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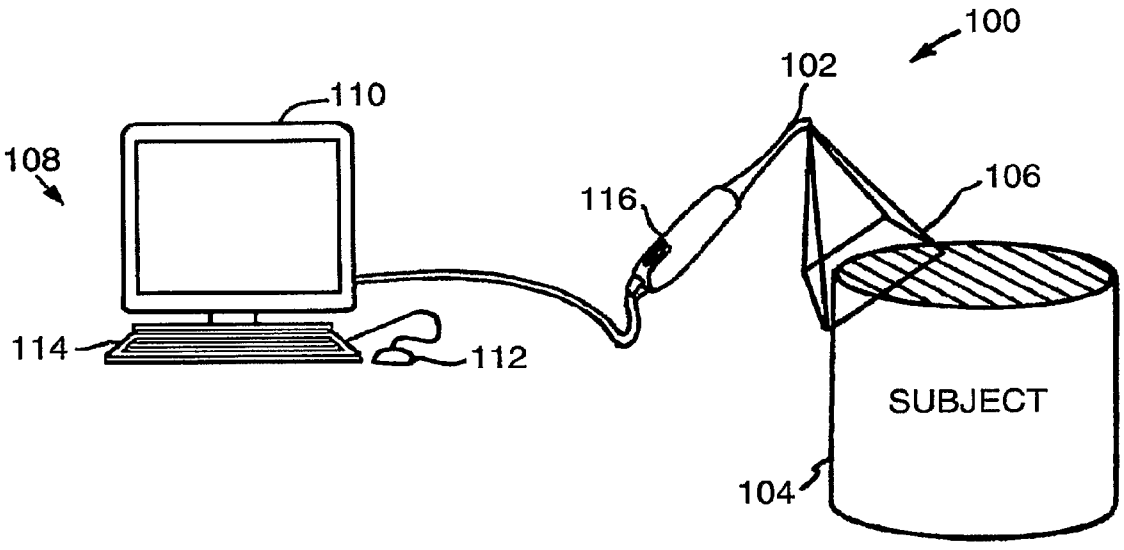
(54) Title: VISUALIZATION OF THREE-DIMENSIONAL DATA ACQUISITION



(57) Abstract: The systems and methods disclosed herein employ superposition of two-dimensional video and a rendered, three-dimensional image to provide visual feedback during acquisition and analysis of three-dimensional data. These systems and methods may be usefully employed in a context such as dentistry to assist in the acquisition of highly detailed and accurate digital dental models from the dentition of a dental patient.

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VISUALIZATION OF THREE-DIMENSIONAL DATA ACQUISITION

RELATED APPLICATIONS

This application claims priority to U.S. App. No. 60/761,078 filed on January 20, 2006; U.S. App. No. 11/469,869 filed on September 3, 2006; U.S. App. No. 11/469,870 filed on September 3, 2006; and U.S. App. No. 11/469,871 filed on September 3, 2006.

BACKGROUND

1.. Field of the Invention.

[0001] The invention relates to three-dimensional data acquisition and more particularly to uses of superposition as a 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.

[0065] The systems and methods disclosed herein employ superposition of two-dimensional video and a rendered, three-dimensional image to provide visual feedback during acquisition and analysis of three-dimensional data. These systems and methods may be usefully employed in a context such as dentistry to assist in the acquisition of highly detailed and accurate digital dental models from the dentition of a dental patient.

[0066] The systems and methods disclosed herein provide real time display of three-dimensional dental data acquired intraorally from a dental patient.

[0067] The systems and methods disclosed herein provide visual feedback concerning one or more scanning parameters to a user during acquisition of a three dimensional scan.

BRIEF DESCRIPTION OF THE FIGURES

[0068] The invention and the following detailed description of certain embodiments thereof may be understood by reference to the following figures.

[0069] Fig. 1 shows a dental image capture system.

[0070] Fig. 2 depicts a view of a user interface for an image capture system.

[0071] Fig. 3 depicts a view of a user interface for an image capture system.

[0072] Fig. 4 depicts a view of a user interface for an image capture system during an acquisition of three-dimensional data.

[0073] Fig. 5 depicts a view of a user interface for an image capture system during an evaluation.

[0074] Fig. 6 depicts a dental model in digital form.

[0075] Fig. 7 depicts a cross-section of a digital dental model.

[0076] Fig. 8 depicts a visualization technique for locating holes in a digital surface representation of dental subject matter.

[0077] Fig. 9 depicts a visualization technique using a simulated external illumination.

DETAILED DESCRIPTION

[0078] The following description relates to 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.

[0079] 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, such as might be 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, for example, 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 otherwise clear from the context.

[0080] 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, a particle system, or any other renderable primitives or 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.

[0081] A "three-dimensional representation" may include any of the three-dimensional surface representations described above, as well as volumetric, vector, and/or other representations, unless a different meaning is explicitly provided or otherwise clear from the context.

[0082] 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 stereoscopic, three-dimensional, and other rendering technologies exist, and may be usefully employed with the systems and methods disclosed herein to render objects in three dimensions. As such, rendering should be interpreted broadly unless a narrower meaning is explicitly provided or otherwise clear from the context.

[0083] 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 various types of occlusion, 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 which may not be intraoral structures as described above, 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 be categorized in a number of ways. For example, dental objects may be categorized as natural dental objects such as the teeth, bone, and other intraoral structures described above and artificial dental objects such as the restorations, prostheses, appliances, hardware, and interim components of dental manufacture as described above. Similarly, dental objects may be categorized intraoral dental objects (which may be natural or artificial) and extraoral dental objects (which are generally but not exclusively artificial).

[0084] 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 or otherwise clear from the context, the term "model", when used alone, may refer to either or both of a physical model and a digital model.

[0085] 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.

[0086] 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, including systems with moving apertures, fixed apertures, and/or electro-mechanically shuttered apertures. 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 or moving 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 (e.g., time of flight in a known direction), or any other technology suitable for acquiring three-dimensional data, or two-dimensional data that can be resolved into three-dimensional data.

[0087] 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.

[0088] 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. In other structured light systems, the illumination may be in the form of an array of laser beams that form a pattern on a surface, which pattern may be employed to recover three-dimensional data from the surface. Other systems employ a single laser beam along with directional information to gather point-by-point direction and range information. All such imaging systems may be usefully employed to acquire three-dimensional data as described herein.

[0089] 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. An optical or textured imaging agent may optionally 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 may be acquired 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.

[0090] 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 that, together with the field of view 106, specifies a measurement volume of the scanner 102. The depth of field may vary with environmental conditions such as lighting (ambient or artificial), the texture or optical properties of the imaging subject, and so forth. It will further be understood that the term "field of view", as used herein may refer to a two-dimensional field such as an internal plane within the optics of an imaging system, an external plane such as a field in an imaging environment, or a region in a display, or may refer to a three-dimensional region such as a current measurement volume in an imaging environment. Thus, "field of view" as used herein should be interpreted in the broadest sense possible, unless a more specific meaning is explicitly provided, or otherwise clear from the context.

[0091] 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, but may generally be considered to fall between about ten frames per second and about thirty frames per second for many of the applications described herein. 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.

[0092] 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, ultrasound 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.

[0093] 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. It will also be understood that terms such as "video" or "video rate" imply a wide range of possible frame rates associated with such video. While most modern video formats employ a frame rate of 25 to 30 frames per second, early video employed frame rates as low as 8 frames per second, and movies of the early 1900's varied from 12 to 18 frames per second. In addition, it is common for specialized imaging equipment to employ a rate adapted to the computational demands of particular imaging and rendering techniques, and some video systems operate with frame rates anywhere from 4 frames per second (for computationally extensive imaging systems) to 100 frames per second or higher (for high-speed video systems). As used herein, the terms video rate and frame rate should be interpreted broadly. Notwithstanding this broad meaning, it is noted that useful and visually pleasing three-dimensional imaging systems have been constructed according to the foregoing with frame rates of at least ten frames per second, frame rates of at least twenty frames per second, and frame rates between 25 and 30 frames per second.

[0094] 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.

[0095] From time to time in continuous or incremental data acquisition systems, the fitting or stitch between two frames 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 commonly-owned U.S. App. No. 11/383,623, filed on May 16, 2006, 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.

[0096] The display 110 may include any display suitable for video or other rate rendering at a level of detail corresponding to the acquired data or a rendered version of the acquired data. Suitable displays include cathode ray tube displays, liquid crystal displays, light emitting diode displays, plasma 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.

[0097] 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 measurement volume of a scanner, such as the image plane 106 of the scanner 102 of Fig. 1. Within the field of view or measurement volume, 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.

[0098] 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, directory or path information, and the like 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.

[0099] 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.

[00100] 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.

[00101] 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.

[00102] 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.

[00103] 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. One useful model for rendering such a dynamic bullseye employs three co-axial cones of different colors, where the bullseye renders a planar cross-section of the three co-axial cones perpendicular to the common axis, and at a point along the common axis selected according to relative range from the subject.

[00104] In another example of 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

or measurement volume 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.

[00105] 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.

[00106] 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 (or conversely, the video image may be superimposed on the rendered three-dimensional surface). 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.

[00107] 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 illustrated in Fig. 3 is intended to assist in explaining the nature of a point cloud distribution and various rendering techniques applicable thereto with reference to the specific points shown (the x's, o's, and encircled x's), 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. It will also be understood that the data in the three-dimensional scan may be internally represented as points, particle systems, vectors, or any other suitable representation. Thus, while the data may be rendered as a point cloud of any desired density, this may or may not correspond to the internal representation of scan data. Further, the rendering may employ techniques other than

point rendering, such as a polygonal mesh or the like, with suitable adaptations to the techniques described above for visualizing range, scan quality, and the like.

[00108] 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.

[00109] 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 an approach employing a fixed point of view, 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.

[00110] 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 with respect to Figs. 4 and 5 below, which show a scanning mode and an evaluation mode respectively.

[00111] 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. Although not depicted, it will be understood that in other

embodiments, the current digital surface representation may be rendered from a fixed point of view.

[00112] 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 or relative fineness/coarseness of a polygonal mesh, with respect to whether data is being successful 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. While specific feedback examples are noted above, it will be understood that more generally, numerous and various uses of brightness, texture, shading, color, and/or rendered point cloud density, or the like may be employed to provide visual feedback to a user concerning scan quality, detail, and the like.

[00113] 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.

[00114] 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 know 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).

[00115] 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.

[00116] 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.

[00117] 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 commonly-owned U.S. App. No. 11/337,182, filed on January 20, 2006, the entire content of which is incorporate herein by reference.

[00118] 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. More generally, rendering may employ a polygonal mesh, point cloud, particle system, and/or other renderable primitive(s).

[00119] 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 as depicted in Fig. 6, or more generally to review any artificial or natural, intraoral or extraoral dental object for which a digital surface representation has been acquired. 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.

[00120] 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 rendering within a display of the model, or textual annotations (which may, for example, be rendered within the display, rendered alongside the display in a separate window, or stored in a file) containing narrative description of conclusions, or a combination of these.

[00121] 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, variations in brightness, 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, reference materials, 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.

[00122] A process of preparing a tooth surface, scanning the tooth surface, and analyzing the tooth surface 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.

[00123] 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. These variations, whether dictated by context (e.g., particular teeth or a particular patient), objective criteria (e.g., manufacturing specifications), or subjective criteria (e.g., dentist preferences), may be accommodated by an automated analysis during an evaluation of a digital model so that resulting annotations or visualizations correspond correctly to a particular patient, dentist, and prescription.

[00124] The types of features in a specification 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.

[00125] 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.

[00126] 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 fossea pit 708 of the prosthetic 702, may be displayed in any manner, such as shading, coloring, brightness, texture, or mixing of cross-hatching styles for overlapped models.

[00127] 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.

[00128] 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, for example, employ 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.

[00129] It will be appreciated that a hole is a relative concept, 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.

[00130] 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 commonly-owned U.S. App. No. 11/337,182, filed on January 20, 2006, the entire content of which is incorporated herein by reference.

[00131] 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.

[00132] 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.

[00133] 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 be used during an acquisition of three-dimensional data to localize the scanner 908 with respect to the underlying physical model that is the subject of a scan. Thus, the simulated external illumination beam may serve as a navigational tool during a scan by providing visual feedback to a user concerning a location of the scanner with respect to a scan subject. A position and/or orientation of the scanner may be depicted within the interface for user feedback, so that a user knows a current location of the scanner 908. Also, or instead, an image of the scanner 908 rendered within the interface may include an illumination beam, line traces, or other visual effects to depict a current measurement

volume for the scanner. 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 or measurement volume 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. That is, when reacquiring a scan, the reacquisition may be based on a localized search of surface data in a correct, or nearly correct, orientation. As a significant advantage, this type of visual cue reduces the need for the large computational overhead associated with a generalized registration process.

[00134] As noted above with reference to Fig. 8, a user may operate navigational controls, which may be in a user interface and/or physically located on a scanner to 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 commonly-owned U.S. App. No. 11/337,182 filed on January 20, 2006, the entire content of which is incorporated herein by reference.

[00135] Numerous additional visualization techniques may be employed with the systems and methods described herein including combinations of the specific techniques described above, as well as combinations of any one or more of the foregoing with additional technologies. By way of example, a second scanner such as a PMD[vision] camera from PMD Technologies may be employed to capture real-time, three-dimensional data on dynamic articulation and occlusion. While this scanner employs different imaging technology (time-of-flight detection from an array of LEDs) than described above, and produces results with resolution generally unsuitable for reconstruction of dental models, such a scanner may be employed to infer motion of, e.g., opposing dental arches with sufficient resolution to select an axis

for articulation or otherwise capture dynamic information that can be applied to two or more rigid bodies of a dental object scan. In another aspect, the video-rate three-dimensional data from the second scanner may be employed to capture one or more reference points, which may be used to animate a rendering of highly detailed models or two or more rigid bodies, such as a detailed model of upper and lower arches as described generally above. Thus real-time animated rendering of relative motion may be provided for detailed models of rigid bodies, to provide a rendered view of relative motion for dental arches (or other bodies). This data may be supplemented with more precise alignment data statically captured from digital or manual bite registration to provide reference or calibration points for continuous, dynamic motion data. Thus in one aspect, there is disclosed herein a technique for capturing, storing, and or rendering dynamic motion data for dental arches using a first scanner to obtain a detailed three-dimensional representation of the dental arches and a second scanner to capture relative motion data that can be mapped to the detailed model from the first scanner.

[00136] 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.

[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, 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.

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.

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.

337. 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 three-dimensional surface representation and a two-dimensional video image of the anatomic structure in a display while acquiring the three-dimensional surface representation.

338. The method of claim 337 further comprising identifying one or more regions of the anatomic structure requiring additional scanning.

339. The method of claim 338 wherein the one or more regions include a region of inadequate scan data.

340. The method of claim 339 wherein the region of inadequate scan data includes a region of inadequate point cloud density.

341. The method of claim 339 wherein the region of inadequate scan data includes a region deficient in one or more of completeness, consistency, or quality.

342. The method of claim 338 wherein the one or more regions include a region deviating substantially from an expected surface contour.

343. The method of claim 338 further comprising providing a visual indication of the one or more regions within the display.

344. The method of claim 343 wherein the visual indication includes a variation in one or more of a color, a brightness, a density of a point cloud rendered in the display, and a surface texture.

345. The method of claim 337 wherein the three-dimensional surface representation includes a point cloud.

346. The method of claim 337 wherein the three-dimensional surface representation includes a polygonal mesh.

347. The method of claim 337 wherein the anatomic structure includes at least one dental object.

348. The method of claim 337 further comprising rendering the three-dimensional surface representation in a manner that provides real time user feedback for at least one of a position and an orientation of a scanner used to acquire the three-dimensional surface representation.

349. A computer program product embodied in a computer readable medium that, when executing on one or more computing devices, performs the steps of:

acquiring a three-dimensional surface representation of an anatomic structure as a plurality of fitted three-dimensional surface scans; and

superimposing the three-dimensional surface representation onto a two-dimensional video image of the anatomic structure in a display while acquiring the three-dimensional surface representation.

350. The computer program product of claim 349 further comprising code performing the step of identifying one or more regions of the anatomic structure requiring additional scanning.

351. The computer program product of claim 350 wherein the one or more regions include a region of inadequate scan data.

352. The computer program product of claim 350 wherein the one or more regions include a region deviating substantially from an expected surface contour.

353. The computer program product of claim 350 further comprising code performing the step of providing a visual indication of the one or more regions within the display.

354. The computer program product of claim 353 wherein the visual indication includes a variation in one or more of a color, a brightness, a density of a point cloud rendered in the display, and a surface texture.

355. The computer program product of claim 349 wherein the three-dimensional surface representation includes a point cloud.

356. The computer program product of claim 349 wherein the anatomic structure includes at least one dental object.

357. The computer program product of claim 349 further comprising code performing the step of rendering the three-dimensional surface representation in a manner that provides real time user feedback for at least one of a position and an orientation of a scanner used to acquire the three-dimensional surface representation.

358. A system comprising:

a scanner for acquiring a three-dimensional surface representation of an anatomic structure as a plurality of fitted three-dimensional surface scans;

a processor for superimposing the three-dimensional surface representation onto a two-dimensional video image of the anatomic structure while acquiring the three-dimensional surface representation to provide a superimposed video image; and

a display for displaying the superimposed video image.

359. The system of claim 358 wherein the processor renders the superimposed video image to provide real time user feedback for at least one of a position and an orientation of the scanner.

360. 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 at a video rate in real time.

361. The method of claim 360 further comprising superimposing the three-dimensional representation on a two-dimensional video image in real time.

362. The method of claim 360 wherein the one or more intraoral structures include at least one tooth.

363. The method of claim 360 wherein the one or more intraoral structures include at least one tooth surface prepared for a dental prosthetic.

364. The method of claim 360 wherein the one or more intraoral structures include at least one area of soft tissue.

365. The method of claim 360 further comprising:

generating user feedback concerning the one or more intraoral structures; and

providing a visual display of the user feedback at the video rate.

366. The method of claim 365 wherein generating user feedback includes highlighting at least one area in the three-dimensional representation requiring user attention.

367. The method of claim 360 wherein the video rate includes a rate of at least eight frames per second.

368. The method of claim 360 wherein the video rate includes a rate of at least twenty frames per second.

369. The method of claim 360 wherein the video rate includes a rate of between twenty-four and thirty frames per second.

370. A computer program product embodied on a computer readable medium that, when executing on one or more computing devices, performs the steps of:

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 at a video rate in real time.

371. The computer program product of claim 370 further comprising code for performing the step of superimposing the three-dimensional representation on a two-dimensional video image in real time.

372. The computer program product of claim 370 wherein the one or more intraoral structures include at least one tooth.

373. The computer program product of claim 370 wherein the one or more intraoral structures include at least one tooth surface prepared for a dental prosthetic.

374. The computer program product of claim 370 wherein the one or more intraoral structures include at least one area of soft tissue.

375. The computer program product of claim 370 further comprising code for performing the steps of:

generating user feedback concerning the one or more intraoral structures; and

providing a visual display of the user feedback at the video rate.

376. The computer program product of claim 375 wherein generating user feedback includes highlighting at least one area in the three-dimensional representation requiring user attention.

377. A system comprising:

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

a processor for generating a visual display signal of the three-dimensional representation at a video rate in real time; and

a display for displaying the visual display signal.

378. The system of claim 377 wherein the processor superimposes the three-dimensional representation on a two-dimensional video image in real time.

379. The system of claim 377 wherein the one or more intraoral structures include at least one of a tooth surface prepared for a dental prosthetic, an area of soft tissue, and a tooth.

380. The system of claim 377 wherein the processor generates user feedback concerning the one or more intraoral structures and includes the user feedback in the visual display signal at the video rate.

381. The system of claim 380 wherein the user feedback includes highlighting at least one area in the three-dimensional representation requiring user attention.

382. 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 from

a subject, 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; and

providing a visual cue within the display that relates to the one or more scanning parameters.

383. The method of claim 382 wherein rendering the digital surface reconstruction includes rendering the digital surface reconstruction from a current point of view of the scanning device.

384. The method of claim 383 further comprising superimposing the digital surface reconstruction and a video image of the subject from the current point of view in the display.

385. The method of claim 382 wherein rendering the digital surface reconstruction includes rendering the digital surface reconstruction in real time.

386. The method of claim 382 wherein the one or more parameters includes an optimal distance from the scanning device to a subject.

387. The method of claim 382 wherein the one or more scanning parameters includes a field of view for data capture within the display, the visual cue including a box bounding the field of view.

388. The method of claim 387 wherein the one or more scanning parameters includes a range of distances for data capture within the display, the visual cue including a three-dimensional box bounding the field of view and the range of distances.

389. The method of claim 382 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.

390. The method of claim 389 wherein color coding includes rendering points more distant than the range of distances in a first color.

391. The method of claim 389 wherein color coding includes rendering points nearer than the range of distances in a second color.

392. The method of claim 389 wherein color coding includes rendering points within the range of distances in a third color.

393. The method of claim 382 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.

394. The method of claim 393 wherein the dynamic object includes an animated bullseye.

395. The method of claim 393 wherein the dynamic object relates to a most recent frame of surface data.

396. The method of claim 393 wherein the dynamic object provides a relative distance indicator for visual feedback to a user concerning whether the scanning device is at least one of too close, too far, or properly distanced from the subject.

397. The method of claim 396 wherein the relative distance indicator provides graduated feedback to assist a user in maintaining a proper scan distance.

398. The method of claim 382 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.

399. The method of claim 382 further comprising capturing a two-dimensional video image with the scanning device and rendering the video image on the display.

400. The method of claim 399 further comprising superimposing the digital surface reconstruction on the video image in the display.

401. The method of claim 399 wherein the visual cue is updated at a video rate of the two-dimensional video image.

402. The method of claim 382 wherein the visual cue is updated in real time.

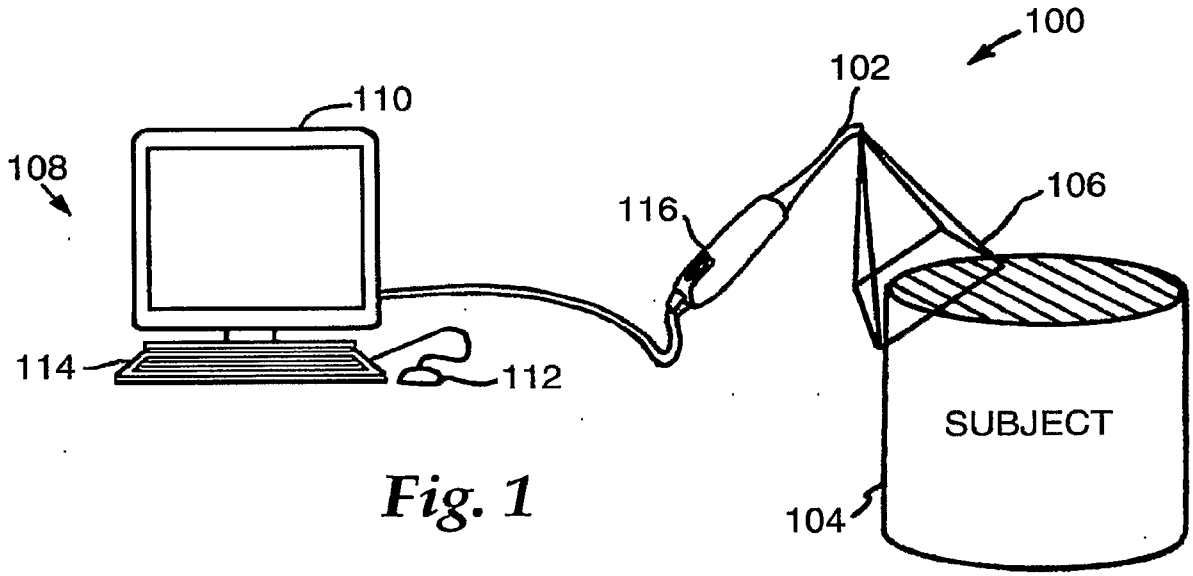
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Fig. 1

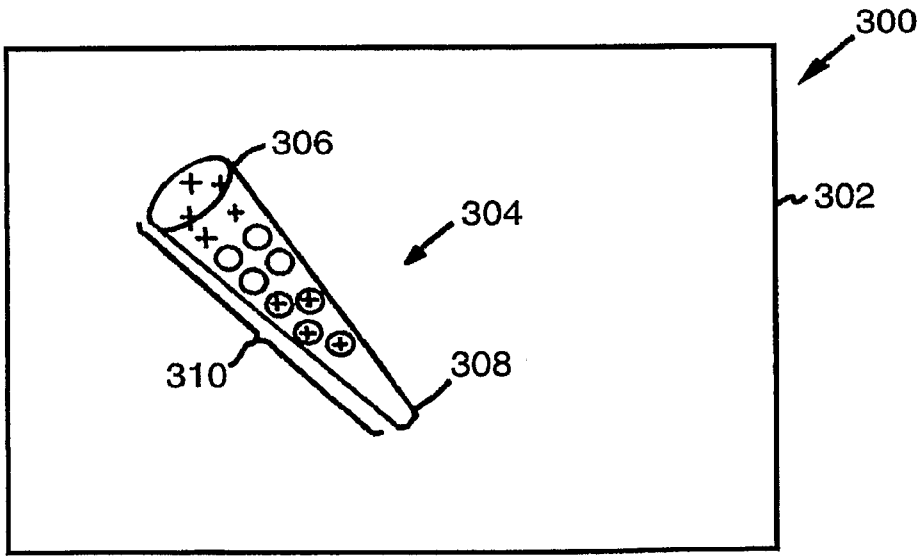
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Fig. 3

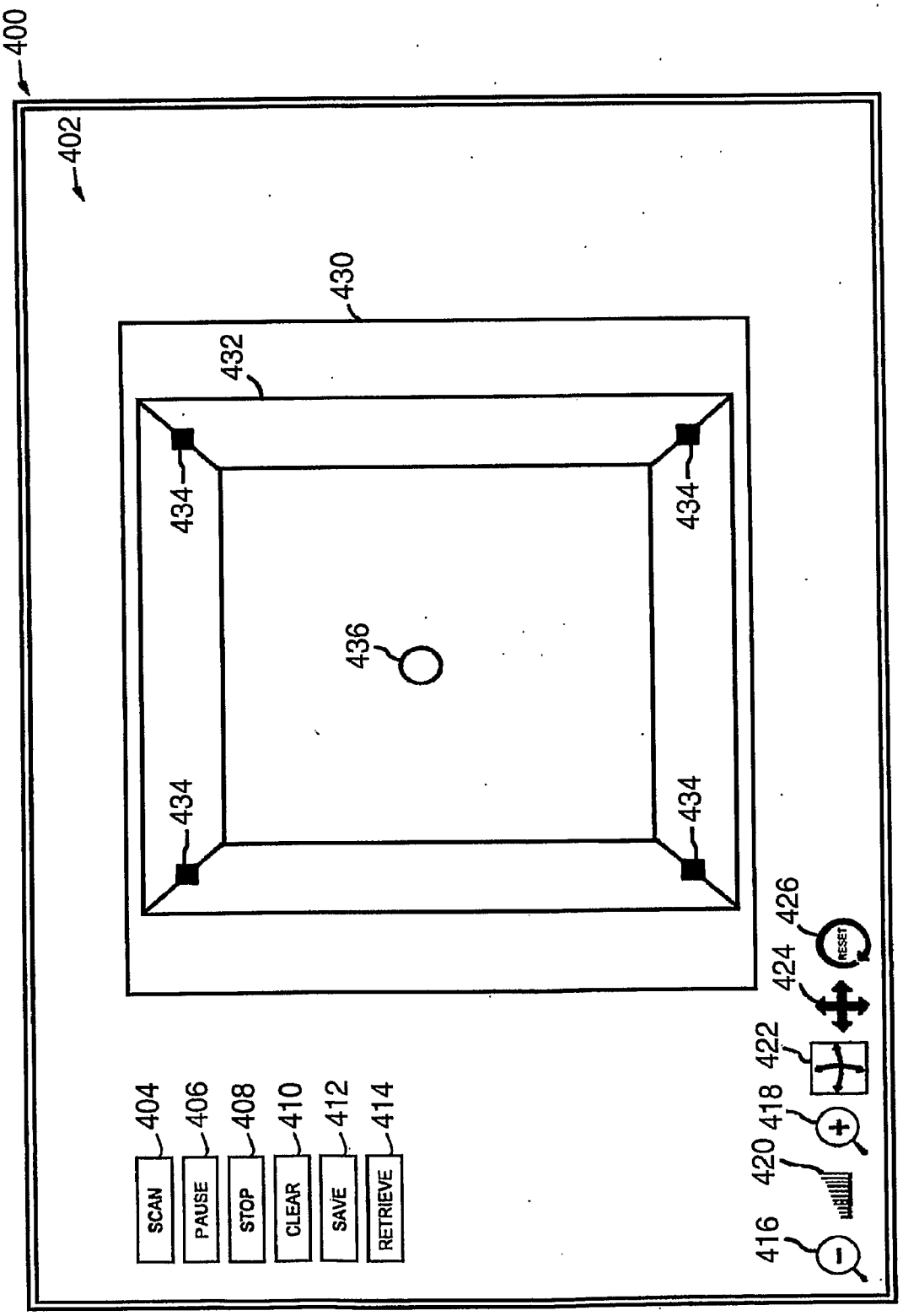
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Fig. 2

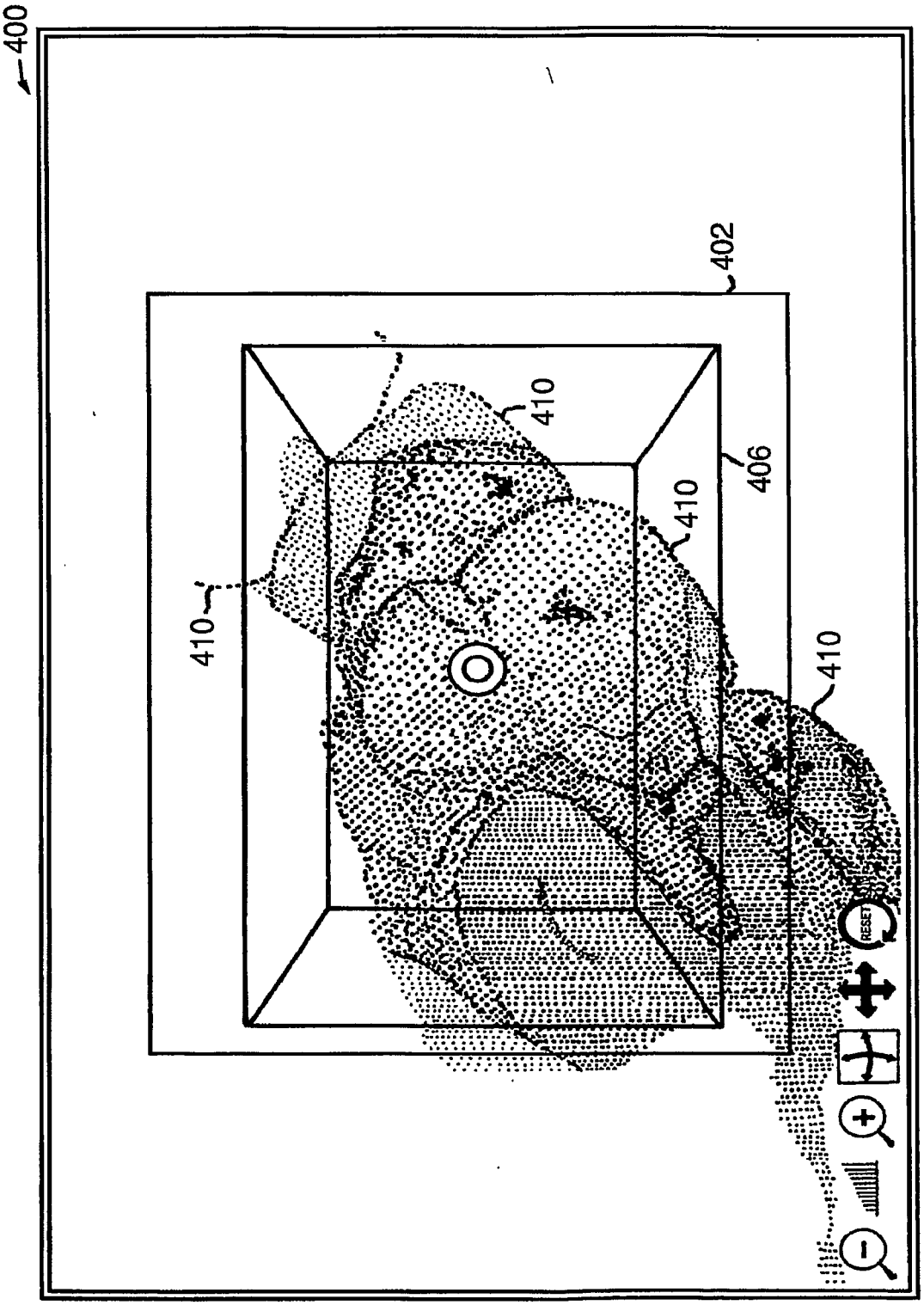

Fig. 4

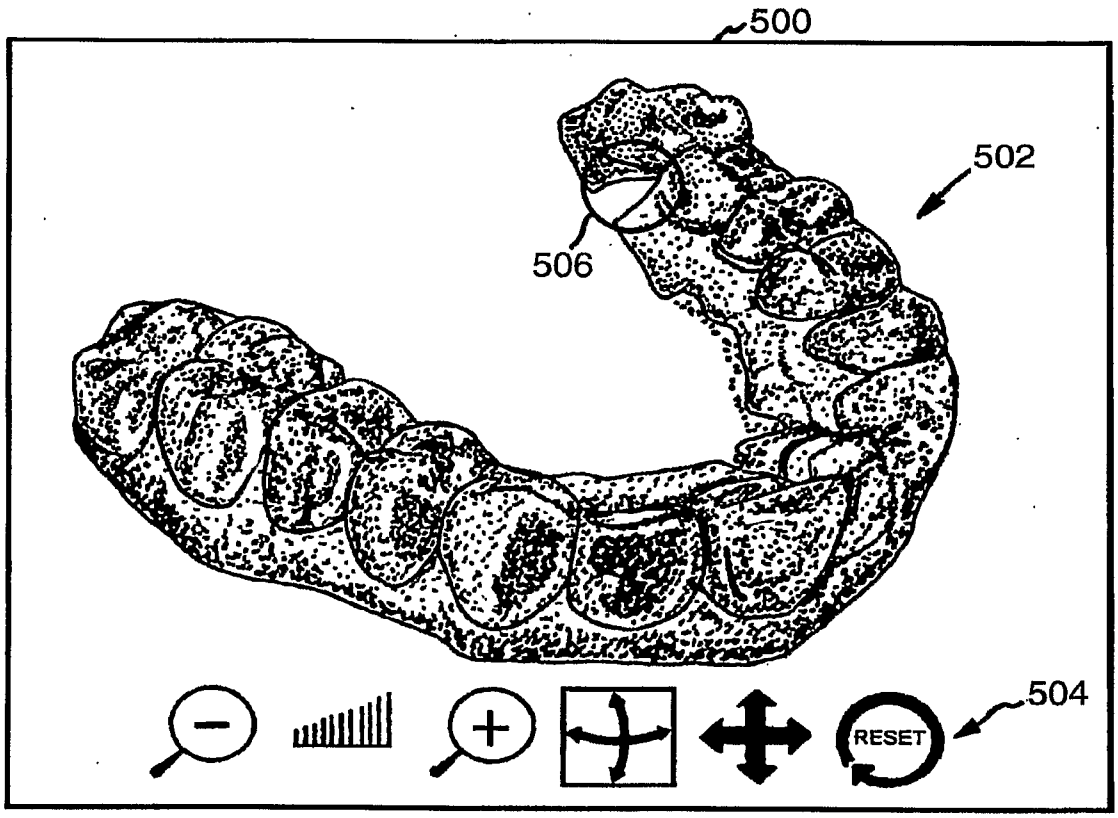

Fig. 5

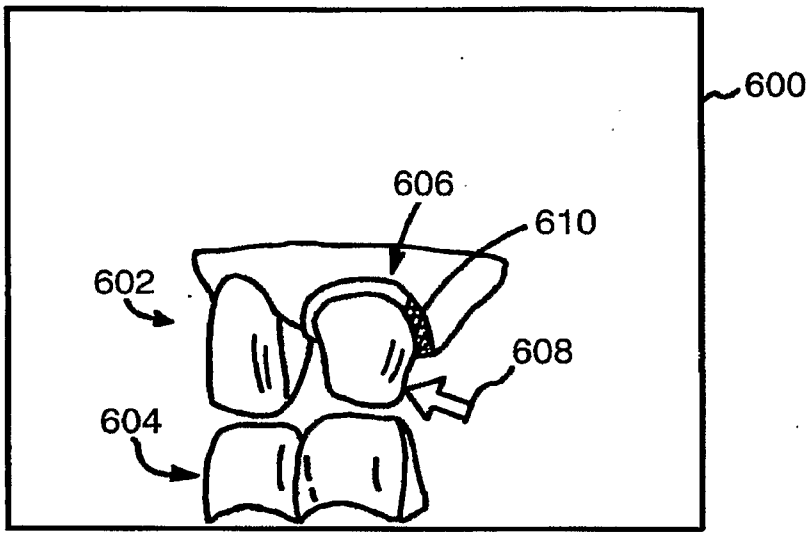

Fig. 6

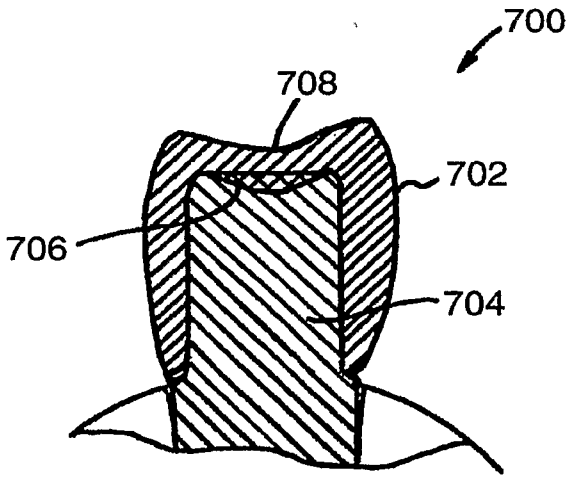

Fig. 7

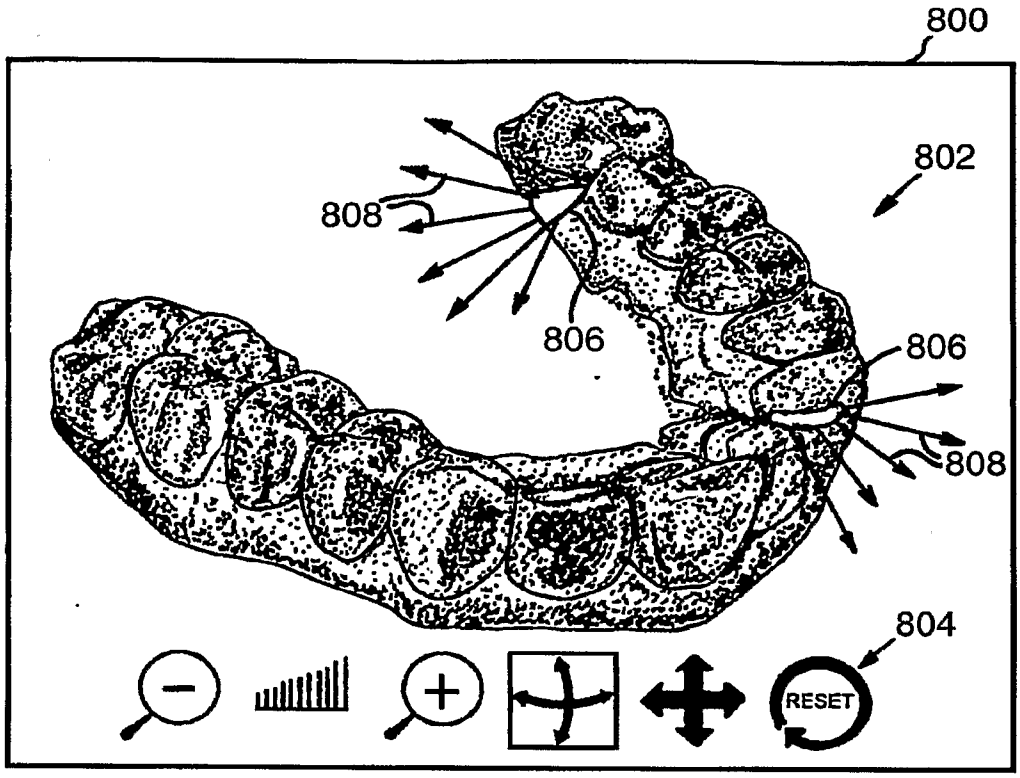

Fig. 8

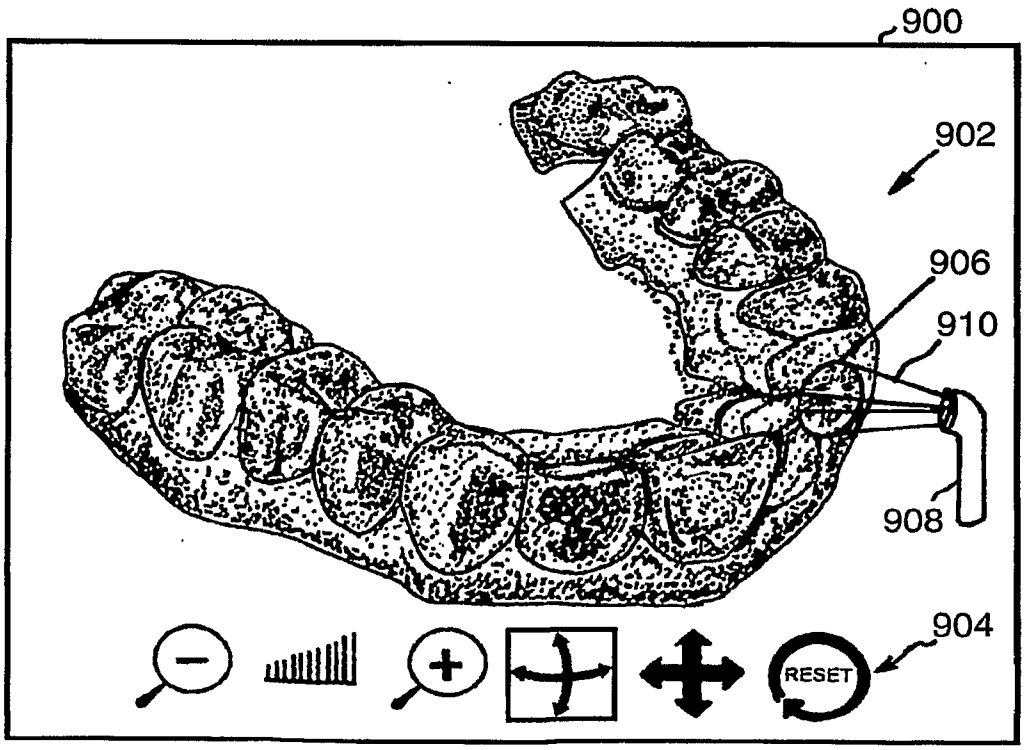

Fig. 9