sets includes three-dimensional surface data.

161. The method of claim 157, wherein the object includes a dental object.

162. The method of claim 161, wherein the object includes dentition in a mouth of a dental patient.

163. The method of claim 161, wherein the object includes a dental model.

164. The method of claim 161, wherein the object includes a dental prosthetic.

165. The method of claim 161, wherein the object includes dental hardware.

166. The method of claim 161, wherein the object includes a dental filling.

167. The method of claim 161, wherein the object includes a dental appliance.

168. The method of claim 161, wherein the object includes an orthodontic fixture.

169. The method of claim 157, wherein the video image includes a two-dimensional video image.

170. The method of claim 157, wherein the display includes a two-dimensional display.

171. The method of claim 157, wherein rendering includes rendering one or more discrete three-dimensional points of the digital surface representation.

172. The method of claim 157, wherein the new image data set is acquired at a video rate.

173. The method of claim 157, wherein rendering includes rendering in two dimensions.
174. The method of claim 157, further comprising displaying the rendered surface representation superimposed on the video image in real time.
175. The method of claim 157, wherein the three-dimensional surface representation includes a region of incomplete scan, the method further comprising acquiring one or more supplemental image data sets from the region of incomplete scan.
176. The method of claim 157, wherein the three-dimensional surface representation includes a region of incomplete scan, the method further comprising visually indicating the region of incomplete scan in the display.
177. The method of claim 176, wherein visually indicating includes rendering the digital surface representation as a plurality of discrete points having a rendered density corresponding to an actual density of points in the digital surface representation.
178. A computer program product comprising computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of:
 constructing a three-dimensional surface representation of an object from a plurality of image data sets, each image data set representing a portion of the object from a point of view;
 selecting a new image data set from a new point of view of the object;
 updating the three-dimensional surface representation based upon the new image data set;
 selecting a video image of the object from the new point of view;
 rendering the three-dimensional surface representation from the new point of view to provide a rendered surface representation; and
 superimposing the rendered surface representation on the video image to provide an image suitable for output to a display.
179. The computer program product of claim 178, wherein the three-dimensional surface representation includes a plurality of three-dimensional points.
180. The computer program product of claim 178, wherein the plurality of image data sets includes two-dimensional image data.
181. The computer program product of claim 178, wherein the plurality of image data sets includes three-dimensional surface data.
182. The computer program product of claim 178, wherein the object includes a dental object.
183. The computer program product of claim 182, wherein the object includes dentition in a mouth of a dental patient.
184. The computer program product of claim 182, wherein the object includes a dental model.
185. The computer program product of claim 182, wherein the object includes a dental prosthetic.
186. The computer program product of claim 182, wherein the object includes dental hardware.
187. The computer program product of claim 182, wherein the object includes a dental filling.

188. The computer program product of claim 182, wherein the object includes a dental appliance.
189. The computer program product of claim 182, wherein the object includes an orthodontic fixture.
190. The computer program product of claim 178, wherein the video image includes a two-dimensional video image.
191. The computer program product of claim 178, wherein the display includes a two-dimensional display.
192. The computer program product of claim 178, wherein rendering includes rendering one or more discrete three-dimensional points of the digital surface representation.
193. The computer program product of claim 178, wherein the new image data set is acquired at a video rate.
194. The computer program product of claim 178, wherein rendering includes rendering in two dimensions.
195. The computer program product of claim 178, further comprising computer code to perform the step of displaying the rendered surface representation superimposed on the video image in real time.
196. The computer program product of claim 178, wherein the three-dimensional surface representation includes a region of incomplete scan, the computer program product further comprising computer code to perform the step of acquiring one or more supplemental image data sets from the region of incomplete scan.
197. The computer program product of claim 178, wherein the three-dimensional surface representation includes a region of incomplete scan, the computer program product further comprising computer code to perform the step of visually indicating the region of incomplete scan in the display.
198. The computer program product of claim 197, wherein visually indicating the region of incomplete scan includes rendering the digital surface representation as a plurality of discrete points having a rendered density corresponding to an actual density of points in the digital surface representation.
199. A system comprising:
 a means for reconstructing a three-dimensional surface representation of an object from a plurality of image data sets, each image data set representing a portion of the object from a point of view;
 a first acquisition means for acquiring a new image data set from a new point of view of the object;
 an update means for updating the three-dimensional surface representation based upon the new image data set;
 a video acquisition means for acquiring a video image of the object from the new point of view;
 a drawing means for rendering the three-dimensional surface representation from the new point of view to provide a rendered surface representation; and
 a display means for superimposing the rendered surface representation on the video image in a display.
200. The system of claim 199, wherein the three-dimensional surface representation includes a plurality of three-dimensional points.

201. The system of claim 199, wherein the plurality of image data sets includes two-dimensional image data.
202. The system of claim 199, wherein the plurality of image data sets includes three-dimensional surface data.
203. The system of claim 199, wherein the object includes a dental object.
204. The system of claim 203, wherein the object includes dentition in a mouth of a dental patient.
205. The system of claim 203, wherein the object includes a dental model.
206. The system of claim 203, wherein the object includes a dental prosthetic.
207. The system of claim 203, wherein the object includes dental hardware.
208. The system of claim 203, wherein the object includes a dental filling.
209. The system of claim 203, wherein the object includes a dental appliance.
210. The system of claim 203, wherein the object includes an orthodontic fixture.
211. The system of claim 199, wherein the video image includes a two-dimensional video image.
212. The system of claim 199, wherein the display includes a two-dimensional display.
213. The system of claim 199, wherein the drawing means includes a means for rendering one or more discrete three-dimensional points of the digital surface representation.
214. The system of claim 199, wherein the new image data set is acquired at a video rate.
215. The system of claim 199, wherein the display means includes a means for rendering in two dimensions.
216. The system of claim 199, further comprising a real time display means for displaying the rendered surface representation superimposed on the video image in real time.
217. The system of claim 199, wherein the three-dimensional surface representation includes a region of incomplete scan, the system further comprising a means for acquiring one or more supplemental image data sets from the region of incomplete scan.
218. The system of claim 199, wherein the three-dimensional surface representation includes a region of incomplete scan, the system further comprising a means for visually indicating the region of incomplete scan in the display.
219. The system of claim 218, wherein the means for visually indicating the region of incomplete scan includes a means for rendering the digital surface representation as a plurality of discrete points having a rendered density corresponding to an actual density of points in the digital surface representation.
220. A method comprising:

displaying a digital surface representation of a dental object; and
simulating within the display an internal illumination for the dental object wherein light is emitted from any holes in the digital surface representation.

221. The method of claim 220, further comprising acquiring additional surface scan data to fill any holes in the digital surface representation.

222. The method of claim 220, wherein the holes include regions of the digital surface representation having a point density below a predetermined threshold.

223. The method of claim 220, wherein the dental object includes dentition.

224. The method of claim 220, wherein the dental object includes a restoration.

225. The method of claim 220, wherein the dental object includes a prosthetic.

226. The method of claim 220, wherein the dental object includes an appliance.

227. The method of claim 220, wherein the dental object includes an item of dental hardware.

228. The method of claim 220, wherein the dental object includes an interim component of dental manufacture.

229. A computer program product comprising computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of:
rendering an image of a digital surface representation of a dental object, the image suitable for output to a display; and
simulating within the image an internal illumination for the dental object wherein light is emitted from any holes in the digital surface representation.

230. The computer program product of claim 229, wherein the holes include regions of the digital surface representation having a point density below a predetermined threshold.

231. The computer program product of claim 229, wherein the dental object includes dentition.

232. The computer program product of claim 229, wherein the dental object includes a restoration.

233. The computer program product of claim 229, wherein the dental object includes a prosthetic.

234. The computer program product of claim 229, wherein the dental object includes an appliance.

235. The computer program product of claim 229, wherein the dental object includes an item of dental hardware.

236. The computer program product of claim 229, wherein the dental object includes an interim component of dental manufacture.

237. A system comprising:
a display means for displaying a digital surface representation of a dental object; and
a simulation means for simulating within the display an internal illumination for the dental object wherein light is emitted from any holes in the digital surface representation.

238. The system of claim 237, further comprising an acquisition means for acquiring additional surface scan data to fill any holes in the digital surface representation.

239. The system of claim 237, wherein the holes include regions of the digital surface representation having a point density below a predetermined threshold.

240. The system of claim 237, wherein the dental object includes dentition.

241. The system of claim 237, wherein the dental object includes a restoration.

242. The system of claim 237, wherein the dental object includes a prosthetic.

243. The system of claim 237, wherein the dental object includes an appliance.

244. The system of claim 237, wherein the dental object includes an item of dental hardware.

245. The system of claim 237, wherein the dental object includes an interim component of dental manufacture.

246. A method comprising:

- acquiring data for a digital surface representation of an object with a scanner, the scanner having a point of view of the object;
- displaying the digital surface representation of the object on a display; and
- simulating within the display an external illumination of the digital surface representation of the object from the point of view of the scanner as an illuminated region of the digital surface representation.

247. The method of claim 246, wherein the illuminated region corresponds to a field of view of the scanner.

248. The method of claim 246, wherein the external illumination localizes a position of the scanner with respect to the object.

249. The method of claim 246, wherein the illuminated region provides a user feedback identifying a current source of surface data for the scanner.

250. The method of claim 246, wherein the object includes a dental object.

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

- generating a digital surface representation of an object from data received from a scanner, the scanner having a point of view of the object;
- generating an image of the digital surface representation of the object, the image suitable for output to a display; and
- simulating within the image an external illumination of the digital surface representation of the object from the point of view of the scanner as an illuminated region of the digital surface representation.

252. The computer program product of claim 251, wherein the illuminated region corresponds to a field of view of the scanner.

253. The computer program product of claim 251, wherein the external illumination localizes a position of the scanner with respect to the object.

254. The computer program product of claim 251, wherein the illuminated region provides a user feedback identifying a current source of surface data for the scanner.

255. The computer program product of claim 251, wherein the object includes a dental object.

256. A system comprising:

an acquisition means for acquiring data for a digital surface representation of an object from a scanner, the scanner having a point of view of the object;

a display means for displaying the digital surface representation of the object on a display; and

a simulation means for simulating within the display an external illumination of the digital surface representation of the object from the point of view of the scanner as an illuminated region of the digital surface representation.

257. The system of claim 256, wherein the illuminated region corresponds to a field of view of the scanner.

258. The system of claim 256, wherein the external illumination includes a means for localizing a position of the scanner with respect to the object.

259. The system of claim 256, wherein the illuminated region includes a means for providing a user feedback identifying a current source of surface data for the scanner.

260. The system of claim 256, wherein the object includes a dental object.

261. A method comprising:

reconstructing a three-dimensional point cloud from a surface of an object using a plurality of image data sets, each image data set including video data of a portion of the object from a point of view;

acquiring a new image data set from a new point of view of the object;

updating the three-dimensional point cloud in real time based upon the new image data set; and

rendering the three-dimensional point cloud in a display in real time to provide a rendered digital surface representation.

262. The method of claim 261, wherein real time includes at a video rate for acquiring the new image data set.

263. The method of claim 261, further comprising superimposing a video image of the object from the new point of view in the display.

264. The method of claim 261, wherein rendering includes rendering from a point of view that remains fixed.

265. The method of claim 261, wherein rendering includes rendering from the new point of view of the object.

266. The method of claim 261, further comprising superimposing a video image of the object and the digital surface representation in the display from a common point of view.

267. A computer program product comprising computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of:
constructing a three-dimensional point cloud from a surface of an object using a plurality of image data sets, each image data set including video data of a portion of the object from a point of view;
detecting a new image data set from a new point of view of the object;
updating the three-dimensional point cloud in real time based upon the new image data set; and
rendering the three-dimensional point cloud in real time to provide a rendered digital surface representation suitable for output to a display.

268. The computer program product of claim 267, wherein real time includes at a video rate for detecting the new image data set.

269. The computer program product of claim 267, wherein rendering includes superimposing a video image of the object from the new point of view on the rendered digital surface representation.

270. The computer program product of claim 267, wherein rendering includes rendering from a point of view that remains fixed.

271. The computer program product of claim 267, wherein rendering includes rendering from the new point of view of the object.

272. The computer program product of claim 267, wherein rendering includes superimposing a video image of the object on the rendered digital surface representation, the video image and the rendered digital surface representation being rendered from a common point of view.

273. A system comprising:
a means for constructing a three-dimensional point cloud from a surface of an object using a plurality of image data sets, each image data set including video data of a portion of the object from a point of view;
an acquisition means for acquiring a new image data set from a new point of view of the object;
an update means for updating the three-dimensional point cloud in real time based upon the new image data set; and
a display means for rendering the three-dimensional point cloud in a display in real time to provide a rendered digital surface representation.

274. The system of claim 273, wherein real time includes at a video rate the acquisition means acquires the new image data set.

275. The system of claim 273, wherein the display means includes a means for superimposing a video image of the object from the new point of view in the display.

276. The system of claim 273, wherein the display means includes a means for rendering from a point of view that remains fixed.

277. The system of claim 273, wherein the display means includes a means for rendering from the new point of view of the object.

278. The system of claim 273, the display means includes a means for superimposing a video image of the object and the digital surface representation in the display from a common point of view.

279. A method comprising:

providing a dental surface including a visually distinguishable feature on the dental surface;
acquiring one or more two-dimensional images of the dental surface; and
resolving the one or more two-dimensional images into a three-dimensional point cloud of the dental surface in real time using the visually distinguishable feature.

280. The method of claim 279 wherein resolving into a three-dimensional point cloud in real time includes resolving into a three-dimensional point cloud at a video frame rate.

281. The method of claim 279, wherein the visually distinguishable feature includes an intrinsic feature of the dental surface.

282. The method of claim 279, wherein the visually distinguishable feature includes an artificial feature added to the dental surface.

283. A computer program product comprising computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of:
detecting a visually distinguishable feature on a dental surface from one or more two-dimensional images of the dental surface; and
resolving the one or more two-dimensional images into a three-dimensional point cloud of the dental surface in real time using the visually distinguishable feature.

284. The computer program product of claim 283 wherein resolving into a three-dimensional point cloud in real time includes resolving into a three-dimensional point cloud at a video frame rate.

285. The computer program product of claim 283, wherein the visually distinguishable feature includes an intrinsic feature of the dental surface.

286. The computer program product of claim 283, wherein the visually distinguishable feature includes an artificial feature added to the dental surface.

287. A system comprising:
a means for providing a dental surface including a visually distinguishable feature on the dental surface;
an acquisition means for acquiring one or more two-dimensional images of the dental surface;
and
a resolution means for resolving the one or more two-dimensional images into a three-dimensional point cloud of the dental surface in real time using the visually distinguishable feature.

288. The system of claim 287 wherein in real time includes at a video rate.

289. The system of claim 287, wherein the visually distinguishable feature includes an intrinsic feature of the dental surface.

290. The system of claim 287, wherein the visually distinguishable feature includes an artificial feature added to the dental surface.

291. A method for operating a scanning system that includes a scanning device and a display, the scanning device adapted for continuous acquisition of surface data, the scanning device having one or more scanning parameters, and the display adapted for displaying a digital surface reconstruction containing a plurality of three-dimensional points recovered from the surface data, the method comprising:

rendering the digital surface reconstruction in the display from a current point of view of the scanning device; and
providing a visual cue that relates to the one or more scanning parameters.

292. The method of claim 291, further comprising superimposing a video image of the object from the current point of view onto the digital surface reconstruction in the display.

293. The method of claim 291, wherein rendering the digital surface reconstruction includes rendering the digital surface reconstruction in real time.

294. The method of claim 291, wherein the one or more scanning parameters includes an optimal distance from the scanning device to a subject.

295. The method of claim 291, wherein the one or more scanning parameters includes a range of distances for data capture and a field of view for data capture, the visual cue including a three-dimensional box bounding the range of distances and the field of view within the display.

296. The method of claim 291, wherein the one or more scanning parameters includes a range of distances for data capture, providing a visual cue further including color coding a plurality of rendered points of the digital surface reconstruction according to a current distance of each one of the plurality of rendered points relative to the range of distances for data capture.

297. The method of claim 296, wherein color coding includes rendering points more distant than the range of distances in a first color.

298. The method of claim 296, wherein color coding includes rendering points nearer than the range of distances in a second color.

299. The method of claim 296, wherein color coding includes rendering points within the range of distances in a third color.

300. The method of claim 291, wherein the visual cue includes a dynamic object within the display, the dynamic object adapted to convey information relating to a distance between the scanning device and a subject of the surface data.

301. The method of claim 300, wherein the dynamic object includes a dynamic bullseye.

302. The method of claim 300, wherein the dynamic object relates to a most recent frame of surface data.

303. The method of claim 300, wherein the dynamic object provides a relative distance indicator for visual feedback to a user concerning whether the scanning device is too close, too far, or properly distanced from the subject.

304. The method of claim 303, wherein the relative distance indicator provides graduated feedback to assist a user in maintaining a proper scan distance.

305. The method of claim 300, wherein the distance between the scanning device and the subject is calculated as a mean distance from a plurality of points within a field of view of the scanning device.

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

processing surface data received from a scanning device adapted for continuous acquisition of the surface data, the scanning device having one or more scanning parameters;
generating a digital surface reconstruction containing a plurality of three-dimensional points recovered from the surface data;
generating a visual cue that relates to the one or more scanning parameters; and
rendering an image of the visual clue and the digital surface reconstruction from a current point of view of the scanning device, the image suitable for output to a display.

307. The computer program product of claim 306, wherein rendering includes superimposing a video image of the object from the current point of view onto the image.

308. The computer program product of claim 306, wherein rendering the image includes rendering the image in real time.

309. The computer program product of claim 306, wherein the one or more scanning parameters includes an optimal distance from the scanning device to a subject.

310. The computer program product of claim 306, wherein the one or more scanning parameters includes a range of distances for data capture and a field of view for data capture, the visual cue including a three-dimensional box bounding the range of distances and the field of view within the image.

311. The computer program product of claim 306, wherein the one or more scanning parameters includes a range of distances for data capture, providing a visual cue further including color coding a plurality of rendered points of the digital surface reconstruction according to a current distance of each one of the plurality of rendered points relative to the range of distances for data capture.

312. The computer program product of claim 311, wherein color coding includes rendering points more distant than the range of distances in a first color.

313. The computer program product of claim 311, wherein color coding includes rendering points nearer than the range of distances in a second color.

314. The computer program product of claim 311, wherein color coding includes rendering points within the range of distances in a third color.

315. The computer program product of claim 306, wherein the visual cue includes a dynamic object, the dynamic object adapted to convey information relating to a distance between the scanning device and a subject of the surface data.

316. The computer program product of claim 315, wherein the dynamic object includes a dynamic bullseye.

317. The computer program product of claim 315, wherein the dynamic object relates to a most recent frame of surface data.

318. The computer program product of claim 315, wherein the dynamic object includes a relative distance indicator concerning whether the scanning device is too close, too far, or properly distanced from the subject.

319. The computer program product of claim 318, wherein the relative distance indicator includes a graduated indication of distance to assist a user in maintaining a proper scan distance.

320. The computer program product of claim 315, wherein the distance between the scanning device and the subject is calculated as a mean distance from a plurality of points within a field of view of the scanning device.

321. A system comprising:

- a scanner for continuously acquiring surface data, the scanner having one or more scanning parameters;
- a processor for generating a digital surface reconstruction containing a plurality of three-dimensional points recovered from the surface data;
- a display means for displaying the digital surface reconstruction from a current point of view of the scanning device; and
- a means for providing a visual cue that relates to the one or more scanning parameters.

322. The system of claim 321, wherein the display means includes a means for superimposing a video image of the object from the current point of view onto the digital surface reconstruction.

323. The system of claim 321, wherein the display means includes a means for displaying the digital surface reconstruction in real time.

324. The system of claim 321, wherein the one or more scanning parameters includes an optimal distance from the scanning device to a subject.

325. The system of claim 321, wherein the display means includes a means for incorporating the visual cue with the digital surface reconstruction.

326. The system of claim 325, wherein the one or more scanning parameters includes a range of distances for data capture and a field of view for data capture, the visual cue including a three-dimensional box bounding the range of distances and the field of view.

327. The system of claim 325, wherein the one or more scanning parameters includes a range of distances for data capture, the means for providing a visual cue further including a means for color coding a plurality of rendered points of the digital surface reconstruction according to a current distance of each one of the plurality of rendered points relative to the range of distances for data capture.

328. The system of claim 327, wherein the means for color coding includes a means for rendering points more distant than the range of distances in a first color.

329. The system of claim 327, wherein the means for color coding includes a means for rendering points nearer than the range of distances in a second color.

330. The system of claim 327, wherein the means for color coding includes a means for rendering points within the range of distances in a third color.

331. The system of claim 325, wherein the visual cue includes a dynamic object, the dynamic object including a means for conveying information relating to a distance between the scanning device and a subject of the surface data.

332. The system of claim 331, wherein the dynamic object includes a dynamic bullseye.

333. The system of claim 331, wherein the dynamic object relates to a most recent frame of surface data.

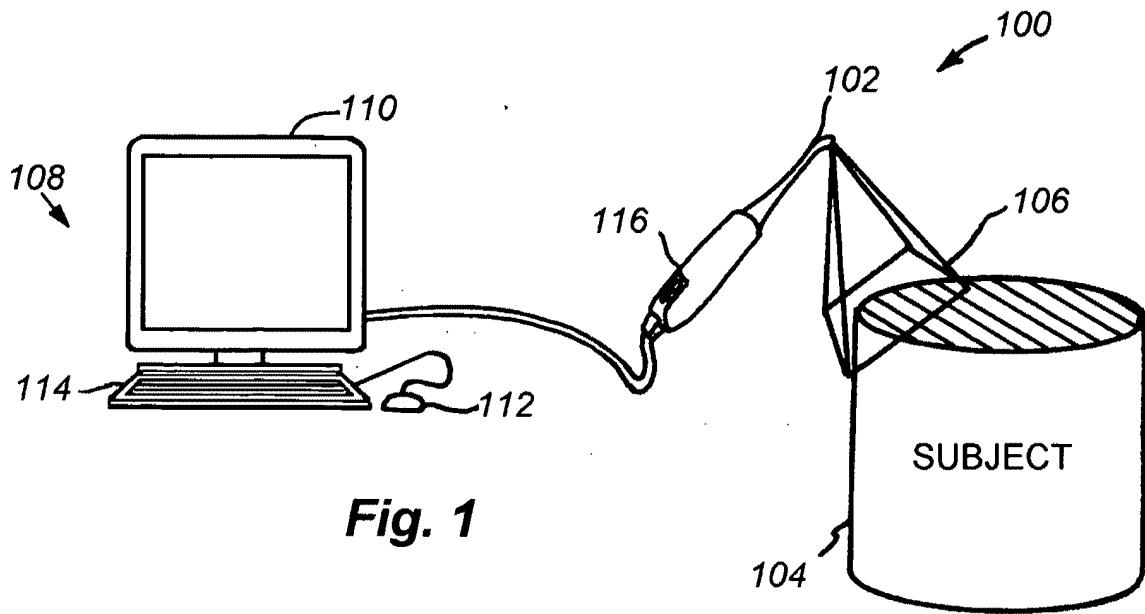
334. The system of claim 331, wherein the dynamic object includes a means for providing a relative distance indicator concerning whether the scanning device is too close, too far, or properly distanced from the subject.

335. The system of claim 334, wherein the relative distance indicator includes a means for providing graduated feedback to assist a user in maintaining a proper scan distance.

336. The system of claim 331, further comprising a means for calculating the distance between the scanning device and the subject as a mean distance from a plurality of points within a field of view of the scanning device.

ABSTRACT

[00135] The systems and methods disclosed herein employ a variety of visual feedback mechanisms to assist in acquisition and analysis of three-dimensional data. Some of these improvements are directed at guiding a user in a successful acquisition of a three-dimensional representation of a subject. Other improvements are directed toward rendering the three-dimensional representation with annotations or other visual cues to assist a user in understanding and analyzing the scanned subject matter. In a dental context, for example, highly detailed, accurate scans may be obtained and various analyses such as adequacy of a tooth surface preparation or suitability of a fabricated prosthetic for a particular patient may be performed in a virtual environment.

**Fig. 1**

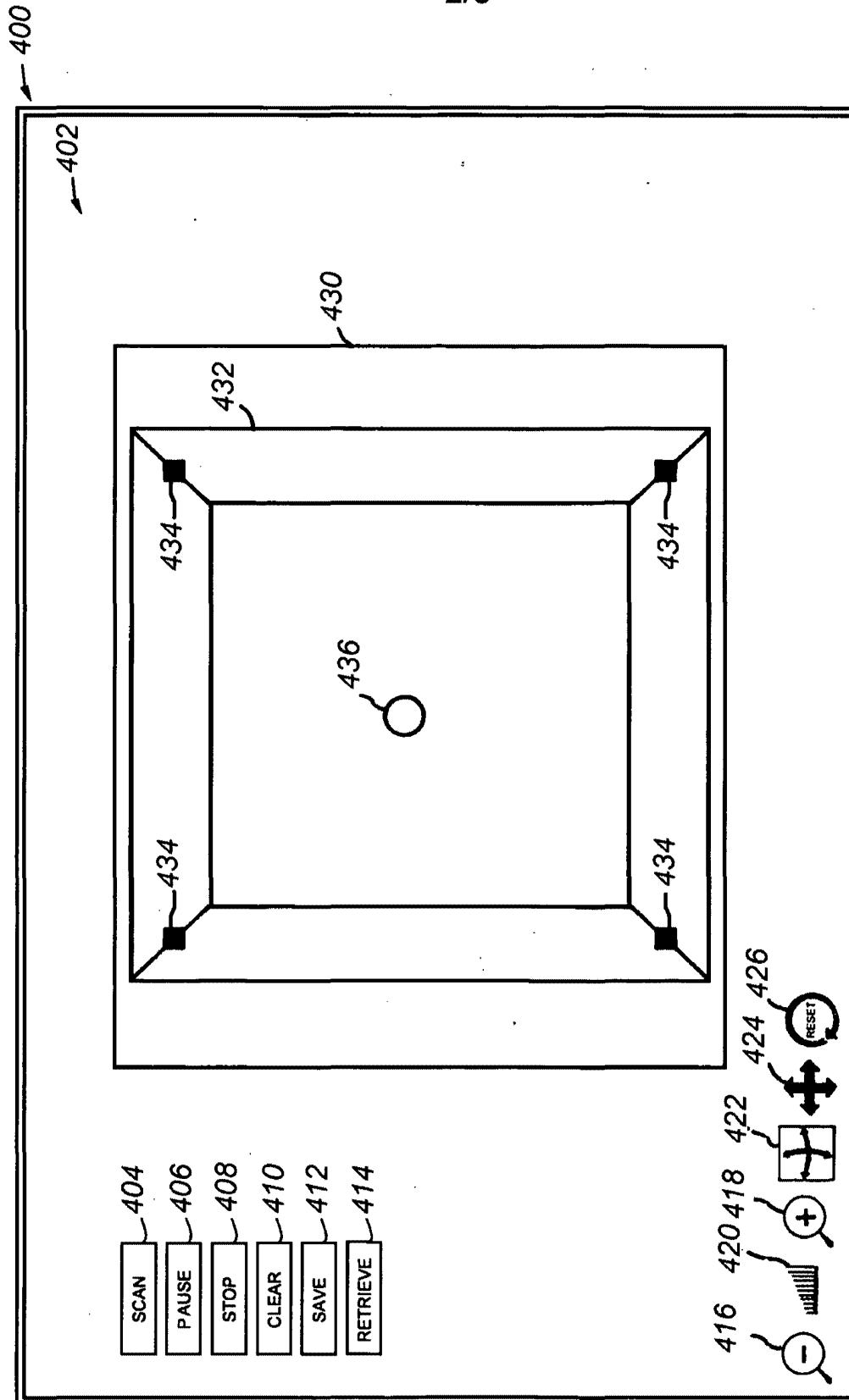


Fig. 2

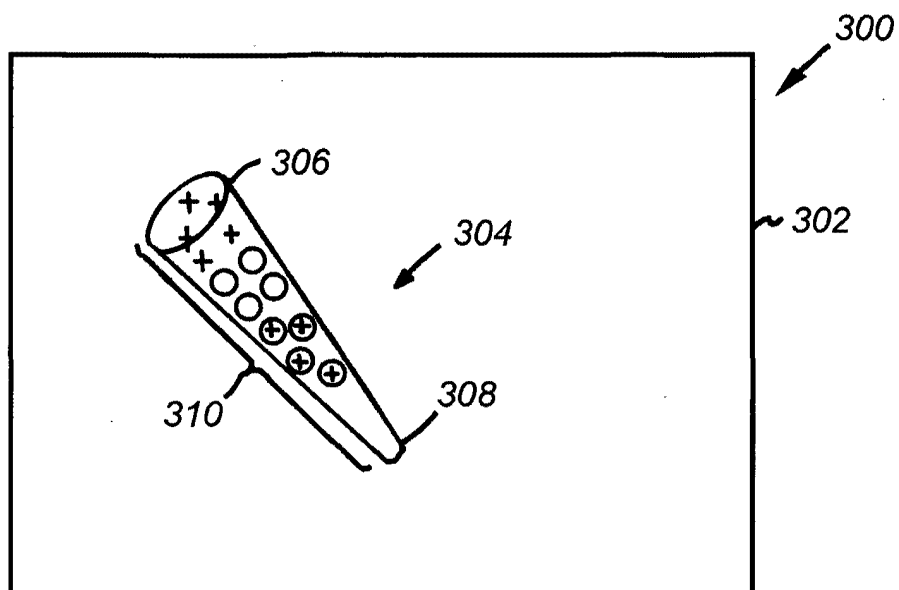


Fig. 3

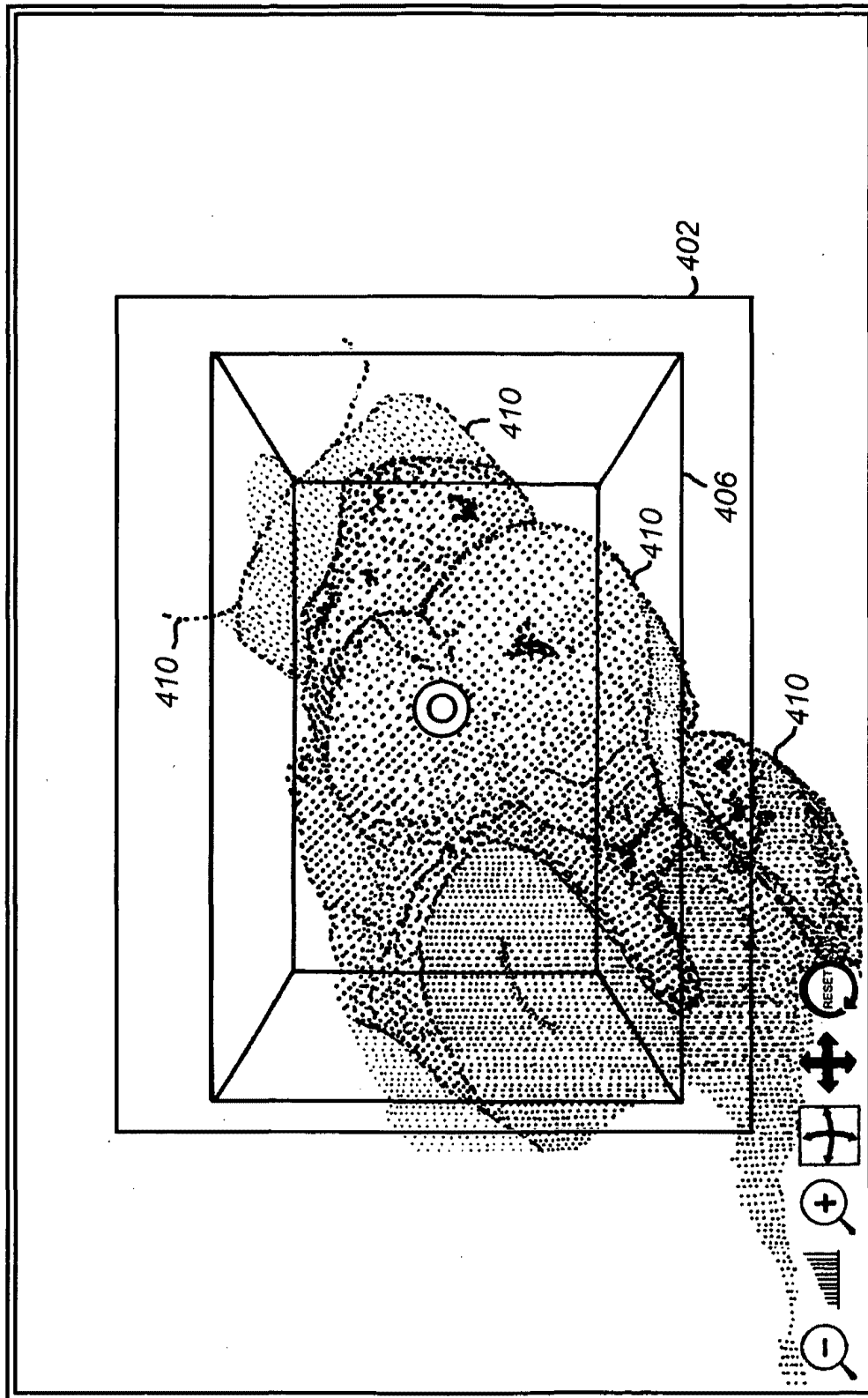


Fig. 4

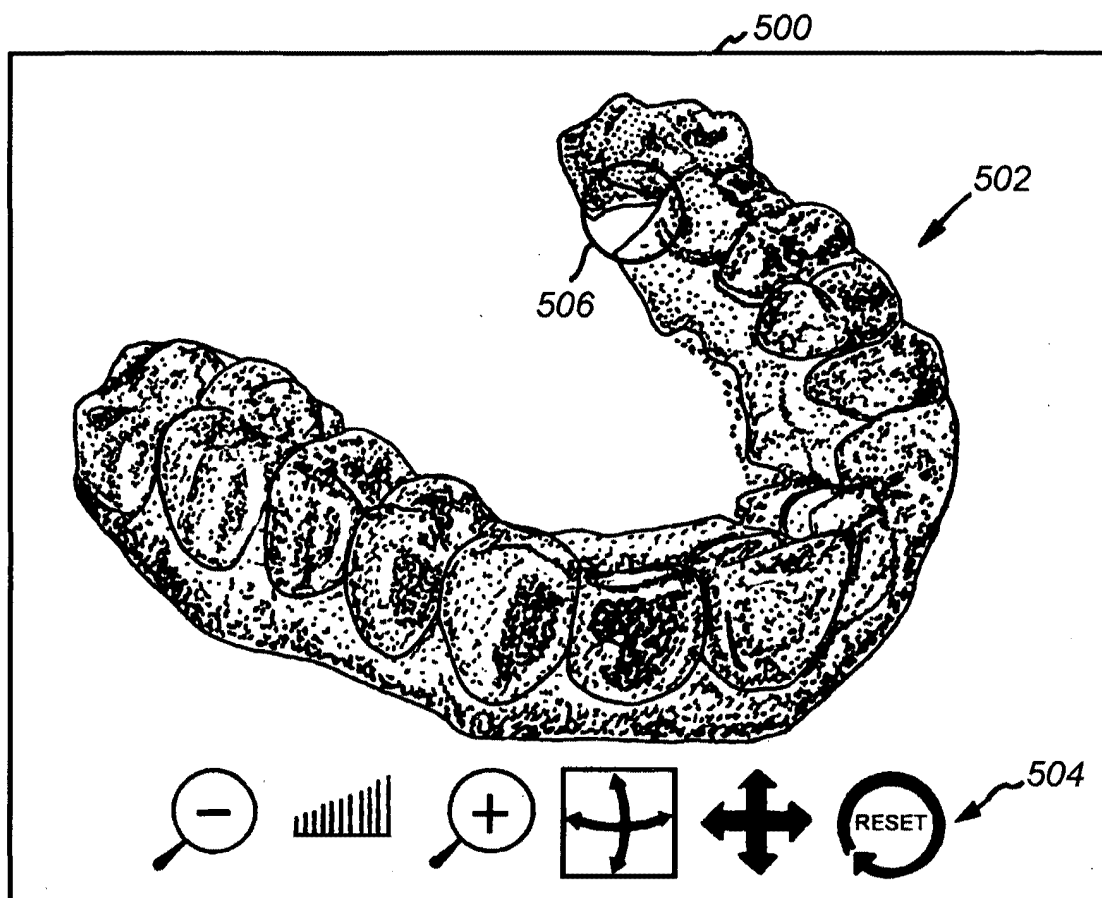


Fig. 5

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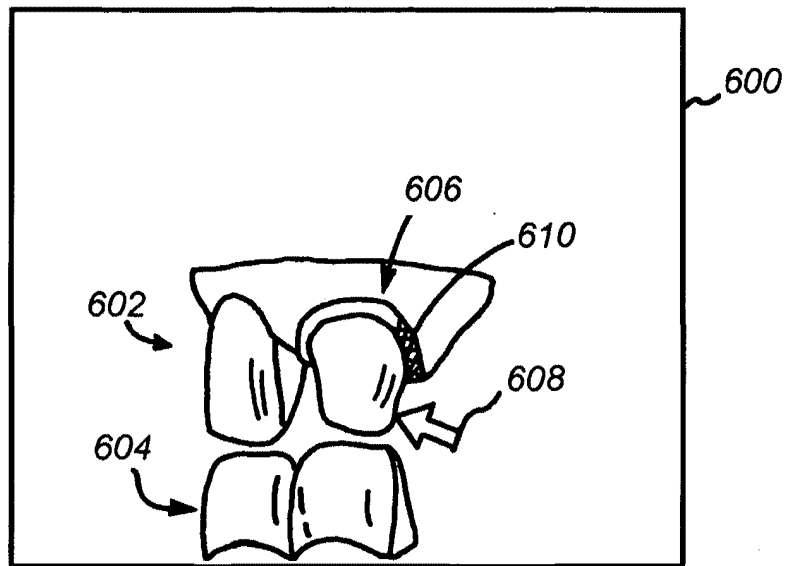


Fig. 6

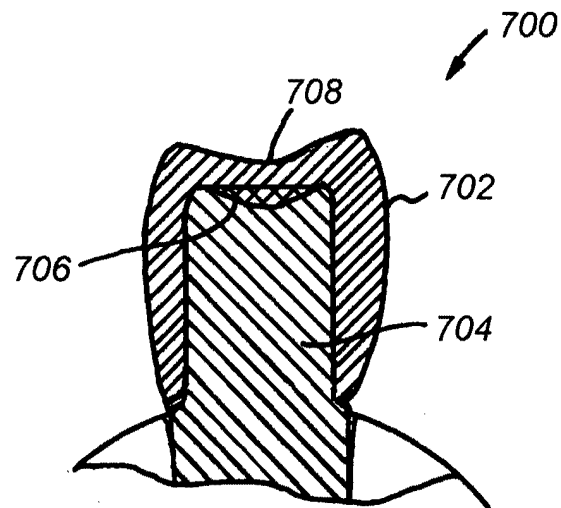
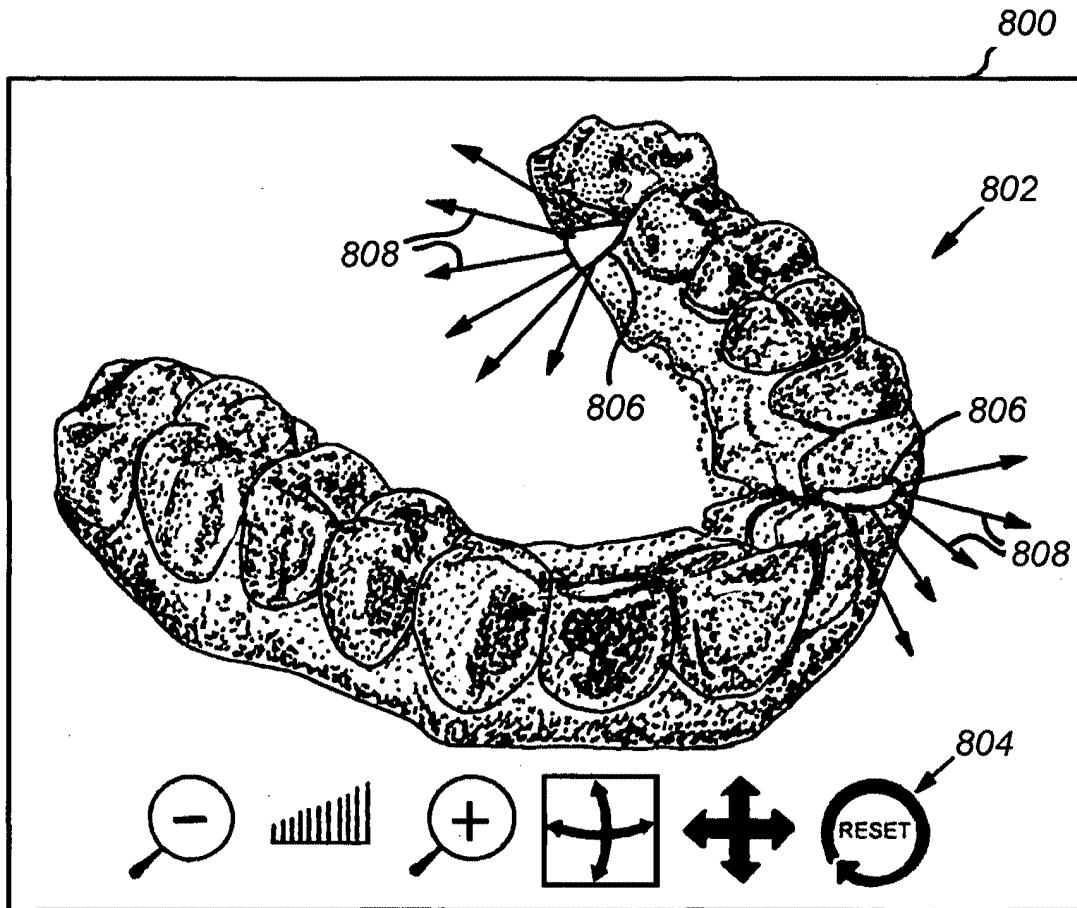
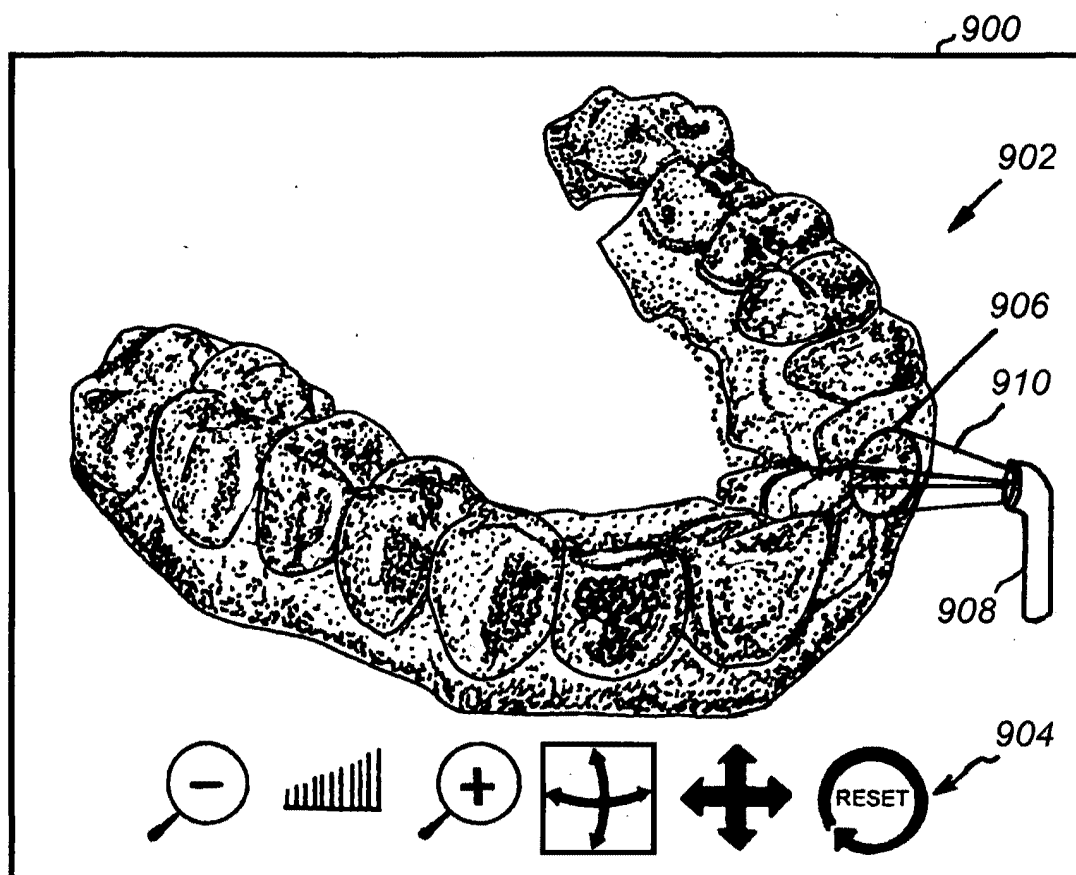


Fig. 7

**Fig. 8**

**Fig. 9**

FABRICATION OF DENTAL WORKS FROM DIGITAL MODELS

BACKGROUND

1. Field of the Invention.

[0001] The invention relates to dentistry, and more particularly to three-dimensional printing and other fabrication of dental objects from digital models.

2. Description of the Related Art.

[0002] Conventional dentistry employs physical casts of human dentition as a foundation for a variety of fabrication techniques. The impression materials used in this process, such as polymerizing silicone and polyether, theoretically capture an accurate dental impression. However, the initial impression may be flawed, and even a perfect impression may degrade over time as a result of thermal fluctuations, inherent plasticity, and rough handling. While the materials used to obtain dental impressions and create subsequent dental models have improved, the basic process steps remain prone to human error.

[0003] Sometimes, errors in an initial impression or errors introduced in subsequent fabrication steps become so severe that the desired end product, such as a crown, cannot be manufactured. In other cases, the process introduces just enough error that the resulting prosthetic simply will not fit into a target space within a dental patient's dentition. This latter difficulty may place significant burdens on the craftsmanship of the practicing dentist to work the prosthetic and/or tooth surface into a suitable shape, or cause increased delay and costs if a new impression is required.

[0004] As another disadvantage, the process of taking the impression may cause significant discomfort to a patient, who must retain the impression material in the mouth while an impression is curing.

[0005] Recent advances in three dimensional imaging technology have introduced the possibility of a handheld, three-dimensional scanner that can be suitably adapted to acquisition of highly accurate, detailed surface data directly from within a dental patient's mouth – a virtual digital dental impression – that, once captured accurately, will not degrade, and can be easily reviewed, analyzed, and/or transmitted to remote manufacturing facilities.

[0006] There remains a need for dental fabrication processes that marry the accuracy and robustness of three-dimensional digital data acquisition with current rapid manufacturing technologies. More generally, there remains a need for end-to-end dental processes that move from the historic artistry of practicing dentists into the precision fitting of modern three-dimensional modeling and fabrication technologies.

SUMMARY

[0007] The systems and methods disclosed herein employ a scanning system for capturing highly detailed three-dimensional representations of dental subject matter that may be used to virtually model a variety of dental objects, including dental hardware, appliances, and prosthetics, as well as interim components of dental manufacture such as waxups, investment casts, and the like. These digital models may be used with fabrication technologies such as stereo lithography, three-dimensional printing, computerized milling, and the like to manufacture dental objects precisely fitted to the dentition of individual dental patients.

[0008] In one aspect, a method disclosed herein may include acquiring a digital surface representation of one or more intraoral structures, processing the digital surface representation to obtain a three-dimensional model may include a plurality of components, and fabricating the three-dimensional model to obtain a dental model of the plurality of components.

[0009] In the method, the plurality of components may include a waxup of a dental object, an investment chamber, a dental model, a die, or a component with a die spacer. The die may include a die spacer integrated into the die, a layer of occlusal relief integrated into the die, or a dental base. The plurality of components may include at least one of a full arch dental model may include one or more tooth preparations, a dental quadrant opposing the one or more tooth preparations, and a full arch

opposing the one or more tooth preparations. The dental model may include a component having a mechanical registration feature. The mechanical registration feature may orient the component in a dental tray. The dental tray may be further adapted to attach to an articulating mechanism in an assembled model wherein the component and one or more other ones of the plurality of components articulate in a manner corresponding to the one or more intraoral structures.

[0010] In the method, the plurality of components may include the dental tray. In the method, the mechanical registration feature may orient the component in a base, it may include one or more grooves, or it may include one or more pins. The mechanical registration feature may be adapted to position a die in a unique location in the dental base. Processing the digital surface representation may include incorporating one or more visual markings, and the dental model may include the one or more visual markings. The visual markings may include three-dimensional markings, or color markings. The plurality of components may further include a pair of opposing bases with one or more pairs of matching beveled edges oriented so that a plurality of teeth in the pair of opposing bases lie in occlusion when the pair of opposing bases are placed on a level surface on any one of the one or more pairs of matching beveled edges. Alternatively, the plurality of components may be pre-indexed for mechanical assembly into the dental model. The at least one of the plurality of components may be adapted to fit a pre-fabricated base. Alternatively, the plurality of components may include a plurality of dies, each one of the plurality of dies may include a mechanical registration feature may be adapted to fit a predetermined location in a dental base. The adapted mechanical registration feature may include one or more pins. Fabricating may include three-dimensionally printing, computerized milling, three-dimensionally printing a physical model and milling directly from the physical model, or fabricating with stereo lithography.

[0011] In another aspect, a system disclosed herein may include a means for acquiring a digital surface representation of one or more intraoral structures, a processor means for processing the digital surface representation to obtain a three-dimensional model may include a plurality of components, and a fabrication means for fabricating the three-dimensional model to obtain a dental model of the plurality of components.

[0012] In the system, the plurality of components may include a waxup of a dental object, an investment chamber, a die, a component with an integrated die spacer, a dental model, or a dental tray. In the system, the die may include a die spacer integrated into the die, a dental base, or a layer of occlusal relief integrated into the die. The plurality of components may include at least one of a full arch dental model may include one or more tooth preparations, a dental quadrant opposing the one or more tooth preparations, and a full arch opposing the one or more tooth preparations. The dental model may include a component having a mechanical registration feature. The mechanical registration feature may include a means for orienting the component in a dental tray, the dental tray may include a means for attaching to an articulating mechanism in an assembled model which may include a means for the component and one or more other ones of the plurality of components to articulate in a manner corresponding to the one or more intraoral structures. The mechanical registration feature may include a means for orienting the component in a base, it may include one or more grooves, or it may include one or more pins. The mechanical registration feature may include a means to position a die in a unique location in the dental base. The processor means may include a means of incorporating one or more visual markings into the three-dimensional model, and the dental model may include the one or more visual markings. The visual markings may include three-dimensional markings, or color markings. The plurality of components may include a pair of opposing bases with one or more pairs of matching beveled edges oriented so that a plurality of teeth in the pair of opposing bases lie in occlusion when the pair of opposing bases are placed on a level surface on any one of the one or more pairs of matching beveled edges. The plurality of components may include a means of pre-indexing for mechanical assembly into the dental model. The at least one of the plurality of components may include a means for fitting a pre-fabricated base.

[0013] In the system, the plurality of components may include a plurality of dies, each one of the plurality of dies may include a means for mechanically registering to a predetermined location in the dental base. The fabrication means may include a means for three-dimensionally printing, a means for

computerized milling, a means for three-dimensionally printing a physical model and milling directly from the physical model, or a means for fabricating with stereo lithography.

[0014] In another aspect, a computer program product disclosed herein may include computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of generating a digital surface representation from one or more images of one or more intraoral structures, processing the digital surface representation to obtain a three-dimensional model may include a plurality of components, and converting the three-dimensional model into a format suitable for fabrication.

[0015] In the computer program product, the plurality of components may include a waxup of a dental object, an investment chamber, a die, a component with an integrated die spacer, or a dental model. In the computer program product, the die may include a die spacer integrated into the die, a dental tray, or a layer of occlusal relief integrated into the die. The plurality of components may include at least one of a full arch dental model may include one or more tooth preparations, a dental quadrant opposing the one or more tooth preparations, and a full arch opposing the one or more tooth preparations. The dental model may include a component having a mechanical registration feature. The mechanical registration feature may orient the component in a dental tray, the dental tray may be further adapted to attach to an articulating mechanism in an assembled model wherein the component and one or more other ones of the plurality of components articulate in a manner corresponding to the one or more intraoral structures. The mechanical registration feature may orient the component in a base, it may include one or more grooves, or it may include one or more pins. The mechanical registration feature may be adapted to position a die in a unique location in the dental base. Processing the digital surface representation may include incorporating one or more visual markings, and the dental model may include the one or more visual markings. The visual markings may include three-dimensional markings, or color markings. The plurality of components may include a pair of opposing bases with one or more pairs of matching beveled edges oriented so that a plurality of teeth in the pair of opposing bases lie in occlusion when the pair of opposing bases are placed on a level surface on any one of the one or more pairs of matching beveled edges. The plurality of components may be pre-indexed for mechanical assembly into the dental model. Alternatively, the at least one of the plurality of components is adapted to fit a pre-fabricated base. The plurality of components include a plurality of dies, each one of the plurality of dies may include a mechanical registration feature which may be adapted to fit a predetermined location in a dental base. The adapted mechanical registration feature may include one or more pins. The format may be adapted for use with a three-dimensional printer, a computerized milling machine, or a stereo lithography apparatus.

[0016] In another aspect, a device disclosed herein may include a first portion adapted to removably attach to a dental articulator in a first fixed orientation, and a second portion may include at least one mechanical registration feature may be adapted to receive a dental model in a predetermined orientation. The device may be formed using injection molding.

[0017] The device may further include a dental model based upon one or more teeth of a person, the dental model may be adapted to be received by the mechanical registration feature such that one or more teeth of the dental model may articulate within the dental articulator in a manner corresponding to articulation by the person. In the device, the dental model may include a full arch, a quadrant, or at least one tooth and one opposing tooth.

[0018] In another aspect, a method disclosed herein may include acquiring a digital surface representation of one or more intraoral structures, processing the digital surface representation to obtain a three-dimensional model of the one or more intraoral structures, with the three-dimensional model including a mechanical registration feature. The method may include fabricating the three-dimensional model to obtain a dental model including the mechanical registration feature, the mechanical registration feature may be adapted to orient the dental model in a dental articulator in an occlusal relationship corresponding to an occlusal relationship of the one or more intraoral structures.

[0019] In the method, the mechanical registration feature may orient the dental model in a dental tray, the dental tray adapted to attach to a dental articulator in a fixed relationship. The mechanical registration feature may include one or more grooves, or one or more pins

[0020] In the method, the mechanical registration feature may be further adapted to position the dental model in the dental articulator such that a motion of the dental model in the dental articulator may correspond to at least one aspect of dynamic occlusion.

[0021] In the method, fabricating may include three-dimensionally printing, computerized milling, three-dimensionally printing a physical model and milling directly from the physical model, or fabricating with stereo lithography.

[0022] In another aspect, a system disclosed herein may include a means for acquiring a digital surface representation of one or more intraoral structures, a processor means for processing the digital surface representation to obtain a three-dimensional model of the one or more intraoral structures, the three-dimensional model may include a registration means for mechanical registration. The system may include a fabrication means for fabricating the three-dimensional model to obtain a dental model including the registration means, the registration means may further include a means to orient the dental model in a dental articulator in an occlusal relationship corresponding to an occlusal relationship of the one or more intraoral structures.

[0023] In the system, the registration means may include a means of orienting the dental model in a dental tray, the dental tray may include a means for attaching to a dental articulator in a fixed relationship. In the system, the registration means may include one or more grooves, or one or more pins. Further, the registration means may include a means to position the dental model in the dental articulator such that a motion of the dental model in the dental articulator may correspond to at least one aspect of dynamic occlusion.

[0024] In the system, the fabrication means may include a means for three-dimensionally printing, a means for computerized milling, a means for three-dimensionally printing a physical model and milling directly from the physical model, or a means for fabricating with stereo lithography.

[0025] In another aspect, a computer program product disclosed herein may include computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of generating a digital surface representation from one or more images of one or more intraoral structures, processing the digital surface representation to obtain a three-dimensional model of the one or more intraoral structures, the three-dimensional model including a mechanical registration feature, the mechanical registration feature may be adapted to orient the dental model in a dental articulator in an occlusal relationship corresponding to an occlusal relationship of the one or more intraoral structures, and converting the three-dimensional model into a format suitable for fabrication.

[0026] In the computer program product, the mechanical registration feature may orient the dental model in a dental tray, the dental tray adapted to attach to a dental articulator in a fixed relationship. The mechanical registration feature may include one or more grooves, or one or more pins

[0027] The computer program product may further include computer code to perform the step of adapting the mechanical registration feature to position the dental model in the dental articulator such that a motion of the dental model in the dental articulator may correspond to at least one aspect of dynamic occlusion.

[0028] The format may be adapted for use with a three-dimensional printer, a computerized milling machine, or a stereo lithography apparatus.

[0029] In another aspect, a method disclosed herein may include obtaining a three-dimensional digital representation of a wax pattern for a dental appliance, adding a sprue to the three-dimensional digital representation, the sprue providing a channel for an investment material in a lost wax casting of the wax pattern, and fabricating the wax pattern including the sprue.

[0030] In the method, fabricating may include three-dimensionally printing, computerized milling, three-dimensionally printing a physical model and milling directly from the physical model, or fabricating with stereo lithography.

[0031] In another aspect, a system disclosed herein may include a means for obtaining a three-dimensional digital representation of a wax pattern for a dental appliance, a feature means for adding a sprue to the three-dimensional digital representation, the sprue providing a flow means for channeling

investment material in a lost wax casting of the wax pattern, and a fabrication means for fabricating the wax pattern including the sprue.

[0032] In the system, the fabrication means may include a means for three-dimensionally printing, a means for computerized milling, a means for three-dimensionally printing a physical model and milling directly from the physical model, or a means for fabricating with stereo lithography.

[0033] In another aspect, a computer program product disclosed herein may include computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of generating a three-dimensional digital representation of a wax pattern for a dental appliance, adding a sprue to the three-dimensional digital representation, the sprue providing a channel for an investment material in a lost wax casting of the wax pattern, and converting the three-dimensional digital representation into a format suitable for fabrication.

[0034] The format may be adapted for use with a three-dimensional printer, a computerized milling machine, or a stereo lithography apparatus.

[0035] In another aspect, a method disclosed herein may include obtaining a three-dimensional digital model of one or more intraoral structures, processing the three-dimensional digital model to obtain a model of a dental object, the dental object including at least one of a dental restoration and a dental appliance, and fabricating a physical realization of the dental object in a medium capable of processing into a material having at least one physical characteristic of human dentition.

[0036] In the method, the dental object may include a dental restoration, a dental appliance, or a temporary restoration. The medium may include a curable resin, a sinterable ceramic, or a sinterable metal. Fabricating may include three-dimensionally printing, computerized milling, three-dimensionally printing a physical model and milling directly from the physical model, or fabricating with stereo lithography.

[0037] In another aspect, a system disclosed herein may include a means for obtaining a three-dimensional digital model of one or more intraoral structures, a processor means for processing the three-dimensional digital model to obtain a model of a dental object, the dental object including at least one of a dental restoration and a dental appliance, a fabrication means for fabricating a physical realization of the dental object in a medium capable of processing into a material having at least one physical characteristic of human dentition.

[0038] In the system, the dental object may include a dental restoration, a dental appliance, or a temporary restoration. The medium may include a curable resin, a sinterable ceramic, or a sinterable metal. The fabrication means may include a means for three-dimensionally printing, a means for computerized milling, a means for three-dimensionally printing a physical model and milling directly from the physical model, or a means for fabricating with stereo lithography.

[0039] In another aspect, a computer program product disclosed herein may include computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of generating a three-dimensional digital model from one or more images of one or more intraoral structures, processing the three-dimensional digital model to obtain a model of a dental object, the dental object including at least one of a dental restoration and a dental appliance, and converting the model of the dental object into a format suitable for fabrication in a medium capable of processing into a material having at least one physical characteristic of human dentition.

[0040] In the computer program product, the dental object may include a dental restoration, a dental appliance, or a temporary restoration. The medium may include a curable resin, a sinterable ceramic, or a sinterable metal. The format may be adapted for use with a three-dimensional printer, a computerized milling machine, or a stereo lithography apparatus.

[0041] In another aspect, a method disclosed herein, performed during a single dentistry visit of a dental patient, may include acquiring a first digital surface representation of an intraoral structure from a mouth of the dental patient, preparing at least one tooth of the intraoral structure for a dental restoration to obtain a prepared intraoral structure, acquiring a second digital surface representation of the prepared intraoral structure from the mouth of the dental patient, processing the first and second digital surface representations to create a three-dimensional model of a temporary dental restoration, fabricating

the temporary dental restoration, and attaching the temporary dental restoration to the prepared intraoral structure.

[0042] In the method, fabricating the temporary dental restoration may include printing the three-dimensional model of the temporary dental restoration in a first material to obtain a printed temporary dental restoration, and copy milling the printed temporary dental restoration into a second material to obtain the temporary dental restoration. The second material may include a ceramic. The method may further include transmitting the first and second digital surface representations to a remote facility for fabrication of a permanent dental restoration. Fabricating may include three-dimensionally printing, computerized milling, three-dimensionally printing a physical model and milling directly from the physical model, or fabricating with stereo lithography.

[0043] In another aspect, a system disclosed herein for preparing and installing a temporary dental restoration during a single dentistry visit of a dental patient may include a first means of acquiring a first digital surface representation of an intraoral structure from a mouth of the dental patient, a manual means for preparing at least one tooth of the intraoral structure for a dental restoration to obtain a prepared intraoral structure, a second means for acquiring a second digital surface representation of the prepared intraoral structure from the mouth of the dental patient, a processor means for processing the first and second digital surface representations to create a three-dimensional model of a temporary dental restoration, a fabrication means for fabricating the temporary dental restoration, and a means for attaching the temporary dental restoration to the prepared intraoral structure.

[0044] In the system, the fabrication means may include a means of printing the three-dimensional model of the temporary dental restoration in a first material to obtain a printed temporary dental restoration, and a means for copy milling the printed temporary dental restoration into a second material to obtain the temporary dental restoration.

[0045] In the system, the second material may include a ceramic. The system may further include a means for transmitting the first and second digital surface representations to a remote facility for fabrication of a permanent dental restoration. The fabrication means may include a means for three-dimensionally printing, a means for computerized milling, a means for three-dimensionally printing a physical model and milling directly from the physical model, or a means for fabricating with stereo lithography.

[0046] In another aspect, a method disclosed herein may include acquiring a digital surface representation of one or more intraoral structures including a soft tissue, processing the digital surface representation to obtain a three-dimensional model of the soft tissue, and fabricating the three-dimensional model of the soft tissue to obtain a physical soft tissue model.

[0047] In the method, the physical soft tissue model may be fabricated from a material that, when cured, may include at least one property resembling the soft tissue. The at least one property may include color, texture, or consistency. The physical soft tissue model may be adapted for removably attaching to a dental cast of the one or more corresponding intraoral structures. Fabricating may include three-dimensionally printing, computerized milling, three-dimensionally printing a physical model and milling directly from the physical model, or fabricating with stereo lithography.

[0048] In another aspect, a system disclosed herein may include a means for acquiring a digital surface representation of one or more intraoral structures including a soft tissue, a processor means for processing the digital surface representation to obtain a three-dimensional model of the soft tissue, and a fabrication means for fabricating the three-dimensional model of the soft tissue to obtain a physical soft tissue model.

[0049] In the system, the physical soft tissue model may include at least one property resembling the soft tissue. The at least one property may include color, texture, or consistency. The physical soft tissue model may include a means for removably attaching to a dental cast of the one or more corresponding intraoral structures. The fabrication means may include a means for three-dimensionally printing, a means for computerized milling, a means for three-dimensionally printing a physical model and milling directly from the physical model, or a means for fabricating with stereo lithography.

[0050] In another aspect, a computer program product disclosed herein may include computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of generating a digital surface representation from one or more images of one or more intraoral structures including a soft tissue, processing the digital surface representation to obtain a three-dimensional model of the soft tissue, and converting the three-dimensional model into a format suitable for fabrication.

[0051] The computer program product may further include computer code to perform the step of adapting the three-dimensional model for removably attaching to a dental cast of the one or more corresponding intraoral structures. The format may be adapted for use with a three-dimensional printer, a computerized milling machine, or a stereo lithography apparatus.

[0052] In another aspect, a method disclosed herein may include obtaining a digital surface representation of one or more intraoral structures, processing the digital surface representation to obtain a digital dental model, adding a marking to the digital dental model, and fabricating the three-dimensional model including the marking to obtain a marked dental model. The dental model may include a dental cast.

[0053] In the method, the marking may include a three-dimensional marking, a two-dimensional marking printed with pigment, or a two-dimensional marking etched by a laser. The marking may include an identification aid. The identification aid may identify a patient, a dentist, or a dental laboratory. It may include a logo of a dental laboratory, a bar code, a 2D matrix code. The identification aid may uniquely identify the marked dental model. The marking may include a treatment aid. The treatment aid may include a restoration margin, a soft tissue boundary, alignment marks for two arches of the marked dental model in occlusion, orthodontic bracket position marks, a landmark, a calibration mark, or a fiducial. The method may further include adding an RFID tag to the marked dental model. The marking may identify a position of a piece of the marked dental model in a tray. Fabricating may include three-dimensionally printing, computerized milling, three-dimensionally printing a physical model and milling directly from the physical model, or fabricating with stereo lithography.

[0054] In another aspect, a system disclosed herein may include a means for obtaining a digital surface representation of one or more intraoral structures, a processor means for processing the digital surface representation to obtain a digital dental model, a marking means for adding a marking to the digital dental model, and a fabrication means for fabricating the three-dimensional model including the marking to obtain a marked dental model. In the system, the dental model may include a dental cast.

[0055] In the system, the marking may include a three-dimensional marking, a two-dimensional marking printed with pigment, or a two-dimensional marking etched by a laser. The marking may include a means of identification. The means of identification may include a means for identifying a patient, a means for identifying a dentist, a means for identifying a dental laboratory, a logo of a dental laboratory, a bar code, a 2D matrix code, or a means for uniquely identifying the marked dental model. The marking may include a treatment aid. The treatment aid may include a means for determining a restoration margin, a means for determining a soft tissue boundary, a means for aligning two arches of the marked dental model in occlusion, a means for positioning an orthodontic bracket, or a landmark. The landmark may include a calibration means for determining calibration status, or a fiducial means for determining orientation visually. The system may further include a means of adding an RFID tag to the marked dental model. The marking may include a means for identifying position of a piece of the marked dental model in a tray. The fabrication means may include a means for three-dimensionally printing, a means for computerized milling, a means for three-dimensionally printing a physical model and milling directly from the physical model, or a means for fabricating with stereo lithography.

[0056] In another aspect, a computer program product disclosed herein may include computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of generating a digital surface representation from one or more images of one or more intraoral structures, processing the digital surface representation to obtain a digital dental model, adding a marking to the digital dental model to obtain a marked digital dental model, and converting the marked digital dental model into a form suitable for fabrication.

[0057] In the computer program product, the digital dental model may include a dental cast. The marking may include a three-dimensional marking, or a two-dimensional marking. The marking may include an identification aid. The identification aid may identify a patient, a dentist, or a dental laboratory. Alternatively, the identification aid may include a logo of a dental laboratory, a bar code, or 2D matrix code. The identification aid may uniquely identify the marked dental model. The marking may include a treatment aid. The treatment aid may include a restoration margin, a soft tissue boundary, alignment marks for two arches of the marked dental model in occlusion, orthodontic bracket position marks, or a landmark. The landmark may include a calibration mark, or a fiducial. The marking may identify a position of a piece of the marked dental model in a tray. The format may be adapted for use with a three-dimensional printer, a computerized milling machine, or a stereo lithography apparatus.

[0058] In another aspect, a method disclosed herein may include obtaining a digital surface representation of one or more intraoral structures including at least one tooth surface prepared for a dental restoration, processing the digital surface representation to obtain a three-dimensional model of a casting model for the dental restoration, and fabricating the three-dimensional model to obtain the casting model.

[0059] In the method, the casting model may include an investment mold, an investment cast, or a pressed ceramic mold. The casting model may correspond to a coping, or the casting model may correspond to a full anatomical form of a tooth. Fabricating may include three-dimensionally printing, computerized milling, three-dimensionally printing a physical model and milling directly from the physical model, or fabricating with stereo lithography.

[0060] In another aspect, a system disclosed herein may include a means for obtaining a digital surface representation of one or more intraoral structures including at least one tooth surface prepared for a dental restoration, a processor means for processing the digital surface representation to obtain a three-dimensional model of a casting model for the dental restoration, and a fabrication means for fabricating the three-dimensional model to obtain the casting model.

[0061] In the system, the casting model may include an investment mold, an investment cast, or a pressed ceramic mold. Alternatively, the casting model may correspond to a coping or a full anatomical form of a tooth. The fabrication means may include a means for three-dimensionally printing, a means for computerized milling, a means for three-dimensionally printing a physical model and milling directly from the physical model, or a means for fabricating with stereo lithography.

[0062] In another aspect, a computer program product disclosed herein may include computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of generating a digital surface representation from one or more images of one or more intraoral structures including at least one tooth surface prepared for a dental restoration, processing the digital surface representation to obtain a three-dimensional model of a casting model for the dental restoration, and converting the three-dimensional model into a format suitable for fabrication.

[0063] In the computer program product, the casting model may include an investment mold, an investment cast, or a pressed ceramic mold. The casting model may correspond to a coping or a full anatomical form of a tooth. The format may be adapted for use with a three-dimensional printer, a computerized milling machine, or a stereo lithography apparatus.

[0064] In another aspect, a method disclosed herein may include obtaining a digital surface representation of one or more intraoral structures from a mouth of a dental patient including at least one tooth surface prepared for a dental restoration, processing the digital surface representation to obtain a three-dimensional model of a wax model for a lost wax fabrication process, and fabricating the three-dimensional model to obtain the wax model.

[0065] The method may further include creating an investment mold from the wax model. The investment mold may include a mold for a coping, a dental restoration in final anatomy form, a substructure for a dental restoration, or a full metal crown. The method may further include creating a pressable from the wax model. The pressable may include a press-to-zirconium restoration, a press-to-alumina restoration, or a ceramic restoration. Fabricating may include three-dimensionally printing, computerized milling, three-dimensionally printing a physical model and milling directly from the physical model, or fabricating with stereo lithography.

[0066] In another aspect, a system disclosed herein may include a means for obtaining a digital surface representation of one or more intraoral structures from a mouth of a dental patient including at least one tooth surface prepared for a dental restoration, a processor means for processing the digital surface representation to obtain a three-dimensional model of a wax model for a lost wax fabrication process, and a fabrication means for fabricating the three-dimensional model to obtain the wax model. The system may further include a means for creating an investment from the wax model.

[0067] In the system, the investment may include a coping, a dental restoration in final anatomy form, a substructure for a dental restoration, or a full metal crown. The system may further include a means for creating a pressable from the wax model. The pressable may include a press-to-zirconium restoration, a press-to-alumina restoration, or a ceramic restoration. The fabrication means may include a means for three-dimensionally printing, a means for computerized milling, a means for three-dimensionally printing a physical model and milling directly from the physical model, or a means for fabricating with stereo lithography.

[0068] In another aspect, a computer program product disclosed herein may include computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of generating a digital surface representation from one or more images of one or more intraoral structures from a mouth of a dental patient including at least one tooth surface prepared for a dental restoration, processing the digital surface representation to obtain a three-dimensional model of a wax model for a lost wax fabrication process, and converting the three-dimensional model into a format suitable for fabrication.

[0069] The wax model may be for an investment. The investment may include a coping, a dental restoration in final anatomy form, a substructure for a dental restoration, or a full metal crown. The wax model may be for a pressable restoration. The pressable restoration may include a press-to-zirconium restoration, a press-to-alumina restoration, or a ceramic restoration. The format may be adapted for use with a three-dimensional printer, a computerized milling machine, or a stereo lithography apparatus.

[0070] In another aspect, a method disclosed herein may include obtaining a digital surface representation of one or more intraoral structures, processing the digital surface representation to obtain a three-dimensional digital model of an item of removable dental hardware, and fabricating the item of removable dental hardware from the three-dimensional digital model.

[0071] In the method, the item of removable dental hardware may include a stent, a surgical guide, a night guard (bruxism or snoring), or a denture. Fabricating may include three-dimensionally printing, computerized milling, three-dimensionally printing a physical model and milling directly from the physical model, or fabricating with stereo lithography.

[0072] In another aspect, a system disclosed herein may include a means for obtaining a digital surface representation of one or more intraoral structures, a processor means for processing the digital surface representation to obtain a three-dimensional digital model of an item of removable dental hardware, and a fabrication means for fabricating the item of removable dental hardware from the three-dimensional digital model.

[0073] In the system, the item of removable dental hardware may include a stent, a surgical guide, a night guard (bruxism or snoring), or a denture. The fabrication means may include a means for three-dimensionally printing, a means for computerized milling, a means for three-dimensionally printing a physical model and milling directly from the physical model, or a means for fabricating with stereo lithography.

[0074] In another aspect, a computer program product disclosed herein may include computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of generating a digital surface representation from one or more images of one or more intraoral structures, the one or more images received from a scanner, processing the digital surface representation to obtain a three-dimensional digital model of an item of removable dental hardware, and converting the three-dimensional digital model into a format suitable for fabrication.

[0075] In the computer program product, the item of removable dental hardware may include a stent, a surgical guide, a night guard (bruxism or snoring), or a denture. The format may be adapted for use with a three-dimensional printer, a computerized milling machine, or a stereo lithography apparatus.

[0076] In another aspect, a method disclosed herein includes obtaining a digital surface representation of one or more intraoral structures; processing the digital surface representation to obtain a three-dimensional digital model including a dental arch and at least one die for the dental arch; three-dimensionally printing the dental arch; and milling the die.

[0077] In another aspect, a method disclosed herein includes acquiring a digital surface representation of one or more intraoral structures; processing the digital surface representation to obtain a three-dimensional model of the one or more intraoral structures; creating at least one void space within the three-dimensional model to provide a voided digital model, the at least one void space having sufficient volume to substantially reduce material costs of fabricating the three-dimensional model; and fabricating the voided digital model to obtain a dental model of the one or more intraoral structures.

BRIEF DESCRIPTION OF THE FIGURES

[0078] The invention and the following detailed description of certain embodiments thereof may be understood by reference to the following figures.

[0079] Fig. 1 shows a dental image capture system.

[0080] Fig. 2 is a block diagram of a generalized manufacturing process for dental objects.

[0081] Fig. 3 shows a milling machine.

[0082] Fig. 4 shows a stereo lithography apparatus.

[0083] Fig. 5 shows a three-dimensional printer.

[0084] Fig. 6 is a high-level flow chart of a dental object fabrication process.

[0085] Fig. 7 illustrates a number of dental objects that can be fabricated from a three-dimensional representation of dentition.

[0086] Figs. 8A-8C show a number of dental objects that can be fabricated from a three-dimensional representation of dentition.

[0087] Fig. 9 shows a dental object that can be fabricated from a three-dimensional representation of dentition.

[0088] Fig. 10 shows a dental object that can be fabricated from a three-dimensional representation of dentition.

[0089] Fig. 11 is a top view of a digital representation of a digital dental model.

[0090] Fig. 12 shows a restoration that can be fabricated from a three-dimensional representation of dentition.

DETAILED DESCRIPTION

[0091] Described herein are systems and methods of fabricating dental objects based upon three-dimensional digital data captured from an intraoral scan. While the description emphasizes certain scanning technologies and certain combinations of fabrication techniques, it will be understood that additional variations, adaptations, and combinations of the methods and systems below will be apparent to one of ordinary skill in the art, such as fabrication of dental restorations not specifically described, or use of three-dimensional output technologies not specifically identified, and all such variations, adaptations, and combinations are intended to fall within the scope of this disclosure.

[0092] In the following description, the term "image" generally refers to a two-dimensional set of pixels forming a two-dimensional view of a subject within an image plane. The term "image set" generally refers to a set of related two dimensional images that might be resolved into three-dimensional data. The term "point cloud" generally refers to a three-dimensional set of points forming a three-dimensional view of the subject reconstructed from a number of two-dimensional views. In a three-dimensional image capture system, a number of such point clouds may also be registered and combined into an aggregate point cloud constructed from images captured by a moving camera. Thus it will be

understood that pixels generally refer to two-dimensional data and points generally refer to three-dimensional data, unless another meaning is specifically indicated or clear from the context.

[0093] The terms “three-dimensional surface representation”, “digital surface representation”, “three-dimensional surface map”, and the like, as used herein, are intended to refer to any three-dimensional surface map of an object, such as a point cloud of surface data, a set of two-dimensional polygons, or any other data representing all or some of the surface of an object, as might be obtained through the capture and/or processing of three-dimensional scan data, unless a different meaning is explicitly provided or otherwise clear from the context.

[0094] A “three-dimensional representation” may include any of the three-dimensional surface representations described above, as well as volumetric and other representations, unless a different meaning is explicitly provided or otherwise clear from the context.

[0095] In general, the terms “render” or “rendering” refer to a two-dimensional visualization of a three-dimensional object, such as for display on a monitor. However, it will be understood that three-dimensional rendering technologies exist, and may be usefully employed with the systems and methods disclosed herein. As such, rendering should be interpreted broadly unless a narrower meaning is explicitly provided or otherwise clear from the context.

[0096] The term “dental object”, as used herein, is intended to refer broadly to subject matter specific to dentistry. This may include intraoral structures such as dentition, and more typically human dentition, such as individual teeth, quadrants, full arches, pairs of arches which may be separate or in occlusion of various types, soft tissue, and the like, as well bones and any other supporting or surrounding structures. As used herein, the term “intraoral structures” refers to both natural structures within a mouth as described above and artificial structures such as any of the dental objects described below that might be present in the mouth. Dental objects may include “restorations”, which may be generally understood to include components that restore the structure or function of existing dentition, such as crowns, bridges, veneers, inlays, onlays, amalgams, composites, and various substructures such as copings and the like, as well as temporary restorations for use while a permanent restoration is being fabricated. Dental objects may also include a “prosthesis” that replaces dentition with removable or permanent structures, such as dentures, partial dentures, implants, retained dentures, and the like. Dental objects may also include “appliances” used to correct, align, or otherwise temporarily or permanently adjust dentition, such as removable orthodontic appliances, surgical stents, bruxism appliances, snore guards, indirect bracket placement appliances, and the like. Dental objects may also include “hardware” affixed to dentition for an extended period, such as implant fixtures, implant abutments, orthodontic brackets, and other orthodontic components. Dental objects may also include “interim components” of dental manufacture such as dental models (full and/or partial), wax-ups, investment molds, and the like, as well as trays, bases, dies, and other components employed in the fabrication of restorations, prostheses, and the like. Dental objects may also be categorized as natural dental objects such as the teeth, bone, and other intraoral structures described above or as artificial dental objects such as the restorations, prostheses, appliances, hardware, and interim components of dental manufacture as described above.

[0097] Terms such as “digital dental model”, “digital dental impression” and the like, are intended to refer to three-dimensional representations of dental objects that may be used in various aspects of acquisition, analysis, prescription, and manufacture, unless a different meaning is otherwise provided or clear from the context. Terms such as “dental model” or “dental impression” are intended to refer to a physical model, such as a cast, printed, or otherwise fabricated physical instance of a dental object. Unless specified, the term “model”, when used alone, may refer to either or both of a physical model and a digital model.

[0098] Fig. 1 shows an image capture system. In general, the system 100 may include a scanner 102 that captures images from a surface 106 of a subject 104, such as a dental patient, and forwards the images to a computer 108, which may include a display 110 and one or more user input devices such as a mouse 112 or a keyboard 114. The scanner 102 may also include an input or output device 116 such as a control input (e.g., button, touchpad, thumbwheel, etc.) or a display (e.g., LCD or LED display) to provide status information.

[0099] The scanner 102 may include any camera or camera system suitable for capturing images from which a three-dimensional point cloud may be recovered. For example, the scanner 102 may employ a multi-aperture system as disclosed, for example, in U.S. Pat. Pub. No. 20040155975 to Hart et al., the entire contents of which is incorporated herein by reference. While Hart discloses one multi-aperture system, it will be appreciated that any multi-aperture system suitable for reconstructing a three-dimensional point cloud from a number of two-dimensional images may similarly be employed. In one multi-aperture embodiment, the scanner 102 may include a plurality of apertures including a center aperture positioned along a center optical axis of a lens and any associated imaging hardware. The scanner 102 may also, or instead, include a stereoscopic, triscopic or other multi-camera or other configuration in which a number of cameras or optical paths are maintained in fixed relation to one another to obtain two-dimensional images of an object from a number of slightly different perspectives. The scanner 102 may include suitable processing for deriving a three-dimensional point cloud from an image set or a number of image sets, or each two-dimensional image set may be transmitted to an external processor such as contained in the computer 108 described below. In other embodiments, the scanner 102 may employ structured light, laser scanning, direct ranging, or any other technology suitable for acquiring three-dimensional data, or two-dimensional data that can be resolved into three-dimensional data.

[00100] In one embodiment, the scanner 102 is a handheld, freely positionable probe having at least one user input device 116, such as a button, lever, dial, thumb wheel, switch, or the like, for user control of the image capture system 100 such as starting and stopping scans. In an embodiment, the scanner 102 may be shaped and sized for dental scanning. More particularly, the scanner may be shaped and sized for intraoral scanning and data capture, such as by insertion into a mouth of an imaging subject and passing over an intraoral surface 106 at a suitable distance to acquire surface data from teeth, gums, and so forth. The scanner 102 may, through such a continuous acquisition process, capture a point cloud of surface data having sufficient spatial resolution and accuracy to prepare dental objects such as prosthetics, hardware, appliances, and the like therefrom, either directly or through a variety of intermediate processing steps. In other embodiments, surface data may be acquired from a dental model such as a dental prosthetic, to ensure proper fitting using a previous scan of corresponding dentition, such as a tooth surface prepared for the prosthetic.

[00101] Although not shown in Fig. 1, it will be appreciated that a number of supplemental lighting systems may be usefully employed during image capture. For example, environmental illumination may be enhanced with one or more spotlights illuminating the subject 104 to speed image acquisition and improve depth of field (or spatial resolution depth). The scanner 102 may also, or instead, include a strobe, flash, or other light source to supplement illumination of the subject 104 during image acquisition.

[00102] The subject 104 may be any object, collection of objects, portion of an object, or other subject matter. More particularly with respect to the dental fabrication techniques discussed herein, the object 104 may include human dentition captured intraorally from a dental patient's mouth. A scan may capture a three-dimensional representation of some or all of the dentition according to particular purpose of the scan. Thus the scan may capture a digital model of a tooth, a quadrant of teeth, or a full collection of teeth including two opposing arches, as well as soft tissue or any other relevant intraoral structures. In other embodiments where, for example, a completed fabrication is being virtually test fit to a surface preparation, the scan may include a dental prosthesis such as an inlay, a crown, or any other dental prosthesis, dental hardware, dental appliance, or the like. The subject 104 may also, or instead, include a dental model, such as a plaster cast, wax-up, impression, or negative impression of a tooth, teeth, soft tissue, or some combination of these.

[00103] The computer 108 may be, for example, a personal computer or other processing device. In one embodiment, the computer 108 includes a personal computer with a dual 2.8GHz Opteron central processing unit, 2 gigabytes of random access memory, a TYAN Thunder K8WE motherboard, and a 250 gigabyte, 10,000 rpm hard drive. This system may be operated to capture approximately 1,500 points per image set in real time using the techniques described herein, and store an aggregated point cloud of over one million points. As used herein, the term "real time" means generally with no

observable latency between processing and display. In a video-based scanning system, real time more specifically refers to processing within the time between frames of video data, which may vary according to specific video technologies between about fifteen frames per second and about thirty frames per second. More generally, processing capabilities of the computer 108 may vary according to the size of the subject 104, the speed of image acquisition, and the desired spatial resolution of three-dimensional points. The computer 108 may also include peripheral devices such as a keyboard 114, display 110, and mouse 112 for user interaction with the camera system 100. The display 110 may be a touch screen display capable of receiving user input through direct, physical interaction with the display 110.

[00104] Communications between the computer 108 and the scanner 102 may use any suitable communications link including, for example, a wired connection or a wireless connection based upon, for example, IEEE 802.11 (also known as wireless Ethernet), Bluetooth, or any other suitable wireless standard using, e.g., a radio frequency, infrared, or other wireless communication medium. In medical imaging or other sensitive applications, wireless image transmission from the scanner 102 to the computer 108 may be secured. The computer 108 may generate control signals to the scanner 102 which, in addition to image acquisition commands, may include conventional camera controls such as focus or zoom.

[00105] In an example of general operation of a three-dimensional image capture system 100, the scanner 102 may acquire two-dimensional image sets at a video rate while the scanner 102 is passed over a surface of the subject. The two-dimensional image sets may be forwarded to the computer 108 for derivation of three-dimensional point clouds. The three-dimensional data for each newly acquired two-dimensional image set may be derived and fitted or “stitched” to existing three-dimensional data using a number of different techniques. Such a system employs camera motion estimation to avoid the need for independent tracking of the position of the scanner 102. One useful example of such a technique is described in commonly-owned U.S. App. No. 11/270,135, filed on November 9, 2005, the entire contents of which is incorporated herein by reference. However, it will be appreciated that this example is not limiting, and that the principles described herein may be applied to a wide range of three-dimensional image capture systems.

[00106] The display 110 may include any display suitable for video or other rate rendering at a level of detail corresponding to the acquired data. Suitable displays include cathode ray tube displays, liquid crystal displays, light emitting diode displays and the like. In some embodiments, the display may include a touch screen interface using, for example capacitive, resistive, or surface acoustic wave (also referred to as dispersive signal) touch screen technologies, or any other suitable technology for sensing physical interaction with the display 110.

[00107] Fig. 2 is a conceptual block diagram of participants in a generalized manufacturing process for dental objects. The system 200 may begin with a patient 202 being scanned by a scanner 204, such as the scanner 102 and image capture system 100 described above, to obtain a digital surface representation 206 of one or more intraoral structures. This may include scans before and/or after a surface has been prepared to receive a dental restoration or other dental object. So, for example, a pre-preparation scan may be taken to capture a shape of the original anatomy and any occlusion information useful in creating a restoration, and a prepared surface scan may be taken to use as a basis for creating the restoration, and in particular for shaping the restoration to the prepared surface. Articulation data relating to the orientation and/or relative motion of an upper and lower arch may also be obtained through one or more scans of the arches in occlusion, or through other techniques such as still images or video of the arches in various orientations, or various dimensional measurements captured directly from the arches, or a physical bite registration captured on a thin sheet of material.

[00108] The digital surface representation 206 may be processed with one or more post-processing steps 208. This may include a variety of data enhancement processes, quality control processes, visual inspection, and so forth. Post-processing steps may be performed at a remote post-processing center or other computer facility capable of post-processing the imaging file, which may be, for example a dental laboratory. In some cases, this post-processing may be done by the image capture

system 100 itself. Post-processing may involve any number of clean-up steps, including the filling of holes, removing of outliers, etc.

[00109] Data enhancement may include, for example, smoothing, truncation, extrapolation, interpolation, and any other suitable processes for improving the quality of the digital surface representation 206 or improving its suitability for an intended purpose. In addition, spatial resolution may be enhanced using various post-processing techniques. Other enhancements may include modifications to the data, such as forming the digital surface representation 206 into a closed surface by virtually providing a base for each arch, or otherwise preparing the digital surface representation for subsequent fabrication steps.

[00110] In a quality control process, the digital surface representation 206 may be analyzed for the presence of holes or regions of incomplete or inadequate scan data. The digital surface representation 206 may also be automatically examined for unexpected curvature or asymmetry to a scanned arch, or other apparent defects in the acquired data. Other quality control processes may incorporate additional data. For example, a current scan may be compared to previous scans for the same patient. As another example, a selection of a dental restoration may be analyzed along with a scan of a tooth surface prepared for the restoration in order to evaluate the suitability of the surface preparation and any surrounding dentition for receiving the restoration. More generally, any process for evaluating data in the digital surface representation 206 with respect to its quality, internal consistency, or intended use, may be used in a post-processing quality control process.

[00111] The digital surface representation 206 may also be displayed for human inspection, such as by providing a perspective rendering of a point cloud of acquired surface data on a display.

[00112] Following any manual or automated post-processing, the resulting digital model may be transmitted to a rapid fabrication facility 216, as indicated by an arrow 209. In addition, articulation data 218 in any suitable form may be transmitted for use in subsequent processing steps, as well as a prescription or other specification for manufacture of a restoration, appliance, hardware, and the like. The rapid fabrication facility 216 may be a dental laboratory, an in-house dental laboratory at a dentist's office, or any other facility with machinery to fabricate physical models from digital models. The rapid fabrication facility 216 may, for example, include a milling system 210, a stereo lithography system 212, or a three-dimensional printer 214, or some combination of these. The milling system 210 may include, for example, a CNC milling machine. Milling systems may be used to take a block of material and create a variety of outputs, including full-arch models, dies, wax-ups, investment chambers or a final restoration or appliance. Such blocks may include ceramic-based, particle-board, wax, metals or a variety of other materials. Dental milling systems such as Procera from Nobel Biocare Inc., or Cerec from Sirona Inc. may also be used to create a final dental hardware component. The stereo lithography system 212 may include, for example, a Viper System by 3D Systems, Inc. The three-dimensional printer 214 may include, for example, an InVision HR printer from 3D Systems. Each of these fabrication techniques will be described in greater detail below.

[00113] The rapid fabrication facility 216 may use the articulation data 218 and the digital model to generate one or more dental objects, such as one or more full arch models 220, one or more dies 222, one or more waxups 224, one or more investment chambers 226, and/or one or more final restorations or appliances 228. Some components, such as the dies 222 and arches 220, may be inserted into an articulated model 134 such as an articulator with a standard base 230 or a custom base 232. A dental laboratory may employ these various components to complete a restoration 236, which may be returned to a dentist for placement into/onto the dentition of the dental patient.

[00114] Various aspects of this system and process will now be described in greater detail, beginning with the rapid fabrication techniques that may be employed with the systems and methods described herein.

[00115] Fig. 3 shows a milling machine that may be used with the systems and methods herein. In particular, Fig. 3 illustrates a Computerized Numerically Controlled ("CNC") milling machine 300 including a table 302, an arm 304, and a cutting tool 306 that cooperate to mill under computer control within a working envelope 308. In operation, a workpiece (not shown) may be attached to the table 302.

The table 302 may move within a horizontal plane and the arm 304 may move on a vertical axis to collectively provide x-axis, y-axis, and z-axis positioning of the cutting tool 306 relative to a workpiece within the working envelope 308. The cutting tool 306 may thus be maneuvered to cut a computer-specified shape from the workpiece.

[00116] Milling is generally a subtractive technology in that material is subtracted from a block rather than added. Thus pre-cut workpieces approximating commonly milled shapes may advantageously be employed to reduce the amount of material that must be removed during a milling job, which may reduce material costs and/or save time in a milling process. More specifically in a dental context, it may be advantageous to begin a milling process with a pre-cut piece, such as a generic coping, rather than a square block. A number of sizes and shapes (e.g., molar, incisor, etc.) of preformed workpieces may be provided so that an optimal piece may be selected to begin any milling job. Various milling systems have different degrees of freedom, referred to as axes. Typically, the more axes available (such as 4-axis milling), the more accurate the resulting parts. High-speed milling systems are commercially available, and can provide high throughputs.

[00117] In addition a milling system may use a variety of cutting tools, and the milling system may include an automated tool changing capability to cut a single part with a variety of cutting tools. In milling a dental model, accuracy may be adjusted for different parts of the model. For example, the tops of teeth, or occlusal surfaces, may be cut more quickly and roughly with a ball mill and the prepared tooth and dental margin may be milled with a tool resulting in greater detail and accuracy.

[00118] CNC milling and other milling technologies can be employed for manufacturing dental models, dental model components, wax-ups, investment chambers, and other dental objects, some of which are described in greater detail below. In addition specialty dental milling equipment exists, such as the Cerac system from Sirona Dental. Another useful milling system for the dental fabrication processes described herein is a copy milling system that permits manual or automated transfer of a three-dimensional form from a physical object to a milled target.

[00119] All such milling systems as may be adapted to use in the dental applications described herein are intended to fall within the scope of the term "milling system" as used herein, and a milling process may employ any of the milling systems described herein.

[00120] Fig. 4 shows a stereo lithography apparatus ("SLA") that may be used with the systems and methods described herein. In general, the SLA 400 may include a laser 402, optics 404, a steering lens 406, an elevator 408, a platform 410, and a straight edge 412, within a vat 412 filled with a polymer. In operation, the laser 402 is steered across a surface of the polymer to cure a cross-section of the polymer, typically a photocurable liquid resin, after which the elevator 408 slightly lowers the platform 408 and another cross section is cured. The straight edge 412 may sweep the surface of the cured polymer between layers to smooth and normalize the surface prior to addition of a new layer. In other embodiments, the vat 412 may be slowly filled with liquid resin while an object is drawn, layer by layer, onto the top surface of the polymer. One useful commercial embodiment of an SLA is the SCS-1000HD available from Sony Corporation.

[00121] Stereo lithography is well-suited for the high volume production of dental models and dies, because parts may be batched on machines for rapid production. When optimized, these parts may be used in lieu of plaster dental models and other dental objects. An SLA may be usefully employed for fabrication of dental models, arches and cast-able parts, as well as for other high-accuracy and/or high-throughput applications. In some embodiments an SLA may receive a digital surface representation directly from a clinician's intraoral scan, and manufacture a dental model corresponding to the patient's dentition with or without surrounding soft tissue.

[00122] An SLA may require significant optimization of operating parameters such as draw speeds, beam diameters, materials, etc. These parameters may be stored in a "style" file, which may also vary accuracy and speed in different areas of a model. So, for example, a tooth within an arch that contains a surface prepared for a dental prosthetic may be optimized for detail/accuracy, while a distant tooth on a different arch may be optimized for speed.

[00123] Fig. 5 shows a three-dimensional printer. The three-dimensional printer 500 may include a print head 502, a material supply 504, a platform 506, and positioning mechanisms (not shown) such as elevators, arms, belts, and the like that may be used to position the print head 502 relative to a printed item 508 during a printing operation. In operation, the print head 502 may deposit curable photopolymers or powders in a layer-by-layer fashion.

[00124] Various types of three-dimensional printers exist. Some printers deposit a polymer in conjunction with a support material or a bonding agent. In some systems, the stage may move as well to control x-y motion of the print head 502 relative to the platform 506 and printed item 508. Models printed on such systems may require finishing steps, such as removal of wax supports and other cleaning processes. Three-dimensional printers are well suited to rapid fabrication of small parts such as wax patterns or wax-ups, as well as dies and other relatively small dental objects. One commercial system suitable for three-dimensional dental printing applications is the InVision HR printer from 3D Systems.

[00125] Three-dimensional printing may be usefully employed for fabricating a variety of dental objects including wax-ups that may be cast by a dental laboratory to create a traditional metal substructure restoration, often referred to as a Porcelain-Fused-to-Metal ("PFM") restoration. Direct three-dimensional printing of the wax-up (much of the shape of which may be directly inferred from a digital surface representation of a patient's dentition) may omit intermediate processing steps in conventional dentistry, where the shape of the dentition travels from an impression to a model to a wax-up. This approach advantageously prevents loss or corruption of data between the source (the patient's dentition) and the target wax-up by transitioning directly from an intraoral scan to a waxup, bypassing intermediate processing steps. Other useful applications of three-dimensional printing are described below in greater detail.

[00126] It will be appreciated that other rapid prototyping systems are known in the art. Thus, the terms fabricate, fabricating, and fabrication, as used herein, will be understood to refer to the fabrication technologies above, as well as any other rapid prototyping or other manufacturing technology that might be adapted to manufacture of custom dental objects, including, without limitation, selective laser sintering ("SLS"), fused deposition modeling ("FDM"), laminated object manufacturing ("LOM"), and so forth. Similarly, any of the above technologies, either alone or in combination, may operate as a means for fabricating, printing, manufacturing, or otherwise creating the dental objects described herein. It will be appreciated that the fabrication steps described above with reference to particular technologies may be followed by additional steps such as curing, cleaning, and so forth to provide a final product.

[00127] The manufacturing techniques described above may be combined in various ways to provide a multimodal fabrication process. Thus, for example, a CNC milling machine may be used to create a die for a tooth requiring greater detail than an SLA can provide, while the SLA may be employed for a model of a dental arch that contains the die. This multimodal approach may deploy the advantages of various technologies in different aspects of the fabrication process, such as using stereo lithography for speed, milling for accuracy, and three-dimensional printing for high-speed fabrication of small parts.

[00128] Fig. 6 is a high-level flow chart of a dental object fabrication process. This process 600 employs a three-dimensional representation of dentition acquired directly from an intraoral scan, and advantageously bypasses a number of processing steps used in conventional dentistry.

[00129] In general the process 600 may begin with data acquisition, as shown in step 602. Data acquisition may include any acquisition of a digital surface representation, or other three-dimensional or other representation of dentition suitable for use in a dental object fabrication process. The data acquisition may be performed using, for example, the scanner 102 and image capture system described above with reference to Fig. 1. In certain embodiment, a number of different scans may be acquired, such as scans to establish articulation and occlusion of arches, or scans before and after a surface preparation, which may be used jointly to create a prosthetic or the like.

[00130] Once suitable data has been acquired, one or more modeling operations may be performed, as shown in step 604. This may include modeling steps such as ditching a virtual die of a digital dental model, specifying a tooth for treatment, filling holes or otherwise correcting data, bite registration, and/or fully designing a restoration, prosthetic, hardware or other dental object(s), as well as

any other modeling or digital model manipulation useful in a dental context. Modeling may be performed using commercially available Computer Automated Design ("CAD") or other three-dimensional modeling tools, or special-purpose dental modeling software such as the inLab CAD/CAM system from Sirona.

[00131] For example, modeling may include bounding the surface representation to form a solid, and then creating a void space, or collection of void spaces within the solid that do not affect dentally significant surfaces such as the dentition or surrounding soft tissue. This may advantageously result in significant reductions in material required to fabricate a dental model from the voided digital model, thus reducing material costs as well as time to manufacture dental models.

[00132] As another example, modeling may include the computer aided design of an item of removable dental hardware. This may account for the shape of teeth and soft tissue, jaw position, occlusal and/or articulating relationships, soft palette and any other spatial or dynamic characteristics of a patient's mouth, as well as any objectives for the hardware. For example, a bruxism night guard may simply serve to separate opposing arches slightly, and may be designed to permit or prohibit breathing through the mouth. A suitable device may be virtually designed that fits the teeth, provides a small amount of intervening material, and conforms to any other aspects of the patient's mouth such as the tongue, lips, and the like. As another example, a snore night guard may be virtually designed to displace one arch slightly in a manner that provides greater clearance for the palette. Other items of removable hardware, such as a surgical guide, removable denture, or stent may similarly be virtually designed within a digital modeling environment. Once a design has been established, the resulting digital model may be fabricated using any of the fabrication techniques described below. A number of other modeling steps are described with reference to specific fabrication processes below. It will be appreciated that the term "modeling" as used herein may refer to any processing of a digital dental model including fully automated, semi-automated, and/or manual processes such as those noted throughout this description.

[00133] As shown in step 606, a prescription may be prepared. This specifies a type of restoration, prosthetic, or the like, and may include a variety of additional information related to a manufacturer, color, finish, die spacing, and so forth. It will be appreciated that the prescription step 606 may be performed before the modeling step 608, such as in a process where a dentist transmits the initial digital surface representation from a patient to a dental laboratory along with a prescription, leaving some or all of the modeling to the dental laboratory.

[00134] As shown in step 608, one or more dental objects may be fabricated. Fabrication may be performed using any of the fabrication technologies described above, either alone or in various combinations, using data from one of the modeling systems described above, which may be reformatted or otherwise adapted as necessary for a particular printing, milling, or other fabrication technology. Also, as will be clear from some of the examples below, fabrication may include a combination of different fabrication technologies. For example, dental model may be three-dimensionally printed with a space for a die, and the die may be milled of a different material for use in subsequent processing steps. Thus, the term "fabrication" as used herein is intended to refer to any suitable fabrication technology unless a specific fabrication technology is explicitly identified, or otherwise clear from the context. A number of specific fabrication examples are discussed below in greater detail.

[00135] As shown in step 610, a prosthetic or other dental object may be returned to a dentist for placement into a patient's dentition.

[00136] It will be appreciated that the above processes may be realized in hardware, software, or any combination of these suitable for the data acquisition and fabrication technologies described herein. This includes realization in one or more microprocessors, microcontrollers, embedded microcontrollers, programmable digital signal processors or other programmable devices, along with internal and/or external memory. The may also, or instead, include one or more application specific integrated circuits, programmable gate arrays, programmable array logic components, or any other device or devices that may be configured to process electronic signals. It will further be appreciated that a realization may include computer executable code created using a structured programming language such as C, an object oriented programming language such as C++, or any other high-level or low-level

programming language (including assembly languages, hardware description languages, and database programming languages and technologies) that may be stored, compiled or interpreted to run on one of the above devices, as well as heterogeneous combinations of processors, processor architectures, or combinations of different hardware and software. At the same time, processing may be distributed across devices such as a camera and/or computer and/or fabrication facility in a number of ways or all of the functionality may be integrated into a dedicated, standalone device. All such permutations and combinations are intended to fall within the scope of the present disclosure.

[00137] It will also be appreciated that means for performing the steps associated with the processes described above may include any suitable components of the image capture system 100 described above with reference to Fig. 1, as well as any components of the fabrication facilities described with reference to Figs. 3-5, along with any software and/or hardware suitable for controlling operation of same. All such realizations and means for performing the processes disclosed herein are intended to fall within the scope of this disclosure.

[00138] Fig. 7 illustrates a number of dental objects that can be fabricated from a three-dimensional representation of dentition. A full arch model 700 may include an upper arch 702, a lower arch 704, a die 706 with a prepare surface 708 and a ditched region 710, and an articulator 712 that maintains the upper arch 702 and the lower arch 704 in a desired occlusal relationship. It will be appreciated that, while Fig. 7 depicts a single die 706 in the upper arch 702, a dental model 700 may include any number of dies 706, some or all of which may be in the lower arch 704.

[00139] Generally, the die 706 is manually cut from a dental model by a dental technician for preparation of a restoration or the like from the prepared surface 708 thereof. However, applying the principles described herein, the die may be virtually cut during the modeling step above, and separately fabricated using any of the techniques above. Thus in one embodiment, a technique for fabricating pre-cut dental models is disclosed. As a significant advantage, this approach removes a manual processing step from conventional dentistry. While the arches 702, 704 may, in general be fabricated using a process selected for high speed or low cost, the die may be fabricated using a process selected for hardness, or more generally, for suitability for subsequent processing steps. Thus in one embodiment the arches 702, 704 of the model may be fabricated using three-dimensional printing or stereo lithography and the pre-cut die 706 may be fabricated using computerized milling. The die 706 may also, or instead, be pre-indexed using, e.g., a pair of posts on the die 706 and matching holes on the upper arch 702, so that, although manufactured separately, the die 706 may be mechanically registered to the upper arch 702.

[00140] In conventional dental fabrication, a die spacer (not shown) such as a thin painted film is often used to provide spacing between a model surface preparation and a dental component such as a crown or other restoration. The spacing may accommodate cement used to attach the final restoration to the actual surface preparation in a patient's mouth. The spacing may also account for dimensional changes that occur to various materials during drying, curing, or other handling during various fabrication steps and may provide a margin of error for a final restoration. In one aspect, a restoration may be virtually modeled directly from a digital surface representation of dentition before and after a surface preparation, which may advantageously remove the need for manually applied die spacers. In some embodiments where control of die spacer thickness is desired, or various types of intermediate physical modeling are anticipated, a die spacers may be virtually created and integrated into a model. The die spacer may be integrated directly into a printed component such as a die to account for any physical displacement or offset that the die spacer would have provided. In addition to virtual integration of dies spacers for a cementation voids or dimensional variation, the modeling step may include the addition of a layer of occlusal relief to provide similar accommodation for occlusal spacing between a restoration and a prepared surface (and by extension, between the restoration and a tooth of an opposing arch).

[00141] In various processes, it may be faster and/or cheaper to fabricate components of a dental model in a hollow form, that is, omitting any material not required for creating a prosthetic or fitting the prosthetic within occlusal surfaces of the arches 702, 704. Thus, portions of the upper arch 702, the lower arch 704, and/or the die 706 may be hollowed during the modeling step(s) in preparation for fabrication. Other modeling steps may usefully be performed. For example, it is common practice to

“ditch” the die(s) of a dental model for increased physical exposure of the surface preparation, and in particular, the margin, for subsequent inspection, manipulation, and processing. This may be performed virtually such as through a modeling tool that permits automatic, semi-automatic, or manual ditching of a die in a digital surface representation or other digital model of dentition. In general, the degree of automation will depend on the ability to either automatically detect or provide by way of electronic annotation, a demarcation of the margin line for a surface preparation below which the die may be ditched.

[00142] Modeling may provide additional useful features to the dental model 700. For example, if articulation and/or occlusion data is provided with the digital version of the dental model, attachment interfaces 716 such as slots, holes, notches, alignment guides, or the like, may automatically added during the modeling step that properly orient the arches 702, 704 in the articulator 712 (provided, of course, the type or dimensions of the articulator are known). The mechanical interface between the articulator 712 and the arches 702, 704 may include screws, interlocking tongue and groove regions, or other mechanical components to removably attach the arches 702, 704 to the articulator. Where a commercial articulator 712 also includes positioning adjustments, the output of the modeling step(s) may also specify one or more settings for these adjustments, which may be included along with a digital dental model, or directly physically marked onto the model for reproduction during fabrication. In another useful technique for aligning the arches 702, 704 one or more outside edges of the upper arch 702 model and the lower arch 704 model may be beveled so that, when placed on a flat surface along that edge, the teeth of the arches 702, 704 remain in their occluded orientation. This may be accomplished by, for example, virtually placing the arches 702, 704 in occlusion within a modeling environment, and then defining a plane within the environment that crosses both arches 702, 704. As illustrated in Fig. 7, a rear edge where the articulator 712 attaches to the model 700 defines such a plane, however one or more additional areas of the edge may be similarly modified, such as the side edges, the front edge, or intermediate regions of the edge of the model 700.

[00143] More generally, the fabrication technologies described above may be used in combination with a variety of digital modeling tools to directly fabricate dental objects such as restorations, prosthetics, appliances, and hardware, as well as a variety of interim components of dental manufacture used to create any of the foregoing.

[00144] Fig. 8 shows a number of dental objects that can be fabricated from a three-dimensional representation of dentition. In particular, Fig. 8A shows a tray 800 for a dental model and Fig. 8B shows a base 850 for a dental model, and Fig. 8C shows a pre-articulated arch 870 for use with the tray 800 of Fig. 8A.

[00145] The tray 800 of Fig. 8A may include a mass 802 with a receptacle 804 such as a groove or indentation and one or more mechanical registration features 806, such as ridges, grooves, slots, or any other physical features that might be used to receive a base (Fig. 8B) into the tray 800 in a predetermined orientation. The mass 802 may be shaped and sized for use with an articulator. In certain embodiments, the mass 802 may be shaped and sized for a particular commercially available articulator. The receptacle 804 and the mechanical registration features 806 may be custom designed for a particular dental model, or they may be standardized so that any base 850 (Fig. 8B) may be modeled with a mating form to the standardized tray 800. In such embodiments, the tray 800 may be mass produced using a process such as injection molding, or any other suitable high volume, low cost manufacturing process. The tray 800 may be mass produced in a number of sizes, such as small, medium, and large, to accommodate various rough sizes of dentition, or the tray 800 may be mass produced in a number of sizes adapted for specific commercially available articulators, or the tray 800 may be mass produced in a single size. Thus, the tray 800 may be created from a three-dimensional digital model of dentition in the modeling step(s) described above, or the tray 800 may be mass produced.

[00146] It will be appreciated that, while the physical registration features 806 of the tray 800 may be adapted to receive a base (Fig. 8) for an entire arch of dentition, the physical registration features 806 may also, or instead, be used to orient a single die (not shown), or a number of dies within a dental model such as an articulated dental model. In one embodiment, an entire arch may be precut and

preindexed within a virtual environment in the modeling step(s) described above, using varying degrees of automation. Thus, while Fig. 8B shows a unitary base 850 for a dental model, the base 850 may actually consist of one or more precut, preindexed dies, and/or a unitary base for any remaining dentition from a digital model.

[00147] The base 850 of Fig. 8B may be created from a three-dimensional digital model of dentition in the modeling step(s) described above. The base 850 may include one or more physical registration features 852 such as ridges, grooves, slots, or any other physical features that might be used to fit the base to the tray into the tray 800 in a predetermined orientation. The base 850 may also include one or more keys 854 for receiving individual teeth or groups of teeth in a dental model. Each key 854 may have a unique shape and or size so that each tooth or group of teeth in the dental model is uniquely indexed to a location on the base 850. While the keys 854 are depicted as cylindrical posts, it will be appreciated that any mechanical registration scheme may be employed to provide a unique location on the base 850 for each tooth or group of teeth in a dental model, including pairs of pins, grooves, slots, varying shapes or impressions, and so forth.

[00148] The base 870 of Fig. 8C may be created from a three-dimensional digital model of dentition in the modeling step(s) described above. The base 870 may, in general function resemble the base 850 of Fig. 8B, and may be precut, pre-indexed, and/or pre-articulated as described herein, except that the base 870 of Fig. 8C includes a surface model of dentition registered to the tray 800, rather than indexed sites for individual teeth of the model as with the base 850 of Fig 8B.

[00149] Although not depicted in Fig. 8, it will be understood that individual teeth or groups of teeth may also be created in a modeling step such that they mate to the keys 854 of the base in a unique arrangement. Varying degrees of automation may be provided for such modeling steps in which, for example, a computerized process fully automates the location of natural teeth and/or surface preparations within the digital model of dentition, or a human identifies some teeth or portions of teeth to assist a computerized process, or a fully manual process in which a human operator places a base 850 and keys within a volumetric representation of dentition. Thus for example, a dental model may be virtually created and directly fabricated that includes a base 850 with holes preprinted for one or more corresponding pins on one or more dies, which may also be directly fabricated from the digital dental model with preprinted, matching pins. In this example, the dental model may be directly printed from the digital model as a plurality of preindexed components ready for assembly at a dental laboratory.

[00150] In addition, as noted above, the model may be prearticulated so that the fabricated dental model assembles on an articulator into a model that articulates in a manner corresponding to articulation of the source dentition. This may include various aspects of static articulation such as occlusal contact points and arch positions in various types of occlusion, as well as dynamic occlusion such as (where available from the digital model or supporting data) lateral excursions, jaw motion, and the like.

[00151] In one embodiment, the base 850 may be used to orient a dental model within an articulator. Articulated models are used by a dental laboratory technician to determine how to contour the anatomy of a crown or other prosthetic so as to maintain, or in some cases, improve the bite of a patient. By pre-articulating the models during a modeling and fabrication process, a laboratory may save considerable time and effort. In the traditional process, labs are forced to prepare plaster dental arch models from physical impressions taken by a dentist, and manually mount dental arch models into a face bow, a hinged apparatus that simulates the jaw of the patient. The alignment is then manually performed on the mounted models with reference to articulation paper -- wax paper on which the patient bites -- received from a dentist.

[00152] Using information concerning a particular articulator, such as a predetermined commercially available articulator, a particular tray 800, such as a mass-produced tray shaped for use with the articulator, and a three-dimensional representation of dentition that includes articulation and/or occlusion information, the base 850 may readily be adapted to orient teeth within the articulated dental model in their natural occlusion and/or with their natural articulation. In general, this may be achieved by positioning the arches of the digital model in occlusion and locating a hinge or pivot point for an

articulator relative to the digital model. The base 850 may then be adapted to bridge any space between a virtual model of the mass-produced tray, as oriented relative to the hinge of the articulator, and the teeth of the digital model of dentition. When the resulting base 850 and any teeth or groups of teeth are fabricated, the articulated model can be assembled using the registration features discussed above to obtain a properly articulated dental model, that is, a model with articulation and/or occlusion corresponding to the source of the digital dental model such as a dental patient.

[00153] It will be understood that, while a full arch model is depicted in Fig. 8, the tray 800 and base 850 may be for a quadrant, or one or more teeth of a quadrant, along with one or more opposing teeth, for use in an articulator that does not require a full arch.

[00154] Leveraging rapid fabrication technologies such as milling and stereo lithography allows for the virtual creation and direct fabrication of the individual components of a precut, preindexed, and/or prearticulated dental model. Thus in one embodiment, disclosed herein is a method and system for fabricating a dental model including a plurality of components. While this may include the components of a dental model described above, it may also, or instead, include other components such as investment molds, waxups, and so forth, which may be modeled with varying degrees of automation and transmitted to a dental laboratory or rapid manufacturer as a virtual model of a kit of cooperating dental components. Some or all of the components of the kit may then be directly fabricated from the virtual model. Additional examples of this general technique are provided below.

[00155] Fig. 9 shows a dental object that can be fabricated from a three-dimensional representation of dentition. More particularly, a waxup 900 of a typical single tooth dental die is shown. Waxups may be employed in a lost wax fabrication process to form restorations or an investment casting chamber or other interim components of dental manufacture. For example, the waxup may instead be employed to create a pressable mold for use with a press-to-zirconium restoration, a press-to alumina restoration, or a pressable ceramic restoration. Waxups may be cosmetic or diagnostic models used first to test a restoration (or other dental object) design, and then to physically fabricate the final restoration in a lost wax process. In a conventional dental fabrication process, a waxup is formed by placing wax directly on a dental model – applied to a surface prepared for a restoration -- and hand-crafting a desired restoration. Using the techniques described herein, a waxup may be fabricated directly from a digital three-dimensional representation. For example, the form of the waxup may be inferred through a direct spatial comparison of a scan of dentition before a preparation to a scan of the dentition after a surface has been prepared for a dental object. Where the prosthetic is cosmetic, rather than simply restorative, a tooth may be automatically, semi-automatically, or manually designed, with the waxup inferred from a spatial comparison of the design to the prepared surface. The digital model of the waxup may then be fabricated using any of the techniques described above.

[00156] In addition to capturing the correct form for a waxup, a modeling step for a waxup may include the addition of one or more sprues that provide paths into (for investment material) and/or out of (for venting) an investment chamber used with the waxup. Thus, one or more sprues may be added to the waxup and directly fabricated using any of the techniques described herein. While a waxup of a single die is depicted in Fig. 9, it will be appreciated that a number of variations, such as a waxup for a restoration bridging two or more teeth, are also intended to fall within the meaning of the term waxup as used herein.

[00157] Fig. 10 shows a dental object that can be fabricated from a three-dimensional representation of dentition. More specifically, Fig. 10 illustrates an investment casting chamber 1000 for a single unit pressed or metal restoration. Investment chambers are used in a lost wax process to create metal or ceramic-pressed copings or final restorations. The investment chamber 1000 includes a first mold 1002 and a second mold 1004 which, when placed together, enclose a space defining a restoration geometry. The molds 1002, 1004 may also include a path 1008 for investment. In a conventional dental fabrication procedure, the investment casting chamber 1000 is physically formed from a model such as the waxup described above. However, applying the principles described herein, the investment chamber 1000 may be virtually created from a digital three-dimensional representation of dentition and directly

fabricated using the techniques described above. In one embodiment, a computerized milling machine may be employed to fabricate an investment chamber from a suitable material for investment or pressing.

[00158] It will be understood that, while the waxups and investment chambers described above may be used to fabricate full restorations such as crowns in their entirety, they may also, or instead, be employed to fabricate a coping or other substructure for use in a Porcelain-Fused-to-Metal ("PFM") restoration, or any other technique in which the final restoration is fabricated in a number of steps that include creation of a substructure.

[00159] Thus there is disclosed herein a method of fabricating casting models from three-dimensional surface data captured during an intraoral scan of a dental patient's mouth. While any number of suitable virtual modeling steps may be performed to obtain a digital version of the casting model, the entire process may advantageously be performed without resort to intermediate physical modeling. The casting model may include the investment chamber described above or other investment molds or pressed ceramic molds, as well as an investment cast for an investment mold such as a model of a full restoration, a coping, or a full anatomical form of one or more teeth.

[00160] While not depicted in Fig. 10, it will be understood that other molds may be fabricated using the techniques described herein. For example, a bruxism or snoring night guard may be fabricated from a soft plastic or rubber. The guard may be virtually designed during the modeling step(s) described above, and a corresponding mold may be virtually created based upon the digital design for the guard. The mold may then be fabricated from any suitable material using the techniques described herein, and the mold may be filled with a pourable, curable polymer or other substance that will dry or cure into the night guard. Still more generally, any dental object suitable for fabrication in a casting or molding process may advantageously be fabricated using a mold, cast, or other similar device created directly from a digital model of corresponding human dentition.

[00161] Fig. 11 is a top view of a digital representation of a digital dental model. The digital dental model 1100 may include a three-dimensional digital surface representation of a plurality of teeth 1102 in a dental arch, such as used for a dental cast or other dental object. The digital dental model 1100 may also include a number of features added during a modeling step as described above.

[00162] For example, the digital dental model 1100 may include one or more beveled edges 1104, as described above in reference to Fig. 7. These edges 1104 may serve to align, e.g., top and bottom arches of a full dental model in an occluded relationship when the two pieces of the model are placed on a flat surface. This feature may aid in handling and working with a physical realization of the full dental model. The edges 1104 may be added to an initial digital representation of scan data from an intraoral scan of dentition, and reproduced in a dental model fabricated from the digital model using any of the techniques described above.

[00163] As another example, the digital dental model 1100 may include marking 1106. While depicted as printed text, it will be understood that a variety of markings may be added to the digital dental model 1100 including coloring or text created with pigment, embossment or other three-dimensional surface markings, bar codes, graphics, and so forth. The marking may perform a number of functions such as specifying a physical arrangement of model components or specifying a location of a component within a model, identifying a source or intended destination of the digital dental model 1100, or highlighting a region of dental significance. For example, the markings 1106 may identify features such as a restoration margin, a soft tissue boundary, an alignment or occlusion point for a pair of arches, an undercut area for design of a removable prosthetic framework, an orthodontic bracket position or positioning guide, and the like. The markings 1106 include an identification aid concerning the model such as a marking that identifies a patient, a dentist, or a dental laboratory. The marking 1106 may include a logo, such as of a dental laboratory, a bar code, a stock keeping unit code, or any other code that uniquely identifies the model or associates the model with a category of models. The markings 1106 may provide conceptual guides such as a fiducial or a calibration landmark. The markings 1106 may also include a void space to receive, e.g., an RFID tag or other tracking device that may be used to manage an inventory of dental models.

[00164] The markings 1106 may, as a specific example, show a margin as a highly contrasted line around a prepared tooth surface. As another example, the prepared surface may itself be marked in a different color from the rest of the model for easy visual identification. These and other markings may be added to a digital dental model 1100, which may be fabricated using any of the techniques described above to provide a marked dental model.

[00165] The digital dental model 1100 may also include soft tissue 1108 such as gums, palate, and so forth. In some embodiments, the soft tissue 1108 may be independently modeled and fabricated. This may entail a degree of estimation concerning the shape of teeth below the gumline, which may be supplemented by one or more direct measurements or scans of sub-gumline dentition or models of characteristic tooth shapes. The soft tissue 1108 may be fabricated using any of the techniques described above, and in particular, fabrication techniques that can yield a pliable fabricated model adapted for removal and reattachment to a corresponding model of the hard dentition. The physical soft tissue model may be fabricated from a material that includes a property of live soft tissue such as color, texture, or consistency, or from a material that can be cured to have such properties. The physical soft tissue model may usefully serve to simulate planned soft tissue contour after healing, or to provide a template or surgical guide to aid a clinician during a surgical procedure.

[00166] Fig. 12 shows a restoration that can be fabricated from a three-dimensional representation of dentition. It will be understood that, while a multi-tooth bridge is depicted, the restoration 1200 may be any indirect restoration or appliance – as distinguished from direct restorations such as amalgams that are created directly within a dental patient's mouth -- suitable for manufacture using the techniques described herein. Thus the restoration 1200 may include an array of components that restore the structure and/or function of existing dentition, such as crowns, bridges, veneers, inlays, onlays, composites, temporary restorations, and various substructures such as copings and the like. Other dental objects such as dentures, partial dentures, implants, retained dentures and so forth may also be directly fabricated from a suitably manipulated model of human dentition and/or any surface preparations of the dentition for the restoration(s).

[00167] The modeling step(s) may include inferring a model from a comparison of pre-preparation and post-preparation scans of a restoration site. Where cosmetic or clinically indicated enhancements or other alterations are indicated, the modeling step(s) may also, or instead, included the virtual creation of a target three-dimensional form for one or more teeth according to aesthetic or other dental principles. The creation of a target form may be automated, semi-automated, or manual, although at least some degree of automation is likely to be used for creation of a full three-dimensional structure. In addition, the modeling step(s) may include adapting the target form to any surrounding dentition including opposing and adjacent teeth. A model for the restoration 1200 (or other dental object as described above) may then be inferred from a comparison of surface preparation (if any) obtained from a scan of a dental patient's mouth to the target form for the restoration 1200.

[00168] Fabrication may include any of the fabrication techniques described above. For example, the restoration 1200 may be fabricated using computerized milling of a pre-formed ceramic blank, such as a zirconia ceramic having a nano-crystalline porous structure. The resulting product may then be sintered into a hard ceramic structure. Sintering may cause some shrinkage – uniform in all dimensions for suitable starting materials – and the milled product may be modeled with a correspondingly larger size in order for the final product to sinter to suitable dimensions for the restoration site. A veneer may then be applied to achieve a restoration that resembles natural human dentition. As above, the model may be sized to account for a thickness of veneer applied to the milled and sintered product.

[00169] As another example, fabrication may include three-dimensional printing or fabricating with a stereo lithography apparatus. The fabrication may be performed with a material that inherently possesses, or cures to possess, or can otherwise be processed to possess one or more characteristics of human dentition, such as color, hardness, strength, wear resistance, texture, and biocompatibility. For example, the material may include a sinterable metal and/or ceramic, or an appropriate resin or other polymer, along with any additives suitable for printing or stereo lithography processes. Suitable materials

are known in the three-dimensional printing and stereo lithography arts. In one embodiment, a biocompatible veneer may be applied to the fabricated model.

[00170] In one embodiment, a temporary restoration may be three-dimensionally printed into a printed model of any suitable material, and the printed model may be used with a copy milling machine – i.e., a milling machine for transferring a physical form from one material such as the printed model to another material such as a ceramic or other material suitable for a temporary restoration. The digital source for the printed model may, at the same time or any other convenient time for the dentist, be transmitted to a remote facility such as a rapid manufacturer or a dental laboratory for manufacture of a permanent restoration. The temporary restoration may be replaced with the permanent restoration at a subsequent dental visit by a dental patient.

[00171] Thus there is disclosed herein direct fabrication of restorations and appliances from digital models such as digital surface representations acquired from human dentition. This fabrication, and any of the other fabrication processes described herein may be performed, for example, at a dental laboratory or at an in-office dental laboratory at a dentist's office.

CLAIMS

What is claimed is:

1. A method comprising:
acquiring a digital surface representation of one or more intraoral structures;
processing the digital surface representation to obtain a three-dimensional model including a plurality of components; and
fabricating the three-dimensional model to obtain a dental model of the plurality of components.
2. The method of claim 1, wherein the plurality of components includes a waxup of a dental object.
3. The method of claim 1, wherein the plurality of components includes an investment chamber.
4. The method of claim 1, wherein the plurality of components includes a die.
5. The method of claim 4, wherein the die includes a die spacer integrated into the die.
6. The method of claim 4, wherein the plurality of components includes a component with an integrated die spacer.
7. The method of claim 4, wherein the die includes a layer of occlusal relief integrated into the die.
8. The method of claim 1, wherein the plurality of components include a dental model.
9. The method of claim 1, wherein the plurality of components includes at least one of a full arch dental model including one or more tooth preparations, a dental quadrant opposing the one or more tooth preparations, and a full arch opposing the one or more tooth preparations.
10. The method of claim 1, wherein the dental model includes a component having a mechanical registration feature.
11. The method of claim 10, wherein the mechanical registration feature orients the component in a dental tray, the dental tray further adapted to attach to an articulating mechanism in an assembled model wherein the component and one or more other ones of the plurality of components articulate in a manner corresponding to the one or more intraoral structures.
12. The method of claim 11, wherein the plurality of components includes the dental tray.
13. The method of claim 10, wherein the mechanical registration feature orients the component in a base.
14. The method of claim 10, wherein the mechanical registration feature includes one or more grooves.
15. The method of claim 10, wherein the mechanical registration feature includes one or more pins.
16. The method of claim 10, wherein the component includes a die, the mechanical registration feature adapted to position the die in a unique location in a dental base.

17. The method of claim 16, wherein the plurality of components includes the dental base.
18. The method of claim 1, wherein processing the digital surface representation includes incorporating one or more visual markings, the dental model including the one or more visual markings.
19. The method of claim 18, wherein the visual markings include three-dimensional markings.
20. The method of claim 18, wherein the visual markings include color markings.
21. The method of claim 1, wherein the plurality of components includes a pair of opposing bases with one or more pairs of matching beveled edges oriented so that a plurality of teeth in the pair of opposing bases lie in occlusion when the pair of opposing bases are placed on a level surface on any one of the one or more pairs of matching beveled edges.
22. The method of claim 1, wherein the plurality of components are pre-indexed for mechanical assembly into the dental model.
23. The method of claim 1, wherein the at least one of the plurality of components is adapted to fit a pre-fabricated base.
24. The method of claim 1, wherein the plurality of components include a plurality of dies, each one of the plurality of dies including a mechanical registration feature adapted to fit a predetermined location in a dental base.
25. The method of claim 24, wherein the mechanical registration feature includes one or more pins.
26. The method of claim 1, wherein fabricating includes three-dimensionally printing.
27. The method of claim 1, wherein fabricating includes computerized milling.
28. The method of claim 1, wherein fabricating includes three-dimensionally printing a physical model and milling directly from the physical model.
29. The method of claim 1, wherein fabricating includes fabricating with stereo lithography.
30. A system comprising:
 - a means for acquiring a digital surface representation of one or more intraoral structures;
 - a processor means for processing the digital surface representation to obtain a three-dimensional model including a plurality of components; and
 - a fabrication means for fabricating the three-dimensional model to obtain a dental model of the plurality of components.
31. The system of claim 30, wherein the plurality of components includes a waxup of a dental object.
32. The system of claim 30, wherein the plurality of components includes an investment chamber.
33. The system of claim 30, wherein the plurality of components includes a die.
34. The system of claim 33, wherein the die includes a die spacer integrated into the die.

35. The system of claim 33, wherein the plurality of components includes a component with an integrated die spacer.
36. The system of claim 33, wherein the die includes a layer of occlusal relief integrated into the die.
37. The system of claim 30, wherein the plurality of components include a dental model.
38. The system of claim 30, wherein the plurality of components includes at least one of a full arch dental model including one or more tooth preparations, a dental quadrant opposing the one or more tooth preparations, and a full arch opposing the one or more tooth preparations.
39. The system of claim 30, wherein the dental model includes a component having a mechanical registration feature.
40. The system of claim 39, wherein the mechanical registration feature includes a means for orienting the component in a dental tray, the dental tray including a means for attaching to an articulating mechanism in an assembled model including a means for the component and one or more other ones of the plurality of components to articulate in a manner corresponding to the one or more intraoral structures.
41. The system of claim 40, wherein the plurality of components includes the dental tray.
42. The system of claim 39, wherein the mechanical registration feature includes a means for orienting the component in a base.
43. The system of claim 39, wherein the mechanical registration feature includes one or more grooves.
44. The system of claim 39, wherein the mechanical registration feature includes one or more pins.
45. The system of claim 39, wherein the component includes a die, the mechanical registration feature including a means to position the die in a unique location in a dental base.
46. The system of claim 45, wherein the plurality of components includes the dental base.
47. The system of claim 30, wherein the processor means includes a means of incorporating one or more visual markings into the three-dimensional model, the dental model including the one or more visual markings.
48. The system of claim 47, wherein the visual markings include three-dimensional markings.
49. The system of claim 47, wherein the visual markings include color markings.
50. The system of claim 30, wherein the plurality of components includes a pair of opposing bases with one or more pairs of matching beveled edges oriented so that a plurality of teeth in the pair of opposing bases lie in occlusion when the pair of opposing bases are placed on a level surface on any one of the one or more pairs of matching beveled edges.
51. The system of claim 30, wherein the plurality of components includes a means of pre-indexing for mechanical assembly into the dental model.

52. The system of claim 30, wherein the at least one of the plurality of components includes a means for fitting a pre-fabricated base.

53. The system of claim 30, wherein the plurality of components include a plurality of dies, each one of the plurality of dies including a means for mechanically registering to a predetermined location in a dental base.

54. The system of claim 53, wherein the mechanical registration feature includes one or more pins.

55. The system of claim 30, wherein the fabrication means includes a means for three-dimensionally printing.

56. The system of claim 30, wherein the fabrication means includes a means for computerized milling.

57. The system of claim 30, wherein the fabrication means includes a means for three-dimensionally printing a physical model and milling directly from the physical model.

58. The system of claim 30, wherein the fabrication means includes a means for fabricating with stereo lithography.

59. A computer program product comprising computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of:
generating a digital surface representation from one or more images of one or more intraoral structures;
processing the digital surface representation to obtain a three-dimensional model including a plurality of components; and
converting the three-dimensional model into a format suitable for fabrication.

60. The computer program product of claim 59, wherein the plurality of components includes a waxup of a dental object.

61. The computer program product of claim 59, wherein the plurality of components includes an investment chamber.

62. The computer program product of claim 59, wherein the plurality of components includes a die.

63. The computer program product of claim 62, wherein the die includes a die spacer integrated into the die.

64. The computer program product of claim 62, wherein the plurality of components includes a component with an integrated die spacer.

65. The computer program product of claim 62, wherein the die includes a layer of occlusal relief integrated into the die.

66. The computer program product of claim 59, wherein the plurality of components include a dental model.

67. The computer program product of claim 59, wherein the plurality of components includes at least one of a full arch dental model including one or more tooth preparations, a dental quadrant opposing the one or more tooth preparations, and a full arch opposing the one or more tooth preparations.

68. The computer program product of claim 59, wherein the dental model includes a component having a mechanical registration feature.

69. The computer program product of claim 68, wherein the mechanical registration feature orients the component in a dental tray, the dental tray further adapted to attach to an articulating mechanism in an assembled model wherein the component and one or more other ones of the plurality of components articulate in a manner corresponding to the one or more intraoral structures.

70. The computer program product of claim 69, wherein the plurality of components includes the dental tray.

71. The computer program product of claim 68, wherein the mechanical registration feature orients the component in a base.

72. The computer program product of claim 68, wherein the mechanical registration feature includes one or more grooves.

73. The computer program product of claim 68, wherein the mechanical registration feature includes one or more pins.

74. The computer program product of claim 68, wherein the component includes a die, the mechanical registration feature adapted to position the die in a unique location in a dental base.

75. The computer program product of claim 74, wherein the plurality of components includes the dental base.

76. The computer program product of claim 59, wherein processing the digital surface representation includes incorporating one or more visual markings, the dental model including the one or more visual markings.

77. The computer program product of claim 76, wherein the visual markings include three-dimensional markings.

78. The computer program product of claim 76, wherein the visual markings include color markings.

79. The computer program product of claim 59, wherein the plurality of components includes a pair of opposing bases with one or more pairs of matching beveled edges oriented so that a plurality of teeth in the pair of opposing bases lie in occlusion when the pair of opposing bases are placed on a level surface on any one of the one or more pairs of matching beveled edges.

80. The computer program product of claim 59, wherein the plurality of components are pre-indexed for mechanical assembly into the dental model.

81. The computer program product of claim 59, wherein the at least one of the plurality of components is adapted to fit a pre-fabricated base.

82. The computer program product of claim 59, wherein the plurality of components include a plurality of dies, each one of the plurality of dies including a mechanical registration feature adapted to fit a predetermined location in a dental base.
83. The computer program product of claim 82, wherein the mechanical registration feature includes one or more pins.
84. The computer program product of claim 82, wherein the format is adapted for use with a three-dimensional printer.
85. The computer program product of claim 82, wherein the format is adapted for use with a computerized milling machine.
86. The computer program product of claim 82, wherein the format is adapted for use with a stereo lithography apparatus.
87. A device comprising:
a first portion adapted to removably attach to a dental articulator in a first fixed orientation; and
a second portion including at least one mechanical registration feature adapted to receive a dental model in a predetermined orientation.
88. The device of claim 87, wherein the device is formed using injection molding.
89. The device of claim 87, further comprising a dental model based upon one or more teeth of a person, the dental model adapted to be received by the mechanical registration feature such that one or more teeth of the dental model articulate within the dental articulator in a manner corresponding to articulation by the person.
90. The device of claim 87, wherein the dental model includes a full arch.
91. The device of claim 87, wherein the dental model includes a quadrant.
92. The device of claim 87, wherein the dental model includes at least one tooth and one opposing tooth.
93. A method comprising:
acquiring a digital surface representation of one or more intraoral structures;
processing the digital surface representation to obtain a three-dimensional model of the one or more intraoral structures, the three-dimensional model including a mechanical registration feature; and
fabricating the three-dimensional model to obtain a dental model including the mechanical registration feature, the mechanical registration feature adapted to orient the dental model in a dental articulator in an occlusal relationship corresponding to an occlusal relationship of the one or more intraoral structures.
94. The method of claim 93, wherein the mechanical registration feature orients the dental model in a dental tray, the dental tray adapted to attach to a dental articulator in a fixed relationship.
95. The method of claim 93, wherein the mechanical registration feature includes one or more grooves.
96. The method of claim 93, wherein the mechanical registration feature includes one or more pins

97. The method of claim 93, wherein the mechanical registration feature further adapted to position the dental model in the dental articulator such that a motion of the dental model in the dental articulator corresponds to at least one aspect of dynamic occlusion.
98. The method of claim 93, wherein fabricating includes three-dimensionally printing.
99. The method of claim 93, wherein fabricating includes computerized milling.
100. The method of claim 93, wherein fabricating includes three-dimensionally printing a physical model and milling directly from the physical model.
101. The method of claim 93, wherein fabricating includes fabricating with stereo lithography.
102. A system comprising:
a means for acquiring a digital surface representation of one or more intraoral structures;
a processor means for processing the digital surface representation to obtain a three-dimensional model of the one or more intraoral structures, the three-dimensional model including a registration means for mechanical registration; and
a fabrication means for fabricating the three-dimensional model to obtain a dental model including the registration means, the registration means further including a means to orient the dental model in a dental articulator in an occlusal relationship corresponding to an occlusal relationship of the one or more intraoral structures.
103. The system of claim 102, wherein the registration means includes a means of orienting the dental model in a dental tray, the dental tray including a means for attaching to a dental articulator in a fixed relationship.
104. The system of claim 102, wherein the registration means includes one or more grooves.
105. The system of claim 102, wherein the registration means includes one or more pins
106. The system of claim 102, wherein the registration means includes a means to position the dental model in the dental articulator such that a motion of the dental model in the dental articulator corresponds to at least one aspect of dynamic occlusion.
107. The system of claim 102, wherein the fabrication means includes a means for three-dimensionally printing.
108. The system of claim 102, wherein the fabrication means includes a means for computerized milling.
109. The system of claim 102, wherein the fabrication means includes a means for three-dimensionally printing a physical model and milling directly from the physical model.
110. The system of claim 102, wherein the fabrication means includes a means for fabricating with stereo lithography.
111. A computer program product comprising computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of:

generating a digital surface representation from one or more images of one or more intraoral structures;

processing the digital surface representation to obtain a three-dimensional model of the one or more intraoral structures, the three-dimensional model including a mechanical registration feature, the mechanical registration feature adapted to orient the dental model in a dental articulator in an occlusal relationship corresponding to an occlusal relationship of the one or more intraoral structures; and converting the three-dimensional model into a format suitable for fabrication.

112. The computer program product of claim 111, wherein the mechanical registration feature orients the dental model in a dental tray, the dental tray adapted to attach to a dental articulator in a fixed relationship.

113. The computer program product of claim 111, wherein the mechanical registration feature includes one or more grooves.

114. The computer program product of claim 111, wherein the mechanical registration feature includes one or more pins

115. The computer program product of claim 111, further comprising computer code to perform the step of adapting the mechanical registration feature to position the dental model in the dental articulator such that a motion of the dental model in the dental articulator corresponds to at least one aspect of dynamic occlusion.

116. The computer program product of claim 111, wherein the format is adapted for use with a three-dimensional printer.

117. The computer program product of claim 111, wherein the format is adapted for use with a computerized milling machine.

118. The computer program product of claim 111, wherein the format is adapted for use with a stereo lithography apparatus.

119. A method comprising:
obtaining a three-dimensional digital representation of a wax pattern for a dental appliance;
adding a sprue to the three-dimensional digital representation, the sprue providing a channel for an investment material in a lost wax casting of the wax pattern; and
fabricating the wax pattern including the sprue.

120. The method of claim 119, wherein fabricating includes three-dimensionally printing.

121. The method of claim 119, wherein fabricating includes computerized milling.

122. The method of claim 119, wherein fabricating includes three-dimensionally printing a physical model and milling directly from the physical model.

123. The method of claim 119, wherein fabricating includes fabricating with stereo lithography.

124. A system comprising:
a means for obtaining a three-dimensional digital representation of a wax pattern for a dental appliance;

a feature means for adding a sprue to the three-dimensional digital representation, the sprue providing a flow means for channeling investment material in a lost wax casting of the wax pattern; and a fabrication means for fabricating the wax pattern including the sprue.

125. The system of claim 124, wherein the fabrication means includes a means for three-dimensionally printing.

126. The system of claim 124, wherein the fabrication means includes a means for computerized milling.

127. The system of claim 124, wherein the fabrication means includes a means for three-dimensionally printing a physical model and milling directly from the physical model.

128. The system of claim 124, wherein the fabrication means includes a means for fabricating with stereo lithography.

129. A computer program product comprising computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of:
generating a three-dimensional digital representation of a wax pattern for a dental appliance;
adding a sprue to the three-dimensional digital representation, the sprue providing a channel for an investment material in a lost wax casting of the wax pattern; and
converting the three-dimensional digital representation into a format suitable for fabrication.

130. The computer program product of claim 129, wherein the format is adapted for use with a three-dimensional printer.

131. The computer program product of claim 129, wherein the format is adapted for use with a computerized milling machine.

132. The computer program product of claim 129, wherein the format is adapted for use with a stereo lithography apparatus.

133. A method comprising:
obtaining a three-dimensional digital model of one or more intraoral structures;
processing the three-dimensional digital model to obtain a model of an dental object, the dental object including at least one of a dental restoration and a dental appliance; and
fabricating a physical realization of the dental object in a medium capable of processing into a material having at least one physical characteristic of human dentition.

134. The method of claim 133, wherein the dental object includes a dental restoration.

135. The method of claim 133, wherein the dental object includes a dental appliance.

136. The method of claim 133, wherein the dental object includes a temporary restoration.

137. The method of claim 133, wherein the medium includes a curable resin.

138. The method of claim 133, wherein the medium includes a sinterable ceramic.

139. The method of claim 133, wherein the medium includes a sinterable metal.

140. The method of claim 133, wherein fabricating includes three-dimensionally printing.
141. The method of claim 133, wherein fabricating includes computerized milling.
142. The method of claim 133, wherein fabricating includes three-dimensionally printing a physical model and milling directly from the physical model.
143. The method of claim 133, wherein fabricating includes fabricating with stereo lithography.
144. A system comprising:
 - a means for obtaining a three-dimensional digital model of one or more intraoral structures;
 - a processor means for processing the three-dimensional digital model to obtain a model of an dental object, the dental object including at least one of a dental restoration and a dental appliance; and
 - a fabrication means for fabricating a physical realization of the dental object in a medium capable of processing into a material having at least one physical characteristic of human dentition.
145. The system of claim 144, wherein the dental object includes a dental restoration.
146. The system of claim 144, wherein the dental object includes a dental appliance.
147. The system of claim 144, wherein the dental object includes a temporary restoration.
148. The system of claim 144, wherein the medium includes a curable resin.
149. The system of claim 144, wherein the medium includes a sinterable ceramic.
150. The system of claim 144, wherein the medium includes a sinterable metal.
151. The system of claim 144, wherein the fabrication means includes a means for three-dimensionally printing.
152. The system of claim 144, wherein the fabrication means includes a means for computerized milling.
153. The system of claim 144, wherein the fabrication means includes a means for three-dimensionally printing a physical model and milling directly from the physical model.
154. The system of claim 144, wherein the fabrication means includes a means for fabricating with stereo lithography.
155. A computer program product comprising computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of:
 - generating a three-dimensional digital model from one or more images of one or more intraoral structures;
 - processing the three-dimensional digital model to obtain a model of an dental object, the dental object including at least one of a dental restoration and a dental appliance; and
 - converting the model of the dental object into a format suitable for fabrication in a medium capable of processing into a material having at least one physical characteristic of human dentition.
156. The computer program product of claim 155, wherein the dental object includes a dental restoration.

157. The computer program product of claim 155, wherein the dental object includes a dental appliance.
158. The computer program product of claim 155, wherein the dental object includes a temporary restoration.
159. The computer program product of claim 155, wherein the medium includes a curable resin.
160. The computer program product of claim 155, wherein the medium includes a sinterable ceramic.
161. The computer program product of claim 155, wherein the medium includes a sinterable metal.
162. The computer program product of claim 155, wherein the format is adapted for use with a three-dimensional printer.
163. The computer program product of claim 155, wherein the format is adapted for use with a computerized milling machine.
164. The computer program product of claim 155, wherein the format is adapted for use with a stereo lithography apparatus.
165. A method comprising the following steps performed during a single dentistry visit of a dental patient:
acquiring a first digital surface representation of an intraroral structure from a mouth of the dental patient;
preparing at least one tooth of the intraoral structure for a dental restoration to obtain a prepared intraoral structure;
acquiring a second digital surface representation of the prepared intraoral structure from the mouth of the dental patient;
processing the first and second digital surface representations to create a three-dimensional model of a temporary dental restoration;
fabricating the temporary dental restoration; and
attaching the temporary dental restoration to the prepared intraoral structure.
166. The method of claim 165, wherein fabricating the temporary dental restoration includes printing the three-dimensional model of the temporary dental restoration in a first material to obtain a printed temporary dental restoration, and copy milling the printed temporary dental restoration into a second material to obtain the temporary dental restoration.
167. The method of claim 166, wherein the second material includes a ceramic.
168. The method of claim 166, wherein the copy milling includes automated copy milling.
169. The method of claim 165, further comprising transmitting the first and second digital surface representations to a remote facility for fabrication of a permanent dental restoration
170. The method of claim 165, wherein fabricating includes three-dimensionally printing.
171. The method of claim 165, wherein fabricating includes computerized milling.

172. The method of claim 165, wherein fabricating includes three-dimensionally printing a physical model and milling directly from the physical model.
173. The method of claim 165, wherein fabricating includes fabricating with stereo lithography.
174. A system for preparing and installing a temporary dental restoration during a single dentistry visit of a dental patient, the system comprising:
a first means of acquiring a first digital surface representation of an intraroral structure from a mouth of the dental patient;
a manual means for preparing at least one tooth of the intraoral structure for a dental restoration to obtain a prepared intraoral structure;
a second means for acquiring a second digital surface representation of the prepared intraoral structure from the mouth of the dental patient;
a processor means for processing the first and second digital surface representations to create a three-dimensional model of a temporary dental restoration;
a fabrication means for fabricating the temporary dental restoration; and
a means for attaching the temporary dental restoration to the prepared intraoral structure.
175. The system of claim 174, wherein the fabrication means includes a means of printing the three-dimensional model of the temporary dental restoration in a first material to obtain a printed temporary dental restoration, and a means for copy milling the printed temporary dental restoration into a second material to obtain the temporary dental restoration.
176. The system of claim 175, wherein the second material includes a ceramic.
177. The system of claim 175, wherein the means for copy milling is automated.
178. The system of claim 174, further comprising a means for transmitting the first and second digital surface representations to a remote facility for fabrication of a permanent dental restoration
179. The system of claim 174, wherein the fabrication means includes a means for three-dimensionally printing.
180. The system of claim 174, wherein the fabrication means includes a means for computerized milling.
181. The system of claim 174, wherein the fabrication means includes a means for three-dimensionally printing a physical model and milling directly from the physical model.
182. The system of claim 174, wherein the fabrication means includes a means for fabricating with stereo lithography.
183. A method comprising:
acquiring a digital surface representation of one or more intraoral structures including a soft tissue;
processing the digital surface representation to obtain a three-dimensional model of the soft tissue; and
fabricating the three-dimensional model of the soft tissue to obtain a physical soft tissue model.
184. The method of claim 183, wherein the physical soft tissue model is fabricated from a material that, when cured, includes at least one property resembling the soft tissue.

185. The method of claim 184, wherein the at least one property includes color.
186. The method of claim 184, wherein the at least one property includes texture.
187. The method of claim 184, wherein the at least one property includes consistency.
188. The method of claim 183, wherein the physical soft tissue model is adapted for removably attaching to a dental cast of the one or more corresponding intraoral structures.
189. The method of claim 183, wherein fabricating includes three-dimensionally printing.
190. The method of claim 183, wherein fabricating includes computerized milling.
191. The method of claim 183, wherein fabricating includes three-dimensionally printing a physical model and milling directly from the physical model.
192. The method of claim 183, wherein fabricating includes fabricating with stereo lithography.
193. A system comprising:
 - a means for acquiring a digital surface representation of one or more intraoral structures including a soft tissue;
 - a processor means for processing the digital surface representation to obtain a three-dimensional model of the soft tissue; and
 - a fabrication means for fabricating the three-dimensional model of the soft tissue to obtain a physical soft tissue model.
194. The system of claim 193, wherein the physical soft tissue model includes at least one property resembling the soft tissue.
195. The system of claim 194, wherein the at least one property includes color.
196. The system of claim 194, wherein the at least one property includes texture.
197. The system of claim 194, wherein the at least one property includes consistency.
198. The system of claim 193, wherein the physical soft tissue model includes a means for removably attaching to a dental cast of the one or more corresponding intraoral structures.
199. The system of claim 193, wherein the fabrication means includes a means for three-dimensionally printing.
200. The system of claim 193, wherein the fabrication means includes a means for computerized milling.
201. The system of claim 193, wherein the fabrication means includes a means for three-dimensionally printing a physical model and milling directly from the physical model.
202. The system of claim 193, wherein the fabrication means includes a means for fabricating with stereo lithography.

203. A computer program product comprising computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of:
generating a digital surface representation from one or more images of one or more intraoral structures including a soft tissue;
processing the digital surface representation to obtain a three-dimensional model of the soft tissue; and
converting the three-dimensional model into a format suitable for fabrication.
204. The computer program product of claim 203, further comprising computer code to perform the step of adapting the three-dimensional model for removably attaching to a dental cast of the one or more corresponding intraoral structures.
205. The computer program product of claim 203, wherein the format is adapted for use with a three-dimensional printer.
206. The computer program product of claim 203, wherein the format is adapted for use with a computerized milling machine.
207. The computer program product of claim 203, wherein the format is adapted for use with a stereo lithography apparatus.
208. A method comprising:
obtaining a digital surface representation of one or more intraoral structures;
processing the digital surface representation to obtain a digital dental model;
adding a marking to the digital dental model; and
fabricating the three-dimensional model including the marking to obtain a marked dental model.
209. The method of claim 208 wherein the dental model includes a dental cast.
210. The method of claim 208 wherein the marking includes a three-dimensional marking.
211. The method of claim 208 wherein the marking includes a two-dimensional marking printed with pigment.
212. The method of claim 208 wherein the marking includes a two-dimensional marking etched by a laser.
213. The method of claim 208 wherein the marking includes an identification aid.
214. The method of claim 213, wherein the identification aid identifies a patient.
215. The method of claim 213, wherein the identification aid identifies a dentist.
216. The method of claim 213, wherein the identification aid identifies a dental laboratory.
217. The method of claim 213, wherein the identification aid includes a logo of a dental laboratory.
218. The method of claim 213, wherein the identification aid includes a bar code.
219. The method of claim 213, wherein the identification aid includes a 2D matrix code.

- 220. The method of claim 213, wherein the identification aid uniquely identifies the marked dental model.
- 221. The method of claim 208, wherein the marking includes a treatment aid.
- 222. The method of claim 221, wherein the treatment aid includes a restoration margin.
- 223. The method of claim 221, wherein the treatment aid includes a soft tissue boundary.
- 224. The method of claim 221, wherein the treatment aid includes alignment marks for two arches of the marked dental model in occlusion.
- 225. The method of claim 221, wherein the treatment aid includes orthodontic bracket position marks.
- 226. The method of claim 221, wherein the treatment aid includes a landmark.
- 227. The method of claim 226, wherein the landmark includes a calibration mark.
- 228. The method of claim 226, wherein the landmark includes a fiducial.
- 229. The method of claim 208, further comprising adding an RFID tag to the marked dental model.
- 230. The method of claim 208, wherein the marking identifies position of a piece of the marked dental model in a tray.
- 231. The method of claim 208, wherein fabricating includes three-dimensionally printing.
- 232. The method of claim 208, wherein fabricating includes computerized milling.
- 233. The method of claim 208, wherein fabricating includes three-dimensionally printing a physical model and milling directly from the physical model.
- 234. The method of claim 208, wherein fabricating includes fabricating with stereo lithography.
- 235. A system comprising:
 - a means for obtaining a digital surface representation of one or more intraoral structures;
 - a processor means for processing the digital surface representation to obtain a digital dental model;
 - a marking means for adding a marking to the digital dental model; and
 - a fabrication means for fabricating the three-dimensional model including the marking to obtain a marked dental model.
- 236. The system of claim 235, wherein the dental model includes a dental cast.
- 237. The system of claim 235, wherein the marking includes a three-dimensional marking.
- 238. The system of claim 235, wherein the marking includes a two-dimensional marking printed with pigment.
- 239. The system of claim 235, wherein the marking includes a two-dimensional marking etched by a laser.

- 240. The system of claim 235, wherein the marking includes a means of identification.
- 241. The system of claim 240, wherein the means of identification includes a means for identifying a patient.
- 242. The system of claim 240, wherein the means of identification includes a means for identifying a dentist.
- 243. The system of claim 240, wherein the means of identification includes a means for identifying a dental laboratory.
- 244. The system of claim 240, wherein the means of identification includes a logo of a dental laboratory.
- 245. The system of claim 240, wherein the means of identification includes a bar code.
- 246. The system of claim 240, wherein the means of identification includes a 2D matrix code.
- 247. The system of claim 240, wherein the means of identification includes a means for uniquely identifying the marked dental model.
- 248. The system of claim 235, wherein the marking includes a treatment aid.
- 249. The system of claim 248, wherein the treatment aid includes a means for determining a restoration margin.
- 250. The system of claim 248, wherein the treatment aid includes a means for determining a soft tissue boundary.
- 251. The system of claim 248, wherein the treatment aid includes a means for aligning two arches of the marked dental model in occlusion.
- 252. The system of claim 248, wherein the treatment aid includes a means for positioning an orthodontic bracket.
- 253. The system of claim 248, wherein the treatment aid includes a landmark.
- 254. The system of claim 253, wherein the landmark includes a calibration means for determining calibration status.
- 255. The system of claim 253, wherein the landmark includes a fiducial means for determining orientation visually.
- 256. The system of claim 235, further comprising a means of adding an RFID tag to the marked dental model.
- 257. The system of claim 235, wherein the marking includes a means for identifying position of a piece of the marked dental model in a tray.

258. The system of claim 235, wherein the fabrication means includes a means for three-dimensionally printing.
259. The system of claim 235, wherein the fabrication means includes a means for computerized milling.
260. The system of claim 235, wherein the fabrication means includes a means for three-dimensionally printing a physical model and milling directly from the physical model.
261. The system of claim 235, wherein the fabrication means includes a means for fabricating with stereo lithography.
262. A computer program product comprising computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of:
generating a digital surface representation from one or more images of one or more intraoral structures;
processing the digital surface representation to obtain a digital dental model;
adding a marking to the digital dental model, to obtain a marked digital dental model; and
converting the marked digital dental model into a format suitable for fabrication.
263. The computer program product of claim 262 wherein the digital dental model includes a dental cast.
264. The computer program product of claim 262 wherein the marking includes a three-dimensional marking.
265. The computer program product of claim 262 wherein the marking includes a two-dimensional marking.
266. The computer program product of claim 262 wherein the marking includes an identification aid.
267. The computer program product of claim 266, wherein the identification aid identifies a patient.
268. The computer program product of claim 266, wherein the identification aid identifies a dentist.
269. The computer program product of claim 266, wherein the identification aid identifies a dental laboratory
270. The computer program product of claim 266, wherein the identification aid includes a logo of a dental laboratory
271. The computer program product of claim 266, wherein the identification aid includes a bar code.
272. The computer program product of claim 266, wherein the identification aid includes a 2D matrix code.
273. The computer program product of claim 266, wherein the identification aid uniquely identifies the marked dental model.
274. The computer program product of claim 262, wherein the marking includes a treatment aid.

275. The computer program product of claim 274, wherein the treatment aid includes a restoration margin.
276. The computer program product of claim 274, wherein the treatment aid includes a soft tissue boundary.
277. The computer program product of claim 274, wherein the treatment aid includes alignment marks for two arches of the marked dental model in occlusion.
278. The computer program product of claim 274, wherein the treatment aid includes orthodontic bracket position marks.
279. The computer program product of claim 274, wherein the treatment aid includes a landmark.
280. The computer program product of claim 278, wherein the landmark includes a calibration mark.
281. The computer program product of claim 278, wherein the landmark includes a fiducial.
282. The computer program product of claim 262, wherein the marking identifies position of a piece of the marked dental model in a tray.
283. The computer program product of claim 262, wherein the format is adapted for use with a three-dimensional printer.
284. The computer program product of claim 262, wherein the format is adapted for use with a computerized milling machine.
285. The computer program product of claim 262, wherein the format is adapted for use with a stereo lithography apparatus.
286. A method comprising:
obtaining a digital surface representation of one or more intraoral structures, the one or more intraoral structures including at least one tooth surface prepared for a dental restoration;
processing the digital surface representation to obtain a three-dimensional model of a casting model for the dental restoration; and
fabricating the three-dimensional model to obtain the casting model.
287. The method of claim 286, wherein the casting model includes an investment mold.
288. The method of claim 286, wherein the casting model includes an investment cast.
289. The method of claim 286, wherein the casting model corresponds to a coping.
290. The method of claim 286, wherein the casting model corresponds to a full anatomical form of a tooth.
291. The method of claim 286, wherein the casting model includes a pressed ceramic mold.
292. The method of claim 286, wherein fabricating includes three-dimensionally printing.

293. The method of claim 286, wherein fabricating includes computerized milling.
294. The method of claim 286, wherein fabricating includes three-dimensionally printing a physical model and milling directly from the physical model.
295. The method of claim 286, wherein fabricating includes fabricating with stereo lithography.
297. A system comprising:
a means for obtaining a digital surface representation of one or more intraoral structures, the one or more intraoral structures including at least one tooth surface prepared for a dental restoration;
a processor means for processing the digital surface representation to obtain a three-dimensional model of a casting model for the dental restoration; and
a fabrication means for fabricating the three-dimensional model to obtain the casting model.
298. The system of claim 297, wherein the casting model includes an investment mold.
299. The system of claim 297, wherein the casting model includes an investment cast.
300. The system of claim 297, wherein the casting model corresponds to a coping.
301. The system of claim 297, wherein the casting model corresponds to a full anatomical form of a tooth.
302. The system of claim 297, wherein the casting model includes a pressed ceramic mold.
303. The system of claim 297, wherein the fabrication means includes a means for three-dimensionally printing.
304. The system of claim 297, wherein the fabrication means includes a means for computerized milling.
305. The system of claim 297, wherein the fabrication means includes a means for three-dimensionally printing a physical model and milling directly from the physical model.
306. The system of claim 297, wherein the fabrication means includes a means for fabricating with stereo lithography.
307. A computer program product comprising computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of:
generating a digital surface representation from one or more images of one or more intraoral structures, the one or more intraoral structures including at least one tooth surface prepared for a dental restoration;
processing the digital surface representation to obtain a three-dimensional model of a casting model for the dental restoration; and
converting the three-dimensional model into a format suitable for fabrication.
308. The computer program product of claim 307, wherein the casting model includes an investment mold.
309. The computer program product of claim 307, wherein the casting model includes an investment cast.

310. The computer program product of claim 307, wherein the casting model corresponds to a coping.
311. The computer program product of claim 307, wherein the casting model corresponds to a full anatomical form of a tooth.
312. The computer program product of claim 307, wherein the casting model includes a pressed ceramic mold.
313. The computer program product of claim 307, wherein the format is adapted for use with a three-dimensional printer.
314. The computer program product of claim 307, wherein the format is adapted for use with a computerized milling machine.
315. The computer program product of claim 307, wherein the format is adapted for use with a stereo lithography apparatus.
316. A method comprising:
obtaining a digital surface representation of one or more intraoral structures from a mouth of a dental patient, the one or more intraoral structures including at least one tooth surface prepared for a dental restoration;
processing the digital surface representation to obtain a three-dimensional model of a wax model for a lost wax fabrication process; and
fabricating the three-dimensional model to obtain the wax model.
317. The method of claim 316, further comprising creating an investment from the wax model
318. The method of claim 317, wherein the investment includes a coping.
319. The method of claim 317, wherein the investment includes a dental restoration in final anatomy form.
320. The method of claim 317, wherein the investment includes a substructure for a dental restoration.
321. The method of claim 317, wherein the investment includes a full metal crown.
322. The method of claim 316, further comprising creating a pressable from the wax model.
323. The method of claim 322, wherein the pressable includes a press-to-zirconium restoration.
324. The method of claim 322, wherein the pressable includes a press-to-alumina restoration.
325. The method of claim 322, wherein the pressable includes a ceramic restoration.
326. The method of claim 316, wherein fabricating includes three-dimensionally printing.
327. The method of claim 316, wherein fabricating includes computerized milling.
328. The method of claim 316, wherein fabricating includes three-dimensionally printing a physical model and milling directly from the physical model.

329. The method of claim 316, wherein fabricating includes fabricating with stereo lithography.
330. A system comprising:
a scanning means for obtaining a digital surface representation of one or more intraoral structures from a mouth of a dental patient, the one or more intraoral structures including at least one tooth surface prepared for a dental restoration;
a processor means for processing the digital surface representation to obtain a three-dimensional model of a wax model for a lost wax fabrication process; and
a fabrication means for fabricating the three-dimensional model to obtain the wax model.
331. The system of claim 330, further comprising a means for creating an investment from the wax model
332. The system of claim 331, wherein the investment includes a coping.
333. The system of claim 331, wherein the investment includes a dental restoration in final anatomy form.
334. The system of claim 331, wherein the investment includes a substructure for a dental restoration.
335. The system of claim 331, wherein the investment includes a full metal crown.
336. The system of claim 330, wherein the wax model is for a pressable restoration.
337. The system of claim 336, wherein the pressable includes a press-to-zirconium restoration.
338. The system of claim 336, wherein the pressable includes a press-to-alumina restoration.
339. The system of claim 336, wherein the pressable includes a ceramic restoration.
340. The system of claim 330, wherein the fabrication means includes a means for three-dimensionally printing.
341. The system of claim 330, wherein the fabrication means includes a means for computerized milling.
342. The system of claim 330, wherein the fabrication means includes a means for three-dimensionally printing a physical model and means for milling directly from the physical model.
343. The system of claim 330, wherein the fabrication means includes a means for fabricating with stereo lithography.
344. A computer program product comprising computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of:
generating a digital surface representation from one or more images of one or more intraoral structures from a mouth of a dental patient, the one or more intraoral structures including at least one tooth surface prepared for a dental restoration;
processing the digital surface representation to obtain a three-dimensional model of a wax model for a lost wax fabrication process; and
converting the three-dimensional model into a format suitable for fabrication.

- 345. The computer program product of claim 344 wherein the wax model includes an investment.
- 346. The computer program product of claim 345, wherein investment includes a coping.
- 347. The computer program product of claim 345, wherein the investment includes a dental restoration in final anatomy form.
- 348. The computer program product of claim 345, wherein the investment includes a substructure for a dental restoration.
- 349. The computer program product of claim 345, wherein the investment includes a full metal crown.
- 350. The computer program product of claim 344, wherein the wax model is for a pressable restoration.
- 351. The computer program product of claim 350, wherein the pressable restoration includes a press-to-zirconium restoration.
- 352. The computer program product of claim 350, wherein the pressable restoration includes a press-to-alumina restoration.
- 353. The computer program product of claim 350, wherein the pressable restoration includes a ceramic restoration.
- 354. The computer program product of claim 350, wherein the format is adapted for use with a three-dimensional printer.
- 355. The computer program product of claim 350, wherein the format is adapted for use with a computerized milling machine.
- 356. The computer program product of claim 350, wherein the format is adapted for use with a stereo lithography apparatus.
- 357. A method comprising:
 - obtaining a digital surface representation of one or more intraoral structures;
 - processing the digital surface representation to obtain a three-dimensional digital model of an item of removable dental hardware; and
 - fabricating the item of removable dental hardware from the three-dimensional digital model.
- 358. The method of claim 357, wherein the item of removable dental hardware includes a stent.
- 359. The method of claim 357, wherein the item of removable dental hardware includes a surgical guide.
- 360. The method of claim 357, wherein the item of removable dental hardware includes a night guard.
- 361. The method of claim 360 wherein the night guard includes a bruxism guard.
- 362. The method of claim 360 wherein the night guard includes a snore guard.

363. The method of claim 357, wherein the item of removable dental hardware includes a denture.
364. The method of claim 357, wherein fabricating includes three-dimensionally printing.
365. The method of claim 357, wherein fabricating includes computerized milling.
366. The method of claim 357, wherein fabricating includes three-dimensionally printing a physical model and milling directly from the physical model.
367. The method of claim 357, wherein fabricating includes fabricating with stereo lithography.
368. A system comprising:
a means for obtaining a digital surface representation of one or more intraoral structures;
a processor means for processing the digital surface representation to obtain a three-dimensional digital model of an item of removable dental hardware; and
a fabrication means for fabricating the item of removable dental hardware from the three-dimensional digital model.
369. The system of claim 368, wherein the item of removable dental hardware includes a stent.
370. The system of claim 368, wherein the item of removable dental hardware includes a surgical guide.
371. The system of claim 368, wherein the item of removable dental hardware includes a night guard.
372. The system of claim 371 wherein the night guard includes a bruxism guard.
373. The system of claim 371 wherein the night guard includes a snore guard.
374. The system of claim 368, wherein the item of removable dental hardware includes a denture.
375. The system of claim 368, wherein the fabrication means includes a means for three-dimensionally printing.
376. The system of claim 368, wherein the fabrication means includes a means for computerized milling.
377. The system of claim 368, wherein the fabrication means includes a means for three-dimensionally printing a physical model and milling directly from the physical model.
378. The system of claim 368, wherein the fabrication means includes a means for fabricating with stereo lithography.
379. A computer program product comprising computer executable code embodied in a computer readable medium that, when executed on one or more computer devices, performs the steps of:
generating a digital surface representation from one or more images of one or more intraoral structures, the one or more images received from a scanner;
processing the digital surface representation to obtain a three-dimensional digital model of an item of removable dental hardware; and
converting the three-dimensional digital model into a format suitable for fabrication.

380. The computer program product of claim 379, wherein the item of removable dental hardware includes a stent.
381. The computer program product of claim 379, wherein the item of removable dental hardware includes a surgical guide.
382. The computer program product of claim 379, wherein the item of removable dental hardware includes a night guard.
383. The computer program product of claim 382 wherein the night guard includes a bruxism guard.
384. The computer program product of claim 382 wherein the night guard includes a snore guard.
385. The computer program product of claim 379, wherein the item of removable dental hardware includes a denture.
386. The computer program product of claim 379, wherein the format is adapted for use with a three-dimensional printer.
387. The computer program product of claim 379, wherein the format is adapted for use with a computerized milling machine.
388. The computer program product of claim 379, wherein the format is adapted for use with a stereo lithography apparatus.
389. A method comprising:
obtaining a digital surface representation of one or more intraoral structures;
processing the digital surface representation to obtain a three-dimensional digital model including a dental arch and at least one die for the dental arch;
three-dimensionally printing the dental arch; and
milling the die.
390. A method comprising:
acquiring a digital surface representation of one or more intraoral structures;
processing the digital surface representation to obtain a three-dimensional model of the one or more intraoral structures;
creating at least one void space within the three-dimensional model to provide a voided digital model, the at least one void space having sufficient volume to substantially reduce material costs of fabricating the three-dimensional model; and
fabricating the voided digital model to obtain a dental model of the one or more intraoral structures.

ABSTRACT

[00172] The systems and methods disclosed herein employ a scanning system for capturing highly detailed three-dimensional representations of dental subject matter that may be used to virtually model a variety of dental objects, including dental hardware, appliances, and prosthetics, as well as interim components of dental manufacture such as waxups, investment casts, and the like. These digital models may be used with fabrication technologies such as stereo lithography, three-dimensional printing, computerized milling, and the like to manufacture dental objects precisely fitted to the dentition of individual dental patients.

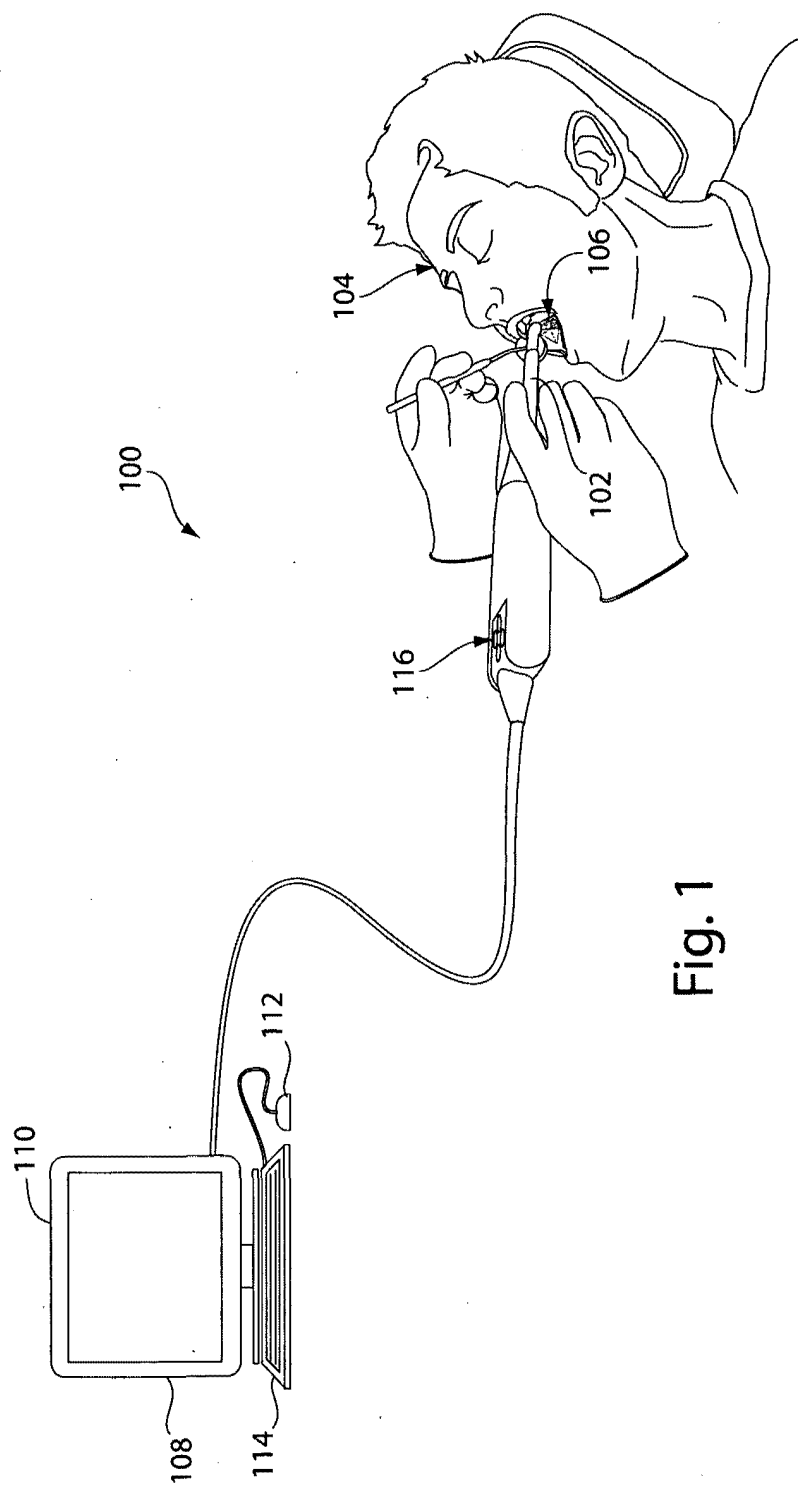


Fig. 1

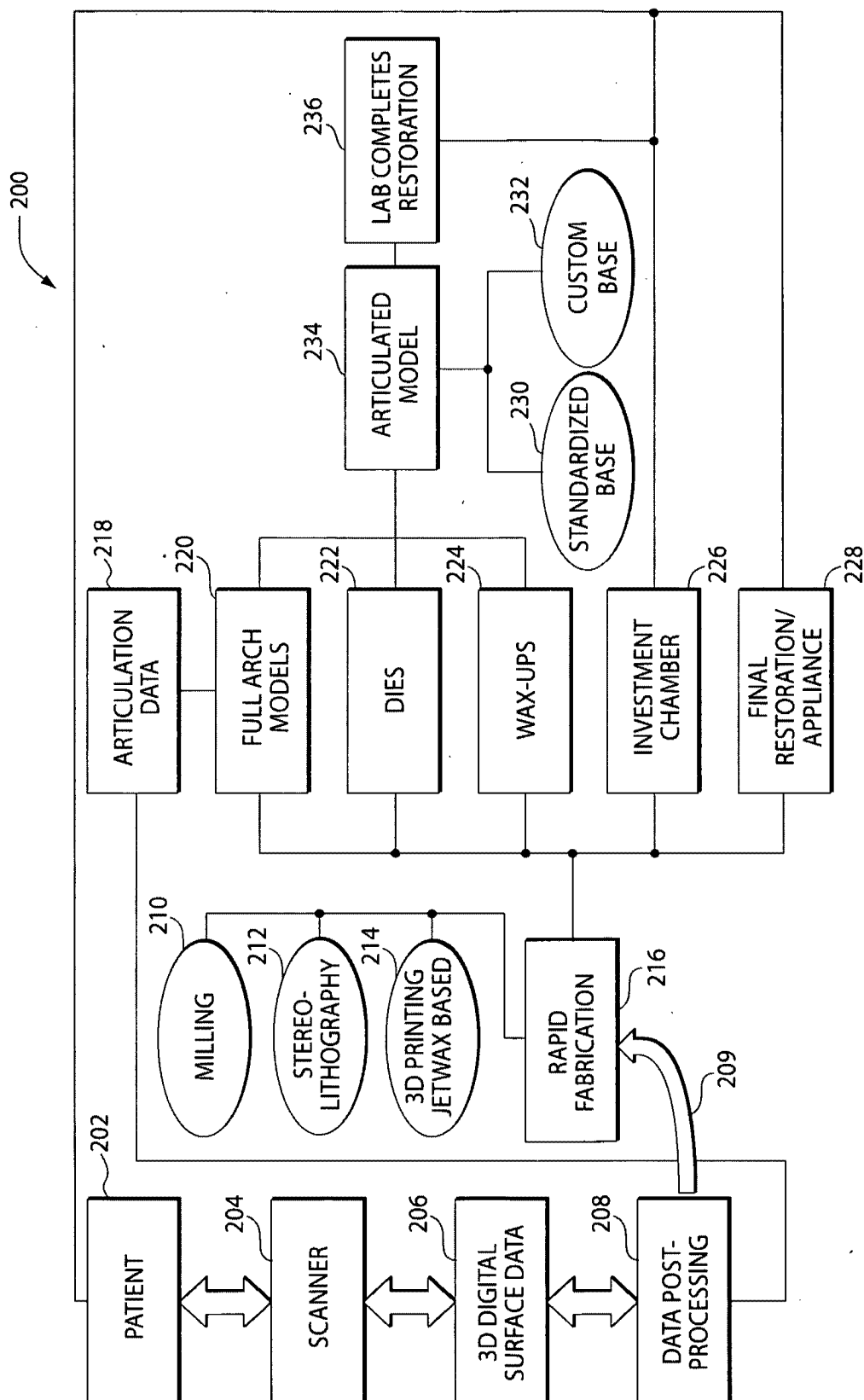


Fig. 2

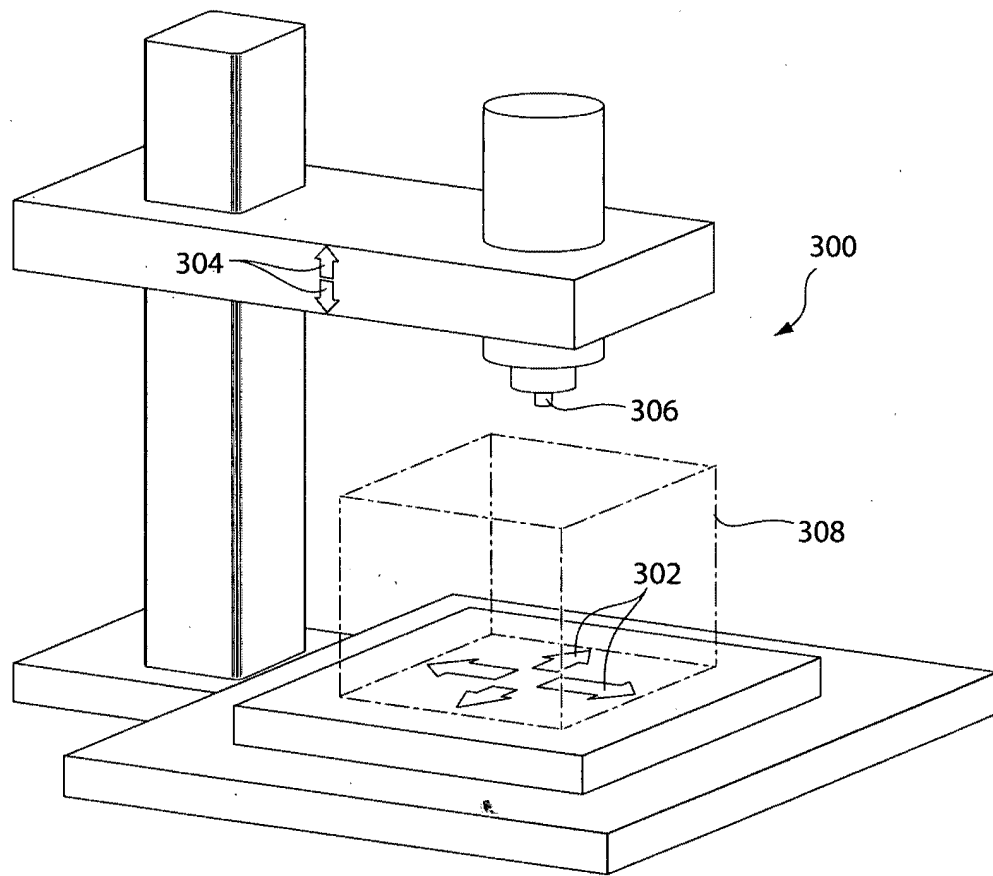


Fig. 3

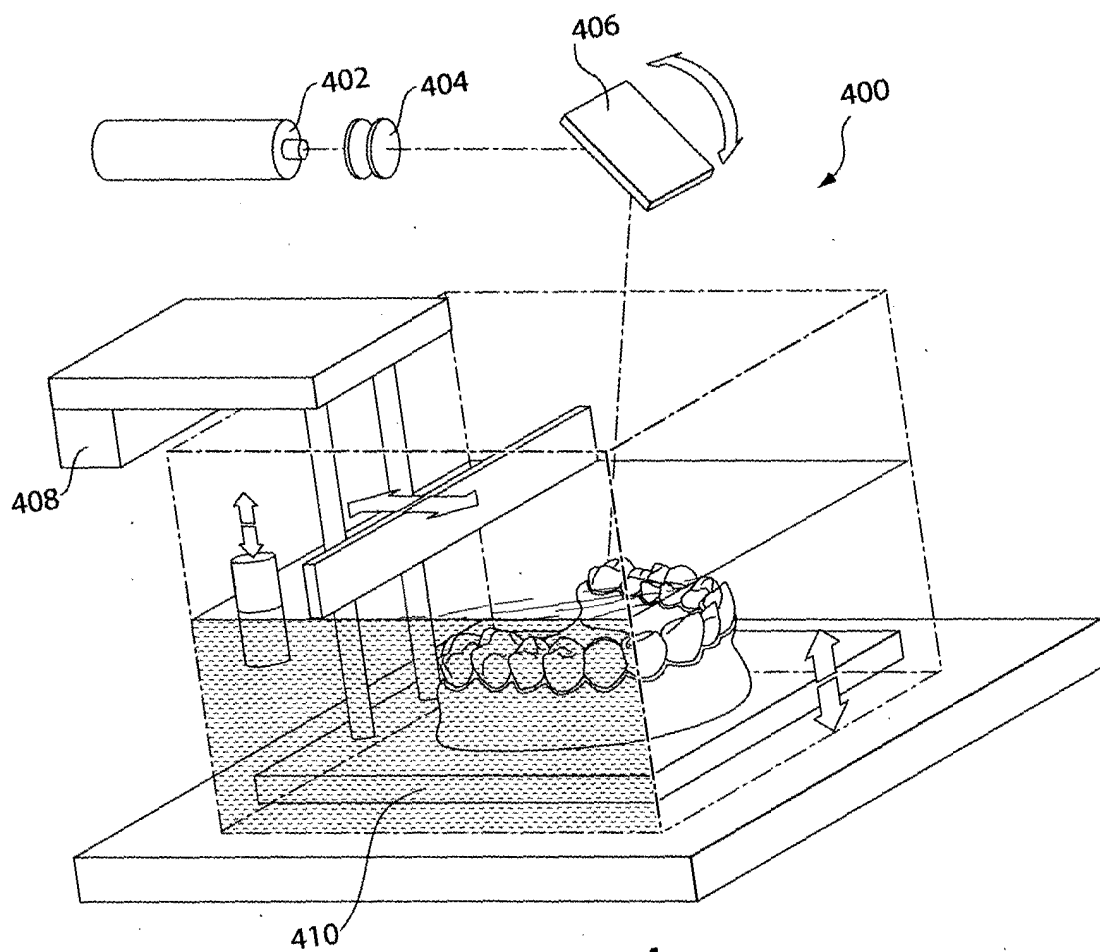


Fig. 4

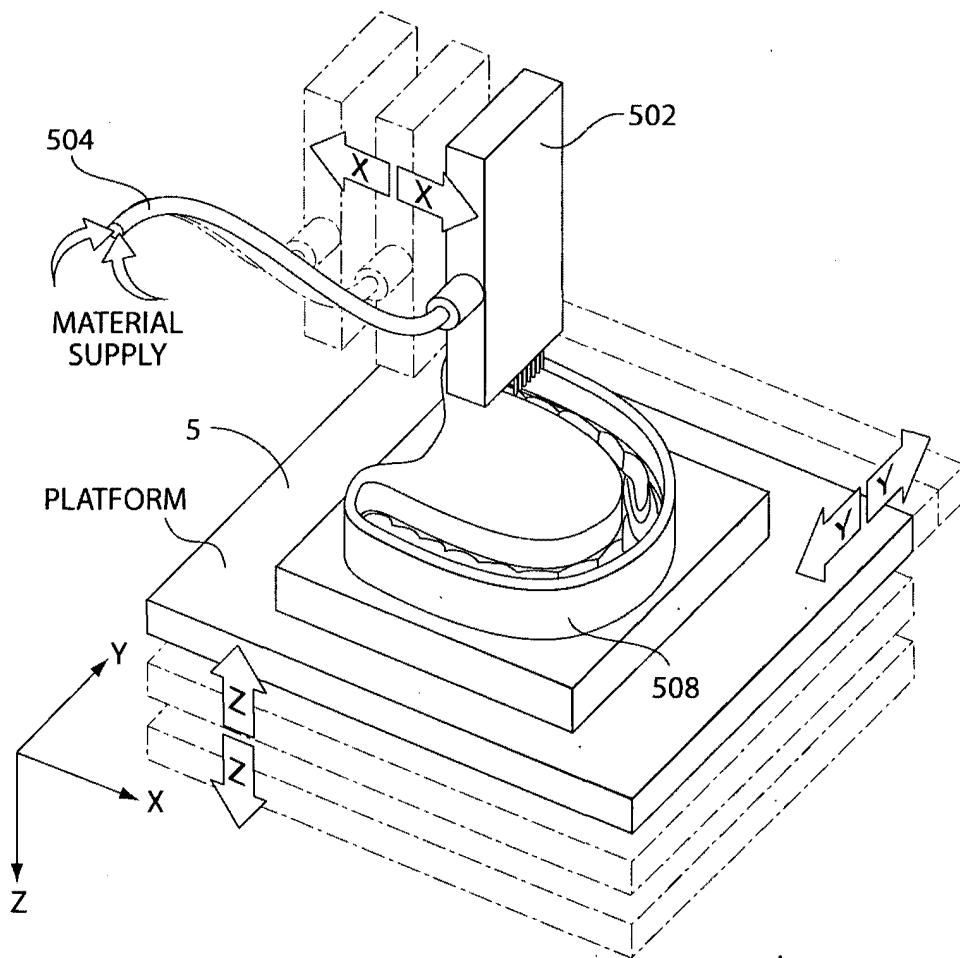


Fig. 5

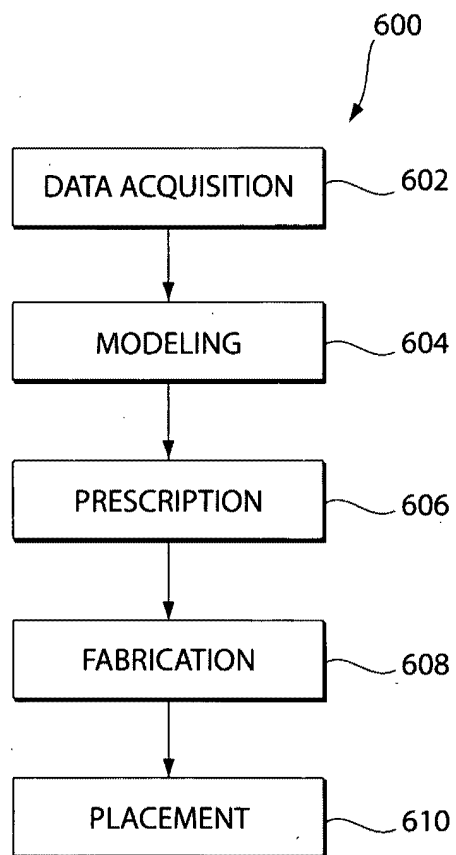


Fig. 6

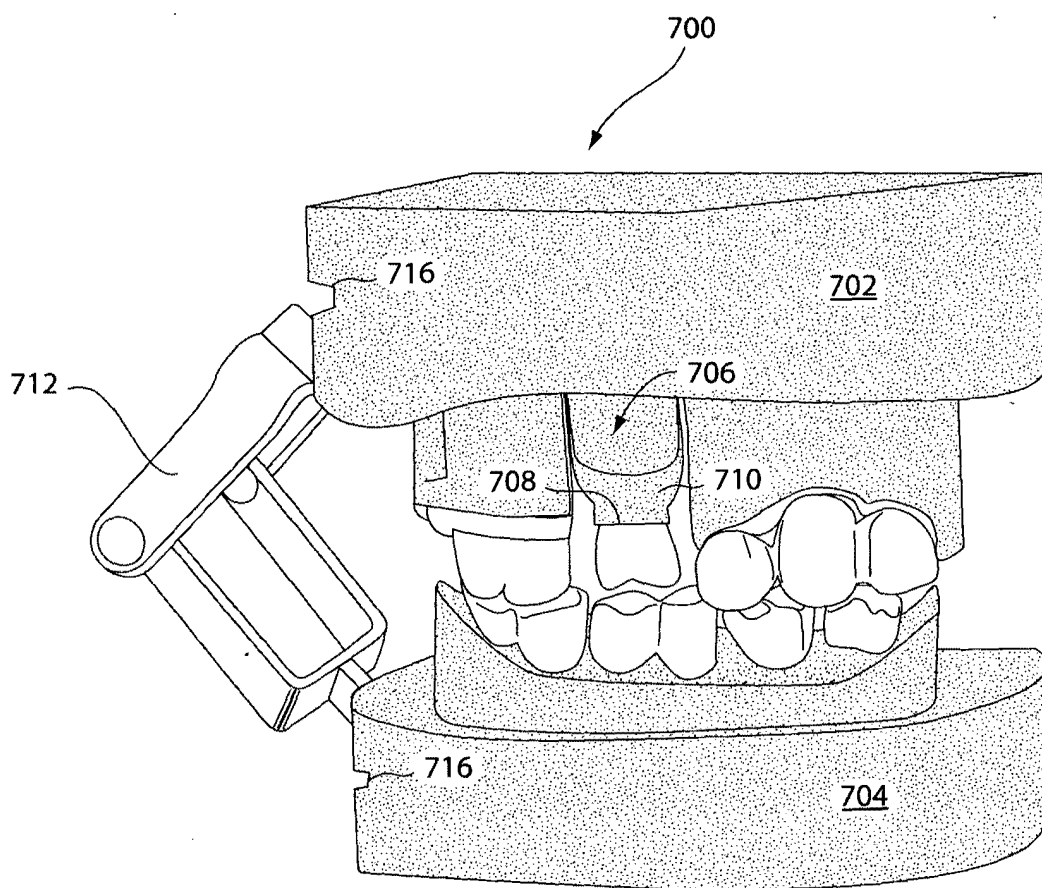


Fig. 7

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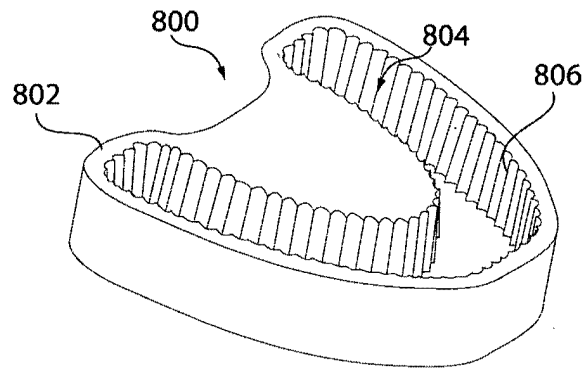


Fig. 8A

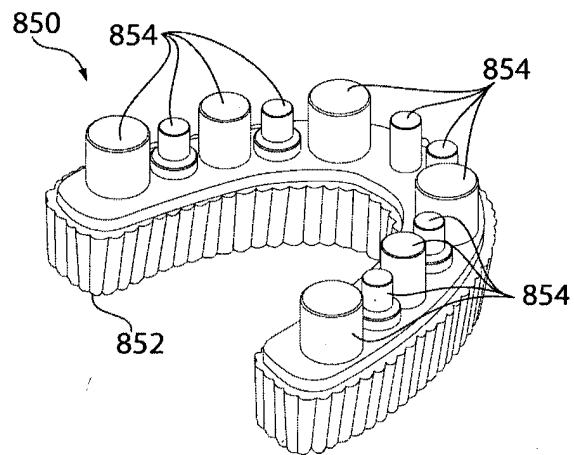


Fig. 8B

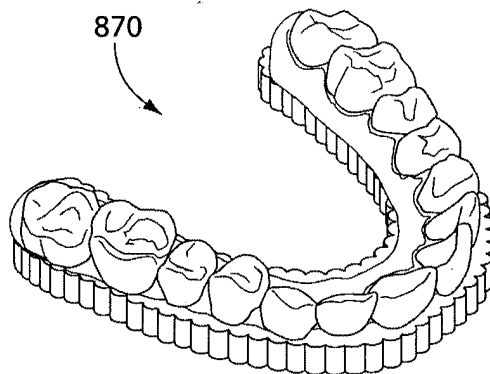


Fig. 8C

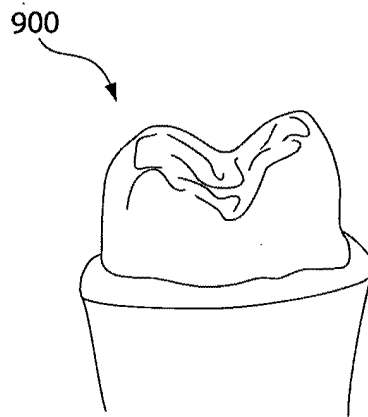


Fig. 9

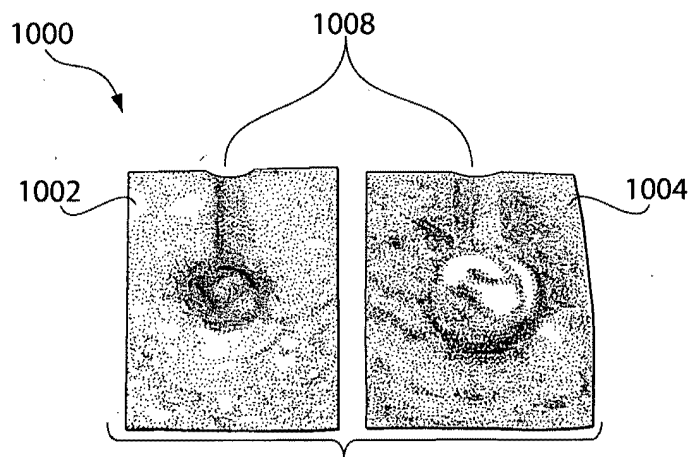


Fig. 10

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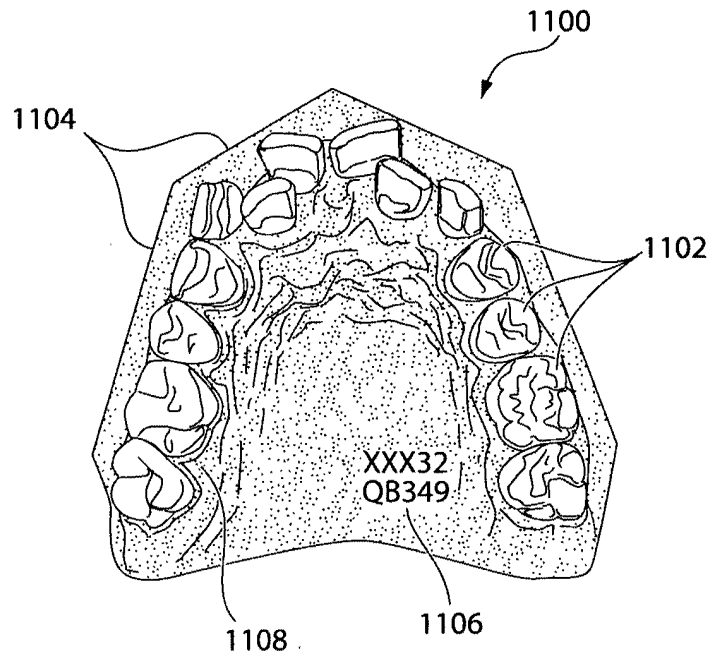


Fig. 11

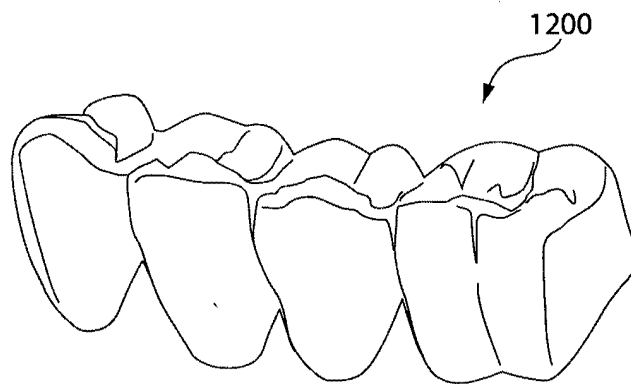


Fig. 12

PATENT APPLICATION SERIAL NO. _____

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01 FC:2005	100.00 OP
02 FC:2085	250.00 OP

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