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(71) Applicant(s)
Ultradent Products, Inc.

(72) Inventor(s)
Jessop, Neil T.;Fisher, Matthew Michael

(74) Agent / Attorney
FB Rice, Level 23 44 Market Street, Sydney, NSW, 2000

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STEREOSCOPIC VIDEO IMAGING

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ABSTRACT OF THE DISCLOSURE

Systems and methods for viewing stereoscopic video images are disclosed. The systems can include a first video camera configured to generate a first video feed of a subject, and a second video camera configured to generate a second video feed of the subject. The first video feed and the second video feed combined generate a near real-time stereoscopic video image. A tracking module can be associated with the first video camera and the second video camera, and can be configured to cause the first video camera and the second video camera to be directed to a desired convergent point relative to a selected tracking point to maintain stereopsis. The system may further include an array of video cameras, a gesture control module, an image adjustment module, a calibration module, or a 3-D modeling module, for example.

STEREOSCOPIC VIDEO IMAGING

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BACKGROUND

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Significant technological advancements have been made in the practice of dentistry. These advancements have enabled better patient care as well decreased anxiety for patients when visiting a dentist.

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Many techniques now used by dentists to provide advanced care involve the ability to see and focus on very small details in a patient's mouth. Glasses with magnification loops are often used by dentists to increase their ability to view fine details. The glasses can be expensive and heavy, becoming burdensome for a dentist to wear for long periods of time. In addition, the magnification loops can cause eye strain and tunnel vision, reducing a dentist's ability to see both the magnified area and the surrounding area simultaneously.

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Additionally, to obtain a desired view of the areas within a patient's intraoral cavity, a dentist often has to lean forward and hunch. Such posture can cause long term health problems for a dentist. Dentists that do not take precautionary measures regarding their posture can have their careers cut short or limited by back pain and other associated back problems. In addition, these injuries can significantly affect a dentist's quality of life outside of the dental office.

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Throughout this specification the word "comprise", or variations such as "comprises" or "comprising", will be understood to imply the inclusion of a stated element, integer or step, or group of elements, integers or steps, but not the exclusion of any other element, integer or step, or group of elements, integers or steps.

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Any discussion of documents, acts, materials, devices, articles or the like which has been included in the present specification is not to be taken as an admission that any or all of these matters form part of the prior art base or were common general knowledge in the field relevant to the present disclosure as it

existed before the priority date of each claim of this application.

SUMMARY

A system for viewing stereoscopic video images comprises: a plurality of
5 video cameras comprising at least three spatially separated video cameras each
configured to generate a video feed of a subject, the plurality of video cameras
adapted so that multiple pairs of video cameras are capable of generating a
stereoscopic video image, each of the pairs of video cameras comprising a first
video camera configured to generate a first video feed of the subject and a
10 second video camera configured to generate a second video feed of the subject;
a tracking module associated with the plurality of video cameras, the tracking
module configured to cause the first video camera and the second video camera
in each pair of video cameras to be directed to a convergent point relative to a
selected tracking point to maintain stereopsis; and a zooming module associated
15 with the plurality of video cameras, the zooming module configured to provide a
magnification of the stereoscopic video image.

A method for viewing stereoscopic video images comprises: selecting a
first video camera and a second video camera from an array of video cameras;
directing the first video camera and the second video camera to a selected area
20 of a subject to generate a respective first video feed and a second video feed of
the selected area, wherein the first video camera is separated from the second
video camera by a selected distance, and wherein the first video camera and the
second video camera are each directed to a convergent point at or near the
selected area to provide stereopsis of the selected area; associating the
25 convergent point with a selected tracking point; adjusting a location of the
convergent point relative to movement of the selected tracking point; displaying
the first video feed and the second video feed on a display system that optically
separates the first video feed and the second video feed to create a stereoscopic
video image; and providing a magnification of the stereoscopic video image using
30 a zooming module associated with the first video camera and second video
camera.

A system for viewing stereoscopic video images comprises: an array of video cameras configured for providing video camera feeds; an image processing module configured to i) receive video camera feeds from the array, ii) geometrically transform one or more of the video camera feeds to create a virtual camera feed; and iii) generate a stereoscopic video image from at least two camera feeds, wherein at least one of the two camera feeds is the virtual camera feed, and wherein the at least two camera feeds are directed to a convergent point; and a tracking module associated with the array, the tracking module configured to follow a tracking point relative to the convergent point in order to maintain stereopsis.

A method for viewing stereoscopic video images comprises: obtaining an array of video cameras; generating multiple video camera feeds from multiple video cameras of the array; geometrically transforming at least a plurality of the video feeds to create a virtual camera feed; tracking a selected tracking point related to a convergent point; and creating a stereoscopic video image, wherein the stereoscopic video image comprises at least two camera feeds, wherein at least one of the two camera feeds is the virtual camera feed, and wherein the at least two camera feeds are directed to the convergent point.

A system for viewing stereoscopic video images comprises: a first video camera configured to generate a first video feed of a subject; a second video camera configured to generate a second video feed of the subject, wherein the first video feed and the second video feed are combined to generate a stereoscopic video image; a tracking module associated with the first video camera and the second video camera, the tracking module configured to cause the first video camera and the second video camera to be directed to a convergent point relative to a selected tracking point to maintain stereopsis; a gesture control module associated with the system, wherein the system responds based on movement of a user, wherein the gesture control module is configured to adjust at least one of an angle and a magnification of the first and second video cameras to adjust the stereoscopic video image based on a movement of the user; and a zooming module associated with the plurality of video cameras, the zooming module configured to provide a magnification of the stereoscopic

video image.

5 A method for viewing stereoscopic video images comprises: directing a first video camera and a second video camera to a selected area of a subject to generate a respective first video feed and a second video feed of the selected area, wherein the first video camera is separated from the second video camera by a selected distance, and wherein the first video camera and the second video camera are each directed to a convergent point at or near the selected area to provide stereopsis of the selected area; associating the convergent point with a selected tracking point; adjusting a location of the convergent point relative to movement of the selected tracking point; displaying the first video feed and the second video feed on a display system that optically separates the first video feed and the second video feed to create a stereoscopic video image; modifying the stereoscopic image as a result of a gesture control motion of a user; and providing a magnification of the stereoscopic video image using a zooming module associated with the first video camera and second video camera.

20 A system for viewing stereoscopic video images comprises: a first video camera configured to generate a first video feed of a subject; a second video camera configured to generate a second video feed of the subject, wherein the first video feed and the second video feed combine to generate a stereoscopic video image; a tracking module associated with the first video camera and the second video camera, the tracking module configured to cause the first video camera and the second video camera to be directed to a convergent point relative to a selected tracking point to maintain stereopsis; and an image adjustment module configured to selectively modify the first video feed generated by the first video camera and second video feed generated by the second video camera, thereby providing a stereoscopic viewable image having at least one adjusted visual property adapted for enhanced diagnostic or treatment visualization.

30 A method for viewing stereoscopic video images comprises: directing a first video camera and a second video camera to a selected area of a subject to generate a respective first video feed and a second video feed of the selected area, wherein the first video camera is separated from the second video camera

by a selected distance, and wherein the first video camera and the second video camera are each directed to a convergent point at or near the selected area to provide stereopsis of the selected area; associating the convergent point with a selected tracking point; adjusting a location of the convergent point relative to movement of the selected tracking point; selectively modifying the first video feed generated by the first video camera and the second video feed generated by the second video camera, thereby providing a viewable image having at least one adjusted visual property adapted for enhanced diagnostic or treatment visualization; and displaying the selectively modified first video feed and the second video feed on a display system that optically separates the first video feed and the second video feed to create a stereoscopic video image having the adjusted visual property.

A system for viewing stereoscopic video images comprises: a first video camera configured to generate a first video feed of a subject; a second video camera configured to generate a second video feed of the subject, wherein the first video feed and the second video feed combine to generate a stereoscopic video image; a tracking module associated with the first video camera and the second video camera, the tracking module configured to cause the first video camera and the second video camera to be directed to a convergent point relative to a selected tracking point to maintain stereopsis; and a calibration module configured to calibrate and adjust a horizontal alignment of the first video feed and the second video feed.

A method for viewing stereoscopic video images comprises: directing a first video camera and a second video camera to a selected area of a subject to generate a respective first video feed and a second video feed of the selected area, wherein the first video camera is separated from the second video camera by a selected distance, and wherein the first video camera and the second video camera are each directed to a convergent point at or near the selected area to provide stereopsis of the selected area; horizontally calibrating the first video feed and the second video feed; associating the convergent point with a selected tracking point; adjusting a location of the convergent point relative to movement of the selected tracking point; and displaying the first video feed and the second

video feed on a display system that optically separates the first video feed and the second video feed to create a stereoscopic video image.

5 A system for viewing stereoscopic video images comprises: a first video camera configured to generate a first video feed of a subject; a second video camera configured to generate a second video feed of the subject, wherein the first video camera and the second video camera are configured to generate a stereoscopic video image; a tracking module associated with the first video camera and the second video camera, the tracking module configured to cause the first video camera and the second video camera to be directed to a
10 convergent point relative to a selected tracking point to maintain stereopsis; and a 3-D modeling module configured to convert the stereoscopic video image into a 3-D model or construct.

A method for viewing stereoscopic video images comprises: directing a first video camera and a second video camera to a selected area of a subject to
15 generate a respective first video feed and a second video feed of the selected area, wherein the first video camera is separated from the second video camera by a selected distance, and wherein the first video camera and the second video camera are each directed to a convergent point at or near the selected area to provide stereopsis of the selected area; associating the convergent point with a
20 selected tracking point; adjusting a location of the convergent point relative to movement of the selected tracking point; displaying the first video feed and the second video feed on a display system that optically separates the first video feed and the second video feed to create a stereoscopic video image; and generating a 3-D model from at least one frame of the stereoscopic video image.

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BRIEF DESCRIPTION OF THE DRAWINGS

Features and advantages of the present disclosure will be apparent from the following detailed description, taken in conjunction with the
30 accompanying drawings, which together illustrate, by way of example, features of the invention.

FIGS. 1a illustrates a block diagram of a system for viewing stereoscopic video images using a pair of cameras selected from a plurality of at least three

video cameras in accordance with embodiments of the present disclosure;

FIGS. 1b illustrates a block diagram of a system for viewing stereoscopic video images using a gesture control module in accordance with embodiments of the present disclosure;

5 FIGS. 1c illustrates a block diagram of a system for viewing stereoscopic video images having an image adjustment module in accordance with embodiments of the present disclosure;

10 FIGS. 1d illustrates a block diagram of a system for viewing stereoscopic video images having a calibration module in accordance with embodiments of the present disclosure;

FIGS. 1e illustrates a block diagram of a system for viewing stereoscopic video images having a 3-D modeling module in accordance with embodiments of the present disclosure;

15 FIG. 1f illustrates a block diagram of a system for viewing stereoscopic video images with a wireless data link in accordance with embodiments of the present disclosure;

FIG. 1g illustrates a block diagram of a system for viewing stereoscopic video images with a wireless data link comprising a single transmitter and receiver in accordance with embodiments of the present disclosure;

20 FIG. 1h illustrates a block diagram of a system for viewing stereoscopic video images with a single motor used to update a position of first and second video cameras in accordance with embodiments of the present disclosure;

25 FIG. 2 provides an example illustration of a dental professional using a stereoscopic display to view a near real-time stereoscopic video image of a patient's intraoral cavity in accordance with embodiments of the present disclosure; and

30 FIG. 3 provides an exemplary diagram illustrating angles at which the first and second video cameras are directed and changed based on a distance of the video cameras from a selected object to maintain stereopsis of the video image in accordance with an embodiment of the present disclosure.

Reference will now be made to the illustrated exemplary embodiments, and specific language will be used herein to describe the same. It will nevertheless be understood that no limitation of the scope of the disclosure is thereby intended.

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DETAILED DESCRIPTION

Before the present disclosure is described, it is to be understood that this disclosure is not limited to the particular structures, process steps, or materials disclosed herein, but is extended to equivalents thereof as would be recognized by those ordinarily skilled in the relevant arts. It should also be understood that terminology employed herein is used for the purpose of describing particular embodiments only and is not intended to be limiting.

As a preliminary matter, it is noted that much discussion is related herein to the dental profession and conducting dental exams and procedures. However, this is done for exemplary purposes only, as the systems and methods described herein are also applicable to other medical professionals that would benefit from high magnification stereoscopic imaging and tracking of a desired site for surgery or examination. For example, the systems and methods herein can be especially useful in imaging locations where movement may occur, such as with minimally invasive surgeries when a patient is awake and moving or with examination of sites of interest of an alert patient. Additionally, the systems and methods of the present disclosure can also be applicable to viewing and tracking in the manner described herein that is outside of the medical professions generally, e.g., research, teaching, microbiology, electronics, jewel cutting, watch repair, etc.

With this in mind, an initial overview of technology embodiments is provided below and then specific technology embodiments are described in further detail thereafter. This initial description is intended to provide a basic understanding the technology, but is not intended to identify all features of the technology, nor is it intended to limit the scope of the claimed subject matter.

A dentist's ability to view a patient's intraoral cavity in detail is valuable

for proper diagnosis of dental issues and performance of dental work in general.

A magnified view of locations within the intraoral cavity can enable a dentist to adequately provide the advanced and complex solutions that are now available to patients. However, a typical solution to obtain a magnified view is through the use of glasses with one or more magnification loops. The use of magnification
5 loops can strain a dentist's eyes and increase drowsiness. In addition, a dentist may need to lean forward and/or slouch in order to obtain a desired viewing angle inside of a patient's mouth. Over long periods of time, this can cause problems with posture, back pain, and debilitating physical damage to a dentist's back. Back pain and injury can reduce the length of the dentist's career and negatively
10 affect the quality of his or her life outside of the dentist's office.

In accordance with embodiments of the present disclosure, systems and methods for viewing stereoscopic video images are disclosed. The systems and methods, in one example, enable a dentist to obtain a desired view of a patient's intraoral cavity while reducing eye strain and enabling the dentist to maintain a
15 proper posture. It is noted that in other fields, such as medicine, electronics, teaching, microbiology, or any other field where high magnification stereoscopic vision may be useful, the systems and methods of the present disclosure are equally applicable. Thus, as mentioned discussion of dentistry is for exemplary purposes only and is not considered limiting except as specifically set forth in the
20 claims.

That being said, in order to provide a desired level of care to patients, a hygienist, dentist, oral surgeon, or other type of dental professional should be able to delicately and accurately move dental tools in a desired direction. Typically, two dimensional images can make it challenging to accurately move
25 dental equipment within a patient's intraoral cavity. The use of a stereoscopic image enables stereopsis to be maintained, thereby allowing a medical professional to perceive depth, enabling dental equipment to be accurately moved in a desired direction while viewing the stereoscopic image. As used herein, the term "stereopsis" refers to the process in visual perception leading to
30 the sensation of depth from viewing two optically separated projections of the world projected onto a person's eyes, respectively. This can be through the use of a head mountable pair of video screens, each with a different optical

projection, or through optical separation of the two optical projections on a single video screen, as will be described hereinafter in greater detail.

In addition, the systems and methods disclosed herein enable multiple persons viewing the stereoscopic video image to view a selected area from the same perspective. For instance, a dentist and a dental assistant can each view
5 the same stereoscopic video image of a location such as a tooth or an area around a tooth in a patient's mouth. The capability for both the dentist and the dental assistant to view a stereoscopic video image of the area from the same perspective can significantly enhance the ability of the dental assistant to assist
10 the dentist as needed. Moreover, the image may also be viewed by additional persons such as the patient or dental school students. The ability of the patient to view the same image as the dentist can enable the dentist to better educate the patient as to the condition of his or her teeth, and the procedures that will be conducted. Viewing the stereoscopic image can significantly enhance student's
15 ability to learn and understand the teachings of their instructor from his or her viewpoint.

In accordance with one embodiment of the present disclosure, a system for viewing stereoscopic video images can comprise a plurality of video cameras including at least three spatially separated video cameras and a tracking module
20 associated with the plurality of video cameras. The plurality of video cameras can be adapted so that multiple pairs of video cameras are capable of generating a near real-time stereoscopic video image, each of the multiple pairs comprising a first video camera configured to generate a first video feed of the subject and a second video camera configured to generate a second video feed of the subject.
25 The tracking module can be configured to cause the first video camera and the second video camera to be directed to a desired convergent point relative to a selected tracking point to maintain stereopsis.

In another example, a system for viewing stereoscopic video images can comprise an array of video cameras configured for providing video camera feeds.
30 An image processing module can be configured to i) receive video camera feeds from the array, ii) geometrically transform one or more of the video camera feeds to create a virtual camera feed; and iii) generate a stereoscopic video image from

at least two camera feeds. In this example, at least one of the two camera feeds can be the virtual camera feed, and the at least two camera feeds can be directed to a convergent point. The system also includes a tracking module associated with the array, and the tracking module can be configured to follow a tracking point relative to the convergent point in order to maintain stereopsis.

In other examples, systems for viewing stereoscopic video images can comprise a first video camera configured to generate a first video feed of a subject and a second video camera configured to generate a second video feed of the subject, wherein the first video feed and the second video feed combine to generate a near real-time stereoscopic video image. These systems can further comprise a tracking module associated with the first video camera and the second video camera. The tracking module can be configured to cause the first video camera and the second video camera to be directed to a desired convergent point relative to a selected tracking point to maintain stereopsis.

In one specific example, a gesture control module can be associated with the system, wherein the system responds based on movement of a user. The gesture control module can include a sensor that senses movement of the user, for example. In another independent example, an image adjustment module can be configured to selectively modify an image received by the first video camera and the second video camera, thereby providing a viewable image having at least one adjusted visual property adapted for enhanced diagnostic or treatment visualization. In yet another specific example, a calibration module can be configured to calibrate and adjust horizontal alignment of the first video feed and the second video feed. In still another independent example, a 3-D modeling module can be configured to convert the stereoscopic video image into a 3-D model or construct.

Turning now to the FIGS., various embodiments of systems 100 for viewing stereoscopic video images are disclosed, as provided in further detail in the example illustrations of FIGS. 1a-h. There are several commonalities between each of these embodiments, including the tracking module 108, the first video camera 102a, the second video camera 102b, motors 112, and the stereoscopic display 106. Other modules or camera configurations are described in more specific detail with respect to certain embodiments of the present

disclosure. Thus, some features will be discussed generally with respect to FIGS. 1a-h, and others will be discussed specifically with respect to a particular FIG. That being stated, any combination of features described herein can be practiced in accordance with examples of the present disclosure.

5 With specific reference to FIG. 1a, the system 100 comprises a plurality of video cameras 102a-d that are spatially separated from one another. The plurality of video cameras can be adapted so that multiple pairs of video cameras are capable of generating a near real-time stereoscopic video image, each of the multiple pairs can comprise a first video camera configured to generate a first
10 video feed of a subject and a second video camera configured to generate a second video feed of the subject. For example, video camera 102a and 102b can be the first video camera and the second video camera in one situation, and video cameras 102c and 102d can be the first and second video cameras in a second situation. Furthermore, the video cameras need not be discrete pairs that
15 are always used together. For example, video camera 102a and video camera 102c or 102d can make up a third pair of cameras, and so forth. Regardless of which two cameras are selected for use, in a dental environment, for example, the first video camera can be directed toward the subject to create a first video feed of a patient's intraoral cavity, and a second video camera can be spaced
20 appropriately at a selected distance from the first video camera to create stereopsis. It is noted that the multiple pairs of video cameras can be spatially separated at a pupillary distance from one another, or can be positioned so that they are not necessarily a pupillary distance from one another, e.g., at a simulated pupillary distance with appropriate angles that are optically aligned with
25 the pupillary distance, or spaced out of optical alignment with the pupillary distance with some signal correction being typical.

The plurality of video cameras can be positioned in a one-dimensional array, such as in a straight line, e.g., 3, 4, 5, . . . 25 video cameras, etc., or an a two-dimensional array, e.g., in an arrangement configured along an x- and y-axis,
30 e.g., 3x3, 5x5, 4x5, 10x10, 20x20 cameras, and so forth. Thus, in either embodiment, any two adjacent video cameras can be used as the first video camera and the second video camera. Alternatively, any two video cameras that

may not be adjacent to one another might also be used to provide the stereoscopic image. Selection of which two video cameras to use can be based on manual selection (such as by positive gesture control, or selection of appropriate buttons, switches, or other interface controls), or can be automatic
5 based on movement of a user, e.g., a dental professional, or a subject, e.g., patient.

In another related example regarding the array of cameras, any of the multiple cameras 102a-d (or typically many more video cameras arranged in an array) can likewise be used to generate a virtual perspective that can arise from
10 the placement of a static array of cameras in a particular orientation in the Cartesian space. For example, the various video cameras can be positioned so that they are known relative to one other and relative to a user or subject of the system. The position of the user or subject within the system can also be known via tracking methods described herein, or as otherwise known in the art, via
15 hardware (e.g., Polhemus' magnetic tracking or other tracking systems or modules) or via software.

In such a system, camera feeds are taken into an image processing module 120 and geometrical transformations can be performed on one or more camera feeds to create virtual camera feeds that present new perspectives, i.e.
20 perspectives other than those generated directly from the camera feeds *per se*. These virtual camera feeds are then multiplexed to a stereoscopic or 3-D signal for a stereoscopic display or sent to a head mounted display (e.g., right eye, left eye), to create a stereoscopic video. Hardware and software packages, including some state of the art packages, can be used or modified for this purpose. For
25 example, NVIDIA has a video pipeline that allows users to take in multiple camera feeds, perform mathematical operations on them, and then output video feeds that have been transformed geometrically to create virtual perspectives that are an interpolation of actual video feeds. These video signals are typically in the Serial Digital Interface (SDI) format. Likewise, software used to perform such
30 transformations is available as open source. OpenCV, OpenGL and CUDA, which can be used to manipulate the video feed. In order to create stereopsis, the images designed for the left and right eye or optically separated video feed to

a single screen, whether virtual or real images are displayed, are typically separated by a pupillary distance or simulated pupillary distance, though this is not required. It is noted that the image processing module shown in this example for purposes of generating virtual camera feeds. However, any other type of image processing that may be beneficial for use in this embodiment or any other embodiment herein that would benefit from image processing can also include an image processing module.

In either of these two embodiments, i.e. pairing of various video cameras from a plurality of camera feeds or generating a virtual image using an array of cameras, there are many ways of controlling the selection of video cameras or generation of virtual images. User or subject movement, for example, may be used to control these systems, and may include movement of a user's head or eyes, or movement of a subject's intraoral cavity. The automatic selection can be configured to provide a desired image based on a position of the dental professional or patient relative to one another. For instance, when the dental professional changes the angle at which he or she is viewing the patient, cameras in the array can be selected and/or moved to provide an image based on the viewing angle of the dental professional.

In further detail regarding gesture controls, FIG. 1b sets for a gesture control module 110 that is associated with the systems 100 of the present disclosure. Though some details regarding gesture controls were described previously with respect to selection of a pair of cameras from a plurality of at least three video cameras, gesture controls are also applicable to embodiments where only two video cameras are present as well. More specifically, the gesture control module can include a sensor that senses movement of a user, such as a dental professional, and responds based on that movement. Gestures can either be deliberate to cause an action, or can be incidental to typical movements of the user. A deliberate gesture might include hand or arm gesture, or deliberate movement of an instrument held in the hand of the user. A voice gesture, e.g., voice commands, is also an example of a deliberate gesture.

Alternatively, the system of the present disclosure can also controlled by incidental movements by the user, such as causing the tracking module to follow

a tracking point based on eye or head movement of the user. When tracking eye movement, sensors can be directed to or present near the user's eyes, such as a camera directed to the user's eyes or sensors on a pair of glasses used to optically separate a stereoscopic image on a video screen or on head mountable stereoscopic display. Thus, the camera or sensors can be used to detect a movement of the user's eyes, and/or the cameras in the array can be selected and/or moved to provide an image based on the viewing angle of the user's (i.e. dental professional's) eyes. In either case, gestures can be used to move a tracking point, adjust light settings, modify a level of magnification (using a zoom module), or any other adjustment that may be desirable for use with the systems of the present disclosure.

Turning now to the system 100 of FIG. 1c, in addition to the tracking module 108, motor 112, first video camera 102a, second video camera 102b, and stereoscopic display 106 set forth in this embodiment, each of which will be described in further detail hereinafter, an image adjustment module 114 is also included. The image adjustment module can be configured to selectively modify images received by a first video camera and a second video camera and provide a viewable image having at least one adjusted visual property adapted for enhanced diagnostic or treatment visualization.

For example, the adjusted visual property may include enhancement or shifting of a specific optical frequency band for enhanced resolving power of a dental professional to view the specific optical frequency band. Specifically, a color or group of colors can be enhanced or shifted in viewable color, such as for diagnosing or treating cancers or lesions in the mouth, diagnosing or treating soft tissue anomalies (e.g., gums, tongue, cheek, etc.), diagnosing or treating teeth (e.g., cavities), etc. To provide a more specific example infrared, green, amber, white, violet, ultraviolet, or a combination of these light frequencies can be used to enhance the detection of cancerous tissue. The image detected by the cameras can be so modified such that the coloration is enhanced using the image adjustment module for diagnosis or treatment purposes.

In another example, there are circumstances where specific lighting profiles are used (or avoided) in conjunction with some materials, e.g., amber light or UV light. For instance, UV lighting may be used to cure certain materials.

Amber lighting may be used when curing of materials is not desired. Thus, the system can be adapted for use under that specific lighting profile, and the adjusted visible property can be to decrease the artificial coloration of the viewable image on the stereoscopic display, making it appear more natural to the user, e.g., amber light environment where the amber light is minimized and other light is enhanced that may be only minimally present.

In still another example, the system can be adapted for use in highly saturating light, and the adjusted visible property can be to decrease the white or other saturation of the viewable image. This may be useful when there is a desire to more accurately visualize a certain color, such as when matching off-white coloration for cosmetic or reconstructive dentistry. In yet another example, there may be advantages in utilizing the system to detect and shift otherwise invisible light into the visible spectrum, e.g., ultraviolet light such as 405 nm light. If this is the case, sensors on the video cameras, such as charged couple device (CCD) sensors or complementary metal oxide semiconductor (CMOS) sensors can be selected that are sensitive to ultraviolet light. In one embodiment, multiple sensors may be provided in a single camera, with different sensors tuned to different parts of the light spectrum. For instance, one sensor may be configured to detect wavelengths from infrared to blue, while another sensor may be configured to detect ultraviolet wavelengths. The appropriate sensor in each camera can be selected based on the color (i.e. wavelength) of light being imaged by the cameras.

In related embodiments, the adjusted visual property can be further enhanced by the presence of a colorant. By selecting certain colorants (pigments or dyes) for use in the intraoral cavity, certain materials or conditions can be amplified. This, coupled with the ability to adjust a visual property of the colorant can provide a combination that would make certain dental tasks easier for the dental professional to visualize. For example, a dye or pigment may be used, and the video image can be used to enhance or even shift coloration of the dye or pigment, making it more easily viewable. In one specific example, certain fluorescent dyes or pigments can be used for determining the presence of a dental material, such as a bonding cement, and the coloration can help the dental professional determine whether it is properly cured. In another example, a

colorant can be used to attach to certain types of dental conditions, such as cavities, lesions, cancers, or the like, to assist the dentist in diagnosing or treating a dental condition. The digital imaging sensors in the cameras and/or the output signals of the digital imaging sensors can be configured to enhance the view of the colorant on the stereoscopic display 106.

FIG. 1d sets forth a system 100 that includes a calibration module 116, in addition to the tracking module 108, motor 112, first video camera 102a, second video camera 102b, and stereoscopic display 106. The calibration module can be configured to calibrate and adjust horizontal alignment of a first video feed and a second video feed so that the pixels from the first video camera are aligned with the pixels of the second video camera. When the stereoscopic display is a head mountable stereoscopic display including a right video display and a left video display, proper alignment of the two images can be calibrated to the eyes of the user horizontally so that the image appears as natural as possible. The more unnatural an image appears, the more eye strain that can result. Horizontal alignment can also provide a clearer image when viewing the near real-time stereoscopic video image on a screen (with or without the assistance of viewing glasses). When the pixels are properly aligned, the image appears more natural and sharper than might be the case when the pixels are misaligned even slightly. Additional calibration can also be used to adjust the vertical alignment of the first video camera and the second video camera to a desired angle to provide stereopsis. In either case, whether the calibration module is used to for vertical or horizontal alignment, the alignment can be configured to be maintained or recalibrated when something changes, e.g., after pan or tilt movements of the first video camera or the second video camera, the selection of different video cameras to pair in the array, and so forth. These movements may cause minor misalignment that can be readjusted as the misalignment occurs. The calibration module can be configured to allow manual adjustment and/or automatic adjustment of horizontal and/or vertical alignment of the camera pair.

Other uses for calibration can occur when the system is first set up, or when multiple users are using the same equipment. In one example, the calibration module can provide for calibration with multiple users. Thus, the system can be calibrated for a first user in a first mode and a second user in a

second mode, and so forth. For example, a focus of each camera in the camera pair can be adjusted to compensate for vision differences. The system can be configured to switch between the first mode and the second mode automatically or manually based on whether the first user or the second user is using the system.

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FIG. 1e sets forth a system 100 that includes a 3-D modeling module 118, in addition to the tracking module 108, motor 112, first video camera 102a, second video camera 102b, and stereoscopic display 106. The 3-D modeling module can be configured to convert the stereoscopic video image into a 3-D model or construct. This module can output one or more frame of the stereoscopic video image to a modeling device, such as a 3-D printer, tooth impression modeling device, or a 3-D CAD drawing that can be further used to prepare a 3-D model. Any 3-D modeling technique can be used, as is known in the art, once the stereoscopic image is outputted to the appropriate technology for generating a 3-D model or construct.

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In the embodiments described above in FIGS. 1a-e, the first video feed from the first video camera 102a and the second video feed from the second video camera 102b can be communicated to the stereoscopic video display 106 through wired communication cables, such as a digital visual interface (DVI) cable, a high-definition multimedia interface (HDMI) cable, component cables, and so forth. Alternatively, the information from the first video feed and the second video feed can be communicated wirelessly to the stereoscopic video display. For instance, FIG. 1f shows a system 100 that provides a wireless data link between the video display and each of the first video camera and the second video camera. In yet another example, as displayed in FIG. 1g, the first and second video feeds are communicated via a wired connection to a single transmitter 146. The transmitter can wirelessly communicate the first and second video feeds from the first and second video cameras, respectively, to the video display. A wireless receiver 144 at the video display can be used to receive the first and second video feeds from the transmitter and communicate the video feeds to the video display.

Various standards which have been developed or are currently being developed to wirelessly communicate video feeds include the WirelessHD

standard, the Wireless Gigabit Alliance (WiGig), the Wireless Home Digital Interface (WHDI), the Institute of Electronics and Electrical Engineers (IEEE) 802.15 standard, and the standards developed using ultrawideband (UWB) communication protocols. In another example, the IEEE 802.11 standard may be
5 used to transmit the signal(s) from the video cameras 102, 104 to the stereoscopic display 106. One or more wireless standards that enable the video feed information from the first and second video feeds to be transmitted to the stereoscopic video display for display in near-real time can be used to eliminate the use of wires and free the user to move about more freely. This can be
10 especially useful when the stereoscopic video display is head mountable, though it is also desirable in any of the video display embodiments described herein.

In further detail with respect to FIGS. 1a-g, it is noted that each camera that is shown can include an individual motor associated therewith to control a direction and/or focus of the camera. FIG. 1h provides an example illustration of
15 another embodiment, wherein a single motor 112 is used to update a position of the first and second video cameras 102a, 102b together. The single motor can be mechanically coupled to the first and second video cameras. For example, the motor may be connected through a series of gears and/or screws that allow the motor to be used to change an angle in which the video cameras are
20 directed. Other types of mechanical couplings can also be used, as can be appreciated. Any type of mechanical coupling that enables the motor to update a direction in which one or both of the first and second video cameras are pointed is considered to be within the scope of this embodiment.

In each of the embodiments described in FIGS. 1a-h, as mentioned,
25 there are several details regarding various elements of the FIGS. that have some commonality. Some of these features will be discussed together hereinafter. For example, regarding the spacing of the first video camera 102a and the second video camera 102b, the cameras can be horizontally spaced to simulate the spacing between a person's eyes in order to produce a first video feed and a
30 second video feed that is combinable to generate a natural stereoscopic image, e.g., the image can be displayed to simulate a person's vision from his or her left eye and right eye. This spacing can be referred to as pupillary distance. A typical

pupillary distance is from about 50 millimeters (mm) to about 75 mm.

Alternatively, the cameras may be spaced a different (typically greater) distance apart, but can still be optically or digitally aligned to provide approximately the pupillary distance. In other embodiments where the distance between the cameras is not the pupillary distance or at least does not optically simulate the pupillary distance, some signal processing may be desirable to otherwise compensate for more unnatural camera convergence angles and distances therebetween.

The systems can further comprise a stereoscopic video display 106, as shown in FIGS. 1a-h. In one embodiment, the stereoscopic display can be a head mountable stereoscopic display with a right video display viewable by a person's right eye and a left video display viewable by a person's left eye. By displaying the first and second video feeds in the left and right video displays, a near real-time stereoscopic video image can be created. Alternatively, the stereoscopic display can be a single video screen wherein the first video feed and the second video feed are optically separated, e.g., shutter separation, polarization separation, color separation, etc. The stereoscopic display can be configured to allow a user to view the stereoscopic image with or without an external viewing device such as glasses. In one embodiment, a pair of appropriate glasses that work with shutter separation, polarization separation, color separation, or the like, can be used to allow the screen to be viewed in three-dimensions. Still further, the video display can comprise multiple video displays for multiple users to view the near real-time stereoscopic video image, such as the dental assistant and/or the patient.

The stereoscopic video image provides a visual perception leading to the sensation of depth from the two slightly different video images projected onto the retinas of the person's two eyes. This visual perception leading to the sensation of depth is referred to as stereopsis. No additional video or computer processing of the first and second video images may be needed when using the head mountable stereoscopic display or the other optical separation technology described above. The sensation of depth is created due to the differing projections of the first and second cameras that are separated by, for example, a pupillary distance or simulated pupillary distance. That being stated, there are

instances where the cameras may be further apart or angled in a manner that does not correspond to a typical pupillary distance, and in those arrangements, the near real-time stereoscopic video image can thus be corrected to provide a simulated pupillary distance based on the images received from two or more cameras in the camera array, as previously discussed.

The ability to perceive depth can be valuable to a dentist that is working with a patient. Proper depth perception enables the dentist to make small, but critical movements when performing dentistry. Previously, the lack of ability to display depth perception has limited the use of cameras and display screens in the practice of dentistry. With the use of two separate cameras that are configured to provide a display with stereopsis, a dentist can view the resulting stereoscopic display that provides the sensation of depth, thereby enabling the dentist to maintain substantially the same hand-eye coordination that the dentist has learned during his or her practice using loops or other magnification systems.

Returning to FIGS. 1a-h, the various systems 100 can also include a tracking module 108 that is in communication with the first video camera 102a and the second video camera 102b (or the plurality of video cameras as described specifically in FIG. 1a). The tracking module can be configured to cause the first video camera and the second video camera to be directed to a desired convergent point relative to a selected tracking point.

The tracking point can be a selected location on or about the patient's body that enables the cameras 102a, 102b to be redirected relative to the motion of the tracking point. For instance, the tracking point may be at a location on the patient's head. When the patient moves his or her head, the cameras can move with the patient so that the image on the display screen is not substantially changed due to movements of the patient. Alternatively, the tracking point may be located at or about a dental patient's intraoral cavity. For instance, the tracking point may be located on a tooth, a dental tool, or on a dental retractor located in or about the patient's intraoral cavity. Further, as discussed with respect to certain examples herein, the tracking point can be associated with the user, e.g., the dental professional, and movement of the user can relate directly to the tracking function.

The tracking point can be provided by any type of device, object, or signal that enables the movement of the patient to be tracked relative to the position of the cameras. For instance, tracking may be accomplished using radio frequency triangulation. Multiple tracking transceivers can be located on or about the patient. A marker, such as a tool, can also include a transceiver. The location of the tool relative to the location of the markers can be calculated based on the timing of the arrival of tracker signals transmitted from the tool transceiver at the tracking transceivers. The location of the tool transceiver can be calculated using trigonometry, for example.

In another embodiment, the tracking point may be an optically trackable marker such as a reflective dot or an optical dot formed using a different colored light or an infrared light source. The light sources for the colored light or the infrared light may be one or more light emitting diodes or lasers. The tracking module can include image recognition software that enables the cameras to be substantially directed relative to the optically trackable marker. Alternatively, an infrared receiver can be used to track a location of an infrared optical dot.

In another embodiment, the tracking module 108 can include image recognition software may be used that can recognize a location or feature, such as a person's nostrils, eyes, or other distinct characteristics. As the person's selected feature moves, the position of the camera can be adjusted to maintain the stereoscopic video image of a selected area within the person's intraoral cavity. The ability to adjust a direction of the video cameras relative to movement of the patient can enable the video cameras to provide a relatively high amount of magnification of a desired location within the intraoral cavity. The image recognition software can be programmed to recognize patterns. For example, software that includes facial recognition technology can be used with the systems of the present disclosure that is similar to that wide used with state of the art point and shoot digital cameras, e.g., boxes in digital display screens appear around faces to inform the user that a face of a subject has been recognized for focus or other purpose.

Accordingly, the systems of the present disclosure can also include an optional zooming module 110, shown in FIG. 1f. Though the zooming module is

shown only in FIG. 1f, it is understood that the zooming module can be used in any of the embodiments described herein. The zooming module can be in communication with the first video camera 102a and the second video camera 102b. The zooming module can be configured to provide a desired magnification of the near real-time stereoscopic video image. As previously discussed, the ability to view a desired location with a selected magnification provides a significant advantage to a dentist to conduct complex and detailed procedures. Dentists typically use glasses with magnification loops to magnify images in the order of about 4 times. However, in accordance with embodiments of the present disclosure, zooming ranges are only limited by the zooming range of the first and second video camera.

In one specific embodiment, the video cameras 102a, 102b can be configured to provide a magnification from one time to over 20 times a standard image, or more. The magnification may be achieved either through the use of an optical magnification, a digital zoom, or a combination of the two. The stereoscopic display can provide a clear, focused image of the desired location within the patient's intraoral cavity at a high magnification. The video cameras can be set at substantially the same magnification to enable the visual perception leading to a sensation of depth to be maintained. In addition, the rate at which the cameras change magnification can be substantially the same to maintain stereopsis of the stereoscopic video image as the image is zoomed in and out using the zooming module to communicate with the first and second video cameras.

In another embodiment, the first and second video cameras 102a, 102b and the stereoscopic display 106 can be configured to display a relatively high resolution. For instance, the cameras and display can be configured to provide a 720P progressive video display with 1280 by 720 pixels (width by height), a 1080i interlaced video display with 1920 x 1080 pixels, or a 1080p progressive video display with 1920 x 1080 pixels. As processing power and digital memory continue to exponentially increase in accordance with Moore's Law, the cameras and display may provide an even higher resolution, such as 4320P progressive video display with 7680 x 4320 pixels. With higher resolution, an image can be

magnified using software (digital zoom) to provide a digital magnification without substantially reducing the image quality. Thus, software alone may be used to provide a desired magnification level of the real-time stereoscopic video image.

5 FIG. 2 provides an example illustration of a dentist 232 using a head mountable stereoscopic display 206 to view a near real-time stereoscopic image of a patient's intraoral cavity in accordance with one embodiment of the present disclosure. The first video camera 202a and the second video camera 202b can be mounted on a fixture 242 above the patient 234.

10 A light 236, such as a dental light source, can be provided to illuminate the patient's intraoral cavity. The light can provide sufficient illumination to enable the first video camera 202 and the second video camera 204 to zoom to a desired magnification level while maintaining a selected depth of field for the near real-time stereoscopic video image. The depth of field can be selected to enable the dentist to have a clear, focused view of all of the desired locations within the
15 patient's intraoral cavity. The aperture of the first and second video cameras may change when the magnification provided by the video cameras is increased. Alternatively, the light source may be sufficiently bright that no change in aperture is needed. The light may also be provided to generate various lighting profiles that would be useful with the image adjustment module previously described in
20 relation to FIG. 1c.

The depth of field of the first and second video cameras 202a, 202b may be greater than a length of the patient's intraoral cavity. For example, if the depth of field of the first and second video cameras is twice the depth of a typical patient's intraoral cavity, then the first and second video cameras can be focused
25 on the patient's lip while maintaining a clear focus to the back of the patient's mouth, assuming that the depth of field of the cameras is centered.

In one embodiment, the head mountable stereoscopic video display 206 can be configured to provide a split field of view, with a bottom portion of the glasses providing separate high definition displays for the left and right eyes, and
30 above the glasses, the dentist can view the environment unencumbered. Alternatively, the glasses can be configured in a split view where the bottom half provides the video image, and the top half of the glasses is substantially

transparent to enable an operator to view both natural surroundings while wearing the head mountable stereoscopic display. This can be especially useful as the dentist is using a high magnification level while working on the patient's mouth and can move quickly to no magnification when viewing the surrounding environment.

Alternatively, a video display other than the head mountable stereoscopic video display can be positioned to display the near real-time stereoscopic video image as well. For instance, a large television screen can be configured to show three dimensional images. The placement is based on a desired application, but in one embodiment, it may be placed behind the patient 234 in a position that enables the dentist 232 to view the video image. It can also be placed for the patient to view, or for students to view for learning in an educational environment, for example. The video display can be configured to enable viewers to view the stereoscopic display 246 as a three dimensional image, either with or without the assistance of eyewear.

For instance, in one embodiment the first and second video feeds can be displayed on a single display screen 246, with the respective video feeds being optically separated. Technologies for optical separation include shutter separation, polarization separation, and color separation. In one embodiment, a viewer or user, such as a dentist, can wear viewing glasses to view the separate images with stereopsis and depth perception. In other embodiments, multiple stereoscopic videos can be displayed, such as on multiple television screens. For instance, the stereoscopic image can be simultaneously displayed on a television screen, a projection display, and a head mountable stereoscopic video display.

Certain types of viewing glasses, such as LCD glasses using shutter separation, may be synchronized with the display screen to enable the viewer to view the optically separated near real-time stereoscopic video image. The optical separation of the video feeds provides a visual perception leading to the sensation of depth from the two slightly different video images projected onto the retinas of the two eyes, respectively, to create stereopsis. As previously discussed, the sensation of depth enables the dentist to maintain substantially the

same hand-eye coordination that the dentist has learned during his or her practice as a dentist.

The stereoscopic video display 206 can also be used to view information pertaining to the patient. For instance, x-rays can be digitized and viewed on the video display. A patient's chart information can also be displayed. This can enable the dentist to quickly come up to speed on the patient's status. The dentist can also make comparisons between previous images and information contained in the patient's chart and the patient's current status. The images can also be used to educate the patient, dental assistants, and so forth.

In one embodiment, the fixture 242 can be hingeably mounted or otherwise height adjustable. The distance of the video cameras to the patient can be varied as desired. For instance, the video cameras may be positioned at a distance from about 5 inches to about 96 inches above the patient's intraoral cavity. As the distance between the video cameras and the patient changes, the angle at which the first video camera and the second video camera are directed relative to one another can be adjusted to maintain stereopsis of the near real-time stereoscopic video image.

FIG. 3 provides an exemplary diagram illustrating how the angles of the first and second video cameras 302a, 302b are related to a distance from an object. It should be noted that the illustration is not drawn to scale. The cameras can be separated by a selected distance, such as a pupillary distance, as previously discussed. In one embodiment, distance d_1 can be substantially equal to distance d_2 . In this example, $d_1 = d_2 = 30$ mm. However, the actual distance may vary based on system needs, e.g., $d_1 + d_2 =$ a value in the range of about 50 mm to 75 mm.

In order to view a selected object 320 or area, such as a tooth in this example, the first video camera 302a is directed to the object at an angle θ_1 with respect to a normal. The second video camera 302b can be directed to the object at an angle θ_2 with respect to the normal. When the object is centered between the cameras 302a, 302b then θ_1 is substantially equal to θ_2 , though this is not necessarily required.

The first video camera 302a can create a video image of a first plane 310, based on the angle θ_1 . The second video camera 302b can create a video image of a second plane 312 based on the angle θ_2 . The first and second planes 310, 312 cross at a location referred to as a convergent point 316. In one
5 embodiment, the convergent point can be selected to be positioned at approximately the location of the object 320. Alternatively, the convergent point may be selected to be within the depth of field of the cameras. When the image is magnified by zooming the first and second cameras, then the convergent point can be selected such that it is within the final, magnified video image.

10 As the distance d_3 between the cameras 302a, 302b and the object 320 changes, the angles θ_1 and θ_2 can be adjusted such that the convergent point is maintained at approximately the same location. The distance of d_3 may change when a position of the fixture 242 of FIG. 2 is adjusted relative to the patient 234. The distance of d_3 may also change when the patient moves.

15 As previously discussed, a tracking point can be used to track movements of the patient. In one embodiment, the convergent point can be separate from the tracking point. For instance, the tracking point may be an optical marker on a patient's forehead and the convergent point can be the focus point on a patient's tooth. The convergent point can be correlated with the
20 tracking point such that when the tracking point moves a certain amount in at least one of the x, y, and z axes, the convergent point can be moved approximately the same distance. Alternatively, the tracking point may be substantially equal to the convergent point. This allows the video feeds of a selected location that are created by the first and second video cameras 302a,
25 302b to be maintained even when the patient moves, thereby enabling the dentist to maintain a view of the near real-time stereoscopic video image of the selected location.

Returning now to FIGS. 1a-h for purposes of describing actuation of the video cameras, the direction in which the first and second video cameras 102a,
30 102b are positioned can be updated using at least one electric motor 112 that is mechanically coupled to each video camera. For instance, a single motor may be used to cause an angle of a video camera to be changed along a first axis, such

as rotating the video camera. A second motor may be used to allow the video camera angle to be adjusted along a second axis. In one embodiment, two motors are sufficient to allow each video camera to be adjusted along an x and y axis to direct each video camera in a desired direction. However, a third motor
5 may be used to allow the video camera's position to be adjusted along a third axis. The three motors can allow each video camera's position to be redirected along an x, y, and z axis to be directed in substantially any direction.

The at least one motor 112 can communicate with the tracking module 108 to update the position of the first and second video cameras. In one
10 embodiment, a user can manually actuate the position of the first and second video cameras 102a, 102b through the use of a software interface that is in communication with the at least one motor 112.

Once the video cameras 102a, 102b are set in a desired direction, enabling the user to view a selected area, such as a patient's tooth, the location
15 can be set as the convergent point. As previously discussed, the convergent point is associated with a selected tracking point. The position of the tracking point can be selected such that there is about a one to one movement of the tracking point in relation to the convergent point. For instance, an optical marker may be placed on a patient's forehead or somewhere else that is convenient for a
20 given application. When the patient moves his or her head, the change in position of the forehead is generally substantially similar as the change in position of the patient's tooth (barring some sort of unnatural twisting movement that would be less likely while sitting in a dentist chair). Thus, when the tracking point moves, the position of the cameras can be updated relative to the movement of
25 the tracking point to enable the convergent point to be maintained over the same selected area, such as the patient's tooth. The dentist may use an insert, such as a retractor inserted in the patient's oral cavity, so that the angle of opening of the jaw remains substantially unchanged. In one embodiment, when using a retractor, the tracking point can be placed thereon, or on another area close to or
30 within the oral cavity, such as a tooth, lip, cheek, nose, chin, etc. In another embodiment, when using a retractor, such as a cheek retractor, LED or other lighting sources can be included on the retractor. Thus, in embodiments of the

present disclosure where an image adjustment module 114 is used (See FIG. 1c), the lighting profile provided by the cheek retractor can be selected for light enhancement or shifting as previously described.

5 The position of the first and second video cameras 102a, 102b can also be affected by physically changing their location relative to a patient. For instance, the cameras may be mounted on a fixture that can be rotated, raised and lowered, hingeably moved, or otherwise repositioned, as discussed in FIG. 2. When the position of the video cameras are changed by moving the fixture, then the at least one motor 112 can be used to redirect the video cameras to the
10 selected area. In one embodiment, the position of the fixture can be used in conjunction with the motors to direct the video cameras in a desired direction. For instance, a dentist may position the fixture to provide desired lighting and align the video cameras with a patient's intraoral cavity to allow the video cameras to be directed to a desired location within the intraoral cavity.

15 In other related embodiments, several methods for viewing stereoscopic medical video images are also disclosed. The methods generally include directing a first video camera and a second video camera to a selected area of a subject to generate a respective first video feed and a second video feed of the selected area, wherein the first video camera is separated from the second video
20 camera by a selected distance, and wherein the first video camera and the second video camera are each directed to a convergent point at or near the selected area to provide stereopsis of the selected area. Additional steps include associating the convergent point with a selected tracking point; adjusting a location of the convergent point relative to movement of the selected tracking
25 point; and displaying the first video feed and the second video feed on a display system that optically separates the first video feed and the second video feed to create a near real-time stereoscopic video image.

This general method can also include additional steps. For example, in one embodiment, the step of selecting the first video camera and the second
30 video camera from an array of video cameras can be included. Two cameras of the array can be selected to generate the near real-time stereoscopic image, or a virtual image can be generated using at least one virtual video feed. In this latter

embodiment, the method for viewing stereoscopic video images can comprise obtaining an array of video cameras and generating multiple video camera feeds from multiple video cameras of the array. Additional steps include geometrically transforming at least a plurality of the video feeds to create a virtual camera feed; 5 tracking a selected tracking point related to a convergent point; and creating a near real-time stereoscopic video image. The stereoscopic video image can comprise at least two camera feeds, and at least one of the two camera feeds is the virtual camera feed. Furthermore, the at least two camera feeds are typically directed to the convergent point.

10 In another example, the method can include the step of modifying the near real-time stereoscopic image as a result of a gesture control motion of a user. In another example, the method can include the step of selectively modifying a light signal received by the first video camera and the second video camera, thereby providing a viewable image having at least one adjusted visual property adapted 15 for enhanced diagnostic or treatment visualization by a user. Thus, when displaying the near real-time stereoscopic video image, the adjusted visual property can provide the user, e.g., medical or dental professional, with added information for diagnostics or treatment. In another example, the method can include a calibration module configured to calibrate and adjust horizontal 20 alignment of the first video feed and the second video feed. In still another embodiment, the method can include the step of generating a 3-D model from at least one frame of the near real-time stereoscopic video image.

Regarding the step of directing the first video camera and the second video camera to a selected area of a subject to generate a respective first video 25 feed and a second video feed of the selected area, it is noted that the first video camera can be separated from the second video camera by a selected distance. In one embodiment, the selected distance can be a pupillary distance, or alternatively, a different distance may be selected, as previously discussed, e.g., distances that simulate the pupillary distance by using appropriate angles, or 30 adjusting the images using a processing step. Typically, the first video camera and the second video camera are each directed to a convergent point at or near the selected area to provide stereopsis of the selected area.

These methods can further comprise associating the convergent point with a selected tracking point on or about a subject. The selected tracking point can include an optically trackable marker, as has been discussed. In one embodiment, the optically trackable marker may be positioned on a dental retractor located in or about the patient's intraoral cavity. Alternatively, the selected tracking point can include a plurality of wireless transceivers configured to triangulate a position of the selected tracking point based on the timing of signals received at a transceiver located at the tracking point relative to at least two other transceivers positioned on or about the patient.

For instance, in one embodiment, a surgical operating room may include four separate radio frequency transceivers positioned at different locations about the operating room. A tracking transceiver can then be placed on a patient entering the operating room. The tracking transceiver can send or receive signals from the transceivers located in the operating room. The timing of the signals between the tracking transceiver and the four transceivers in the operating room can be used to determine the position of the tracking transceiver in three dimensions using trigonometry, as can be appreciated. The accuracy of the triangulation calculation is based, at least in part, on the frequency of the transceivers. Higher frequency transceivers have shorter wavelengths, thereby enabling a more accurate determination of the position of the tracking transceiver. Increased accuracy can also be obtained by merely tracking the change in movement. As the tracking transceiver moves closer to one of the transceivers in the room, and further from another, the resulting change in the timing of the signals can enable a substantially accurate determination of the change in position of the tracking transceiver.

The methods further comprise adjusting a location of the convergent point relative to movement of the selected tracking point. In one embodiment, the convergent point can be selected as a virtual point that has an x, y, and z axis distance from the tracking point. When the tracking point is moved then the first video camera and the second video camera can be redirected to maintain a view of the selected area based on the change in the x, y, and z axis distance of the tracking point. For instance, once the convergent point has been selected

relative to the tracking point, the tracking point may move 1 inch in each of the x, y, and z axes due to a movement of the patient on which the tracking point is located. It can be assumed that the convergent point has also been moved 1 inch in each of the x, y, and z axes and the position of the first and second video cameras can be redirected to adjust the location of the convergent point to the new location.

The methods may further include displaying the first video feed and the second video feed on a display system that optically separates the first video feed and the second video feed to create a near real-time stereoscopic video image. In one embodiment, the first video feed can be displayed on a right video display of a head mountable video display and the second video feed can be displayed on a left video display of the head mountable video display. The right and left video displays can be projected onto a user's right and left eyes, respectively. The stereoscopic video image provides a visual perception leading to the sensation of depth from the two slightly different video images projected onto the retinas of the two eyes.

Alternatively, the first video feed and the second video feed can be displayed on a single display wherein the first video feed and the second video feed are optically separated using at least one of shutter separation, polarization separation, and color separation, as previously discussed. Depending on the type of optical separation used, glasses may be used to enable a user to separate the image displayed on the single display to the first video feed being directed to the user's right eye and the second video feed being directed to the user's left eye, or vice versa.

The first video camera and the second video camera can each be zoomed to provide a desired level of magnification of a selected portion of the near real-time stereoscopic image. The rate at which the magnification changes for each of the first and second video cameras can be substantially equal to maintain the stereopsis of the stereoscopic video image. The final amount of magnification can also be substantially equal for the same reason. In addition to optically magnifying the stereoscopic video image using the first and second cameras, the video image can be further magnified using digital magnification, as

can be appreciated.

In discussing the systems and methods of the present disclosure above, is also understood that many of the functional units described herein have been labeled as "modules," in order to more particularly emphasize their

5 implementation independence. For example, a module may be implemented as a hardware circuit comprising custom VLSI circuits or gate arrays, off-the-shelf semiconductors such as logic chips, transistors, or other discrete components. A module may also be implemented in programmable hardware devices such as field programmable gate arrays, programmable array logic, programmable logic
10 devices, or the like.

Modules may also be implemented in software for execution by various types of processors. An identified module of executable code may, for instance, comprise one or more physical or logical blocks of computer instructions, which may, for instance, be organized as an object, procedure, or function.

15 Nevertheless, the executables of an identified module need not be physically located together, but may comprise disparate instructions stored in different locations which, when joined logically together, comprise the module and achieve the stated purpose for the module.

Indeed, a module of executable code may be a single instruction, or
20 many instructions, and may even be distributed over several different code segments, among different programs, and across several memory devices. Similarly, operational data may be identified and illustrated herein within modules, and may be embodied in any suitable form and organized within any suitable type of data structure. The operational data may be collected as a single data set, or
25 may be distributed over different locations including over different storage devices, and may exist, at least partially, merely as electronic signals on a system or network. The modules may be passive or active, including agents operable to perform desired functions.

While the forgoing examples are illustrative of the principles of the
30 present disclosure in one or more particular applications, it will be apparent to those of ordinary skill in the art that numerous modifications in form, usage and

details of implementation can be made without the exercise of inventive faculty, and without departing from the principles and concepts of the disclosure. Accordingly, it is not intended that the disclosure be limited, except as by the claims set forth below.

5

CLAIMS

What is claimed is:

- 5 1. A system for viewing stereoscopic video images, comprising:
 a plurality of video cameras comprising at least three spatially separated
video cameras each configured to generate a video feed of a subject, the plurality
of video cameras adapted so that multiple pairs of video cameras are capable of
generating a stereoscopic video image, each of the pairs of video cameras
10 comprising a first video camera configured to generate a first video feed of the
subject and a second video camera configured to generate a second video feed
of the subject;
 a tracking module associated with the plurality of video cameras, the
tracking module configured to cause the first video camera and the second video
15 camera in each pair of video cameras to be directed to a convergent point
relative to a selected tracking point to maintain stereopsis; and
 a zooming module associated with the plurality of video cameras, the
zooming module configured to provide a magnification of the stereoscopic video
image.
- 20 2. The system of claim 1, wherein each of the video cameras in the pairs
of video cameras are spatially separated at a pupillary distance from one another.
3. The system of claim 1 or 2, wherein at least one of the video cameras
25 in the pairs of video cameras is not spatially separated at a pupillary distance
from one another.
4. The system of claim 1, 2 or 3, wherein the first video camera or the
second video camera of a first pair of video cameras is the first video camera or
30 the second video camera of a second pair of video cameras.
5. The system of any one of the preceding claims, wherein the plurality of
video cameras are aligned in a 1-dimensional array.

6. The system of any one of the preceding claims, wherein the plurality of video cameras are configured in a 2-dimensional array.

5 7. The system of any one of the preceding claims, wherein at least one of the first video camera and the second video camera is selected based on a movement of the subject.

10 8. The system of any one of the preceding claims, wherein at least one of the first video camera and the second video camera is selected based on a movement of a user.

15 9. The system of any one of the preceding claims, further comprising a video display configured to display the stereoscopic video image.

10. The system of claim 9, wherein the video display comprises a right eye display and a left eye display for viewing by a user's right eye and left eye, respectively, to create the stereopsis.

20 11. The system of claim 9, wherein the video display comprises a single video screen wherein the first video feed and the second video feed are optically separated using at least one of shutter separation, polarization separation, and color separation.

25 12. The system of any one of the preceding claims, wherein the tracking module maintains the stereopsis as movement occurs for at least one of the tracking point, the first video camera, and the second video camera.

13. A method for viewing stereoscopic video images, comprising:
selecting a first video camera and a second video camera from an array of
video cameras;
directing the first video camera and the second video camera to a selected
5 area of a subject to generate a respective first video feed and a second video
feed of the selected area, wherein the first video camera is separated from the
second video camera by a selected distance, and wherein the first video camera
and the second video camera are each directed to a convergent point at or near
the selected area to provide stereopsis of the selected area;
10 associating the convergent point with a selected tracking point;
adjusting a location of the convergent point relative to movement of the
selected tracking point;
displaying the first video feed and the second video feed on a display
system that optically separates the first video feed and the second video feed to
15 create a stereoscopic video image; and
providing a magnification of the stereoscopic video image using a zooming
module associated with the first video camera and second video camera.

14. The method of claim 13, further comprising the step of selecting a
20 different first video camera or a different second video camera from the array of
video cameras, and as a result, displaying a different stereoscopic video image.

15. A system for viewing stereoscopic video images, comprising:
an array of video cameras configured for providing video camera feeds;
25 an image processing module configured to i) receive video camera feeds
from the array, ii) geometrically transform one or more of the video camera feeds
to create a virtual camera feed; and iii) generate a stereoscopic video image from
at least two camera feeds, wherein at least one of the two camera feeds is the
virtual camera feed, and wherein the at least two camera feeds are directed to a
30 convergent point; and
a tracking module associated with the array, the tracking module
configured to follow a tracking point relative to the convergent point in order to
maintain stereopsis.

16. The system of claim 15, wherein the at least two camera feeds are spatially separated at a pupillary distance from one another.

5 17. The system of claim 15 or 16, wherein the tracking point is associated with movement of a subject.

10 18. The system of claim 15, 16 or 17, wherein the tracking point is associated with movement of a user.

19. The system of any one of claims 15 to 18, further comprising a zooming module associated with the array, the zooming module configured to provide a magnification of the stereoscopic video image.

15 20. The system of any one of claims 15 to 19, further comprising a video display configured to display the stereoscopic video image.

20 21. The system of claim 20, wherein the video display comprises a right eye display and a left eye display for viewing by a user's right eye and left eye, respectively, to create the stereopsis.

25 22. The system of claim 20, wherein the video display comprises a single video screen wherein the first video feed and the second video feed are optically separated using at least one of shutter separation, polarization separation, and color separation.

23. A method for viewing stereoscopic video images, comprising:
obtaining an array of video cameras;
generating multiple video camera feeds from multiple video cameras of the
array;
5 geometrically transforming at least a plurality of the video feeds to create a
virtual camera feed;
 tracking a selected tracking point related to a convergent point; and
 creating a stereoscopic video image, wherein the stereoscopic video
image comprises at least two camera feeds, wherein at least one of the two
10 camera feeds is the virtual camera feed, and wherein the at least two camera
feeds are directed to the convergent point.

24. A system for viewing stereoscopic video images, comprising:
a first video camera configured to generate a first video feed of a subject;
15 a second video camera configured to generate a second video feed of the
subject, wherein the first video feed and the second video feed are combined to
generate a stereoscopic video image;
 a tracking module associated with the first video camera and the second
video camera, the tracking module configured to cause the first video camera and
20 the second video camera to be directed to a convergent point relative to a
selected tracking point to maintain stereopsis;
 a gesture control module associated with the system, wherein the system
responds based on movement of a user, wherein the gesture control module is
configured to adjust at least one of an angle and a magnification of the first and
25 second video cameras to adjust the stereoscopic video image based on a
movement of the user; and
 a zooming module associated with the plurality of video cameras, the
zooming module configured to provide a magnification of the stereoscopic video
image.

30 25. The system of claim 24, wherein the movement is a deliberate gesture
of the user.

26. The system of claim 25, wherein the deliberate gesture is a hand, arm, voice, or instrument gesture.

5 27. The system of claim 25, wherein a sensor is associated with the tracking module, and wherein the tracking point follows a movement of the user.

28. The system of claim 27, wherein the movement is a head movement or an eye movement of the user.

10 29. The system of any one of claims 24 to 28, wherein the first video camera and the second video camera are spatially separated at a pupillary distance from one another.

15 30. The system of any one of claims 24 to 29, adapted for use in a dental setting, wherein the stereoscopic video image is of the subject's intraoral cavity.

31. The system of any one of claims 24 to 30, further comprising a video display configured to display the stereoscopic video image.

20 32. The system of claim 31, wherein the video display comprises a right eye display and a left eye display for viewing by a user's right eye and left eye, respectively, to create stereopsis.

25 33. The system of claim 31, wherein video display comprises a single video screen wherein the first video feed and the second video feed are optically separated using at least one of shutter separation, polarization separation, and color separation.

30 34. The system of claim 31, wherein the video display comprises multiple video displays for multiple users to simultaneously view the stereoscopic video image.

35. The system of any one of claims 24 to 34, wherein the tracking module maintains stereopsis as movement occurs for at least one of the tracking point, the first video camera, and the second video camera.

5 36. A method for viewing stereoscopic video images, comprising:
directing a first video camera and a second video camera to a selected area of a subject to generate a respective first video feed and a second video feed of the selected area, wherein the first video camera is separated from the second video camera by a selected distance, and wherein the first video camera and the second video camera are each directed to a convergent point at or near
10 the selected area to provide stereopsis of the selected area;
associating the convergent point with a selected tracking point;
adjusting a location of the convergent point relative to movement of the selected tracking point;
15 displaying the first video feed and the second video feed on a display system that optically separates the first video feed and the second video feed to create a stereoscopic video image;
modifying the stereoscopic image as a result of a gesture control motion of a user; and
20 providing a magnification of the stereoscopic video image using a zooming module associated with the first video camera and second video camera.

25 37. The method of claim 36, wherein the gesture is a deliberate gesture performed by user's hand, arm, voice, or instrument.

38. The method of claim 36 or 37, wherein the gesture is a head movement or an eye movement.

30 39. A system for viewing stereoscopic video images, comprising:
a first video camera configured to generate a first video feed of a subject;
a second video camera configured to generate a second video feed of the subject, wherein the first video feed and the second video feed combine to generate a stereoscopic video image;

a tracking module associated with the first video camera and the second video camera, the tracking module configured to cause the first video camera and the second video camera to be directed to a convergent point relative to a selected tracking point to maintain stereopsis; and

5 an image adjustment module configured to selectively modify the first video feed generated by the first video camera and second video feed generated by the second video camera, thereby providing a stereoscopic viewable image having at least one adjusted visual property adapted for enhanced diagnostic or treatment visualization.

10 40. The system of claim 39, wherein the adjusted visual property includes enhancement of a specific color or group of colors.

15 41. The system of claim 40, wherein the specific color or group of colors is enhanced for diagnosing or treating cancers or lesions in the mouth.

42. The system of claim 40, wherein the specific color or group of colors is enhanced for diagnosing or treating soft tissue.

20 43. The system of claim 40, wherein the specific color or group of colors is enhanced for diagnosing or treating cavities.

25 44. The system of any one of claims 39 to 43, wherein the system is adapted for use under amber light, and the adjusted visible property is a decrease in amber coloration of the viewable image.

30 45. The system of any one of claims 39 to 44, wherein the system is adapted for use in saturating light, and the adjusted visible property is a decrease in saturation of the viewable image.

46. The system of any one of claims 39 to 45, wherein the system is adapted so that the adjusted visible property provides accurate visualization for the matching of white coloration for cosmetic or reconstructive dentistry.

5 47. The system of any one of claims 39 to 46, wherein the image adjustment module is configured to display ultraviolet light detected by the first and second video cameras that is adjusted to be visible in the stereoscopic video image.

10 48. The system of any one of claims 39 to 47, wherein the image adjustment module is configured to adjust a lighting profile of the stereoscopic video image for a light provided by an intraoral cheek retractor.

49. The system of any one of claims 39 to 48, wherein the image adjustment module is configured to enhance the display of a colorant in the stereoscopic video image.

15 50. The system of claim 49, wherein the colorant is a fluorescent dye or pigment.

20 51. The system of claim 50, wherein fluorescent dye or pigment is a fluorescent dye adapted to visualize the presence of a material.

52. The system of claim 49, wherein colorant is adapted to change colors as a chemical cures or hardens.

25 53. The system of any one of claims 39 to 52, further comprising a zooming module associated with the first video camera and the second video camera, the zooming module configured to provide a magnification of the stereoscopic video image.

30 54. The system of any one of claims 39 to 53, wherein the first video camera and the second video camera are spatially separated at a pupillary distance from one another.

55. The system of any one of claims 39 to 54, further comprising a video display configured to display the stereoscopic video image.

56. The system of claim 55, wherein the first video feed and the second video feed are wirelessly communicated to the display.

57. The system of claim 55, wherein the video display comprises a right eye display and a left eye display for viewing by a user's right eye and left eye, respectively, to create stereopsis.

58. The system of claim 55, wherein video display comprises a single video screen wherein the first video feed and the second video feed are optically separated using at least one of shutter separation, polarization separation, and color separation.

59. The system of claim 55, wherein the video display comprises multiple video displays for multiple users to simultaneously view the stereoscopic video image.

60. The system of any one of claims 39 to 59, wherein the tracking module maintains stereopsis as movement occurs for at least one of the tracking point, the first video camera, and the second video camera.

61. A method for viewing stereoscopic video images, comprising:
directing a first video camera and a second video camera to a selected area of a subject to generate a respective first video feed and a second video feed of the selected area, wherein the first video camera is separated from the second video camera by a selected distance, and wherein the first video camera and the second video camera are each directed to a convergent point at or near the selected area to provide stereopsis of the selected area;
associating the convergent point with a selected tracking point;
adjusting a location of the convergent point relative to movement of the selected tracking point;

selectively modifying the first video feed generated by the first video camera and the second video feed generated by the second video camera, thereby providing a viewable image having at least one adjusted visual property adapted for enhanced diagnostic or treatment visualization; and

5 displaying the selectively modified first video feed and the second video feed on a display system that optically separates the first video feed and the second video feed to create a stereoscopic video image having the adjusted visual property.

10 62. The method of claim 61, further comprising zooming the first video camera and the second video camera to provide a magnification of the stereoscopic image.

15 63. The method claim 61 or 62, wherein the adjusted visual property includes enhancement of a specific color or group of colors.

20 64. The method of claim 63, wherein the specific color or group of colors is enhanced for diagnosing or treating cancers or lesions in the mouth, soft tissue, or cavities.

25 65. The method of any one of claims 61 to 64, further comprising illuminating the selected area with a wavelength of light, and the adjusted visible property is a modification of coloration of the wavelength of light displayed in the stereoscopic video image.

30 66. The method of claim 65, wherein the modification of coloration includes visually enhancing or diminishing the wavelength of light displayed in the stereoscopic video image.

67. The method of claim 65, wherein the modification of coloration includes shifting the wavelength of light from ultraviolet light that is viewed by the first and second video cameras to visible light displayed in the stereoscopic video image.

68. The method of any one of claims 61 to 67, wherein the step of selectively modifying the light signal includes modifying the visual properties of a colorant.

5

69. A system for viewing stereoscopic video images, comprising:
a first video camera configured to generate a first video feed of a subject;
a second video camera configured to generate a second video feed of the subject, wherein the first video feed and the second video feed combine to generate a stereoscopic video image;

10

a tracking module associated with the first video camera and the second video camera, the tracking module configured to cause the first video camera and the second video camera to be directed to a convergent point relative to a selected tracking point to maintain stereopsis; and

15

a calibration module configured to calibrate and adjust a horizontal alignment of the first video feed and the second video feed.

70. The system of any one of claims 39 to 60, further comprising a head mountable stereoscopic display including a right video display and a left video display to create a stereoscopic video image from the first video feed and the second video feed, respectively.

20

71. The system of claim 70, wherein the horizontal alignment is calibrated to a user's eyes to reduce stress on the eyes during use.

25

72. The system of claims 69, 70 or 71, wherein the calibration module is further configured to adjust vertical alignment of the first video camera and the second video camera.

30

73. The system of any one of claims 69 to 72, wherein the horizontal alignment is maintained during pan or tilt movements of the first video camera or the second video camera.

74. The system of any one of claims 69 to 73, wherein the calibration module provides for calibration with multiple users, wherein the system calibrates to a first user in a first mode, and a second user in a second mode.

5 75. The system of claim 74, wherein the system switches between the first mode and the second mode automatically based on whether the first user or the second user is using the system.

10 76. The system of any one of claims 69 to 75, further comprising a zooming module associated with the first video camera and the second video camera, the zooming module configured to provide a magnification of the stereoscopic video image.

15 77. The system of any one of claims 69 to 76, wherein the first video camera and the second video camera are spatially separated at a pupillary distance from one another.

20 78. The system of any one of claims 69 to 77, adapted for use in a dental setting, wherein the first video feed and the second video feed is of the subject's intraoral cavity.

79. The system of any one of claims 69 to 78, further comprising a video display configured to display the stereoscopic video image.

25 80. The system of claim 79, wherein the first video feed and the second video feed are wirelessly communicated to the display.

30 81. The system of claim 79, wherein the video display comprises a right eye display and a left eye display for viewing by a user's right eye and left eye, respectively, to create stereopsis.

82. The system of claim 79, wherein video display comprises a single video screen wherein the first video feed and the second video feed are optically

separated using at least one of shutter separation, polarization separation, and color separation.

5 83. The system of claim 79, wherein the video display comprises multiple video displays for multiple users to view the stereoscopic video image.

10 84. The system of claim 79, wherein the tracking module maintains stereopsis as movement occurs for at least one of the tracking point, the first video camera, and the second video camera.

15 85. A method for viewing stereoscopic video images, comprising:
directing a first video camera and a second video camera to a selected area of a subject to generate a respective first video feed and a second video feed of the selected area, wherein the first video camera is separated from the second video camera by a selected distance, and wherein the first video camera and the second video camera are each directed to a convergent point at or near the selected area to provide stereopsis of the selected area;
20 horizontally calibrating the first video feed and the second video feed;
associating the convergent point with a selected tracking point;
adjusting a location of the convergent point relative to movement of the selected tracking point; and
displaying the first video feed and the second video feed on a display system that optically separates the first video feed and the second video feed to create a stereoscopic video image.

25 86. The method of claim 85, further comprising vertically calibrating the first video feed and the second video feed.

30 87. The method of claim 85 or 86, wherein the horizontal alignment is maintained during pan or tilt movements of the first video camera or the second video camera.

88. The method of claim 85, 86 or 87, further comprising horizontally calibrating the first video feed and the second video feed for a second user.

5 89. A system for viewing stereoscopic video images, comprising:
a first video camera configured to generate a first video feed of a subject;
a second video camera configured to generate a second video feed of the subject, wherein the first video camera and the second video camera are configured to generate a stereoscopic video image;

10 a tracking module associated with the first video camera and the second video camera, the tracking module configured to cause the first video camera and the second video camera to be directed to a convergent point relative to a selected tracking point to maintain stereopsis; and

15 a 3-D modeling module configured to convert the stereoscopic video image into a 3-D model or construct.

90. The system of claim 89, further comprising a zooming module associated with the first video camera and the second video camera, the zooming module configured to provide a magnification of the stereoscopic video image.

20 91. A method for viewing stereoscopic video images, comprising:
directing a first video camera and a second video camera to a selected area of a subject to generate a respective first video feed and a second video feed of the selected area, wherein the first video camera is separated from the second video camera by a selected distance, and wherein the first video camera and the second video camera are each directed to a convergent point at or near
25 the selected area to provide stereopsis of the selected area;

associating the convergent point with a selected tracking point;
adjusting a location of the convergent point relative to movement of the selected tracking point;

30 displaying the first video feed and the second video feed on a display system that optically separates the first video feed and the second video feed to create a stereoscopic video image; and

generating a 3-D model from at least one frame of the stereoscopic video image.

5 92. A system for viewing stereoscopic video images of any one of claims 1, 15, 24, 39, 69 or 89 and substantially as hereinbefore described with reference to the accompanying drawings.

10 93. A method for viewing stereoscopic video images of any one of claims 13, 23, 36, 61, 85 or 91 and substantially as hereinbefore described with reference to the accompanying drawings.

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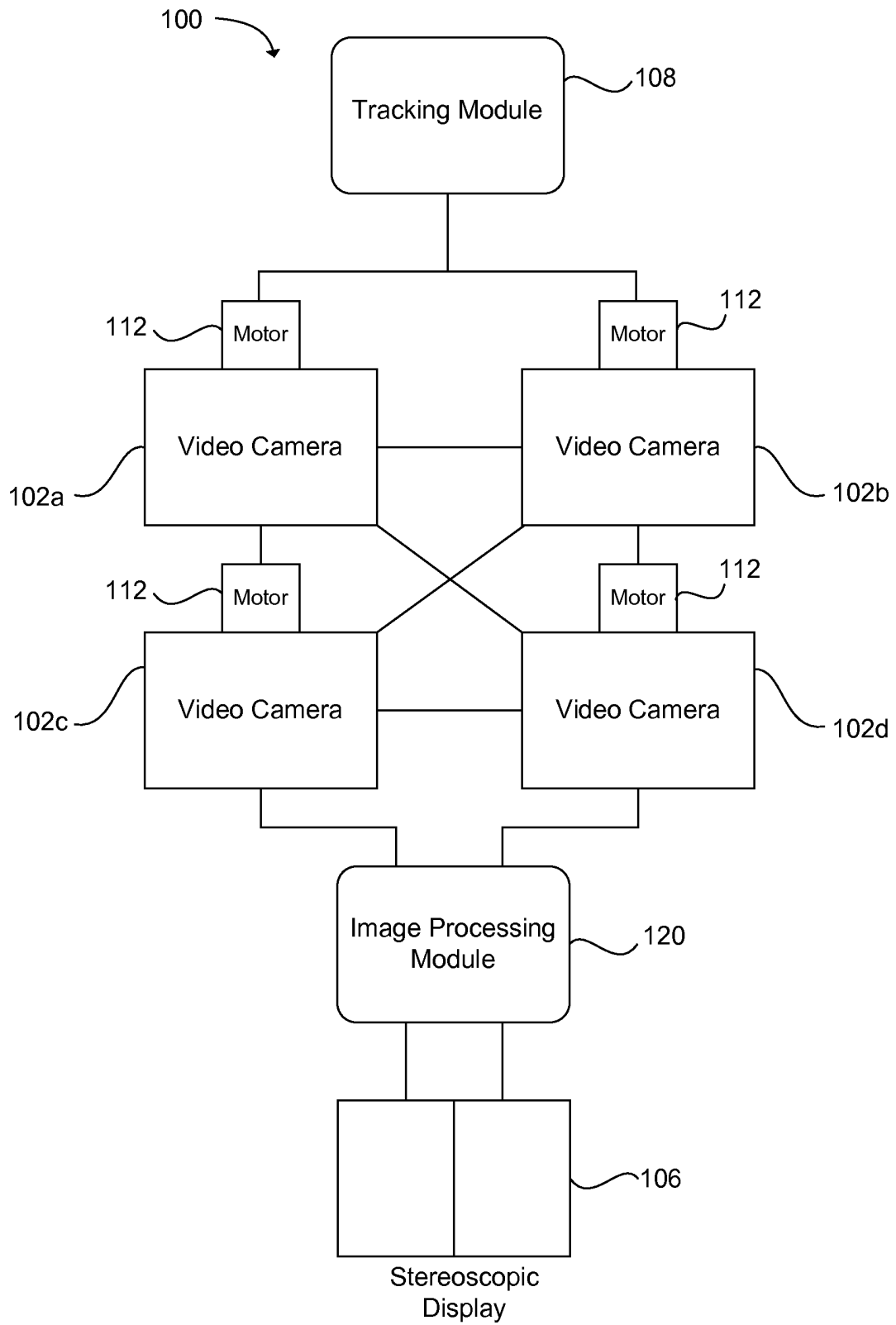


FIG. 1a

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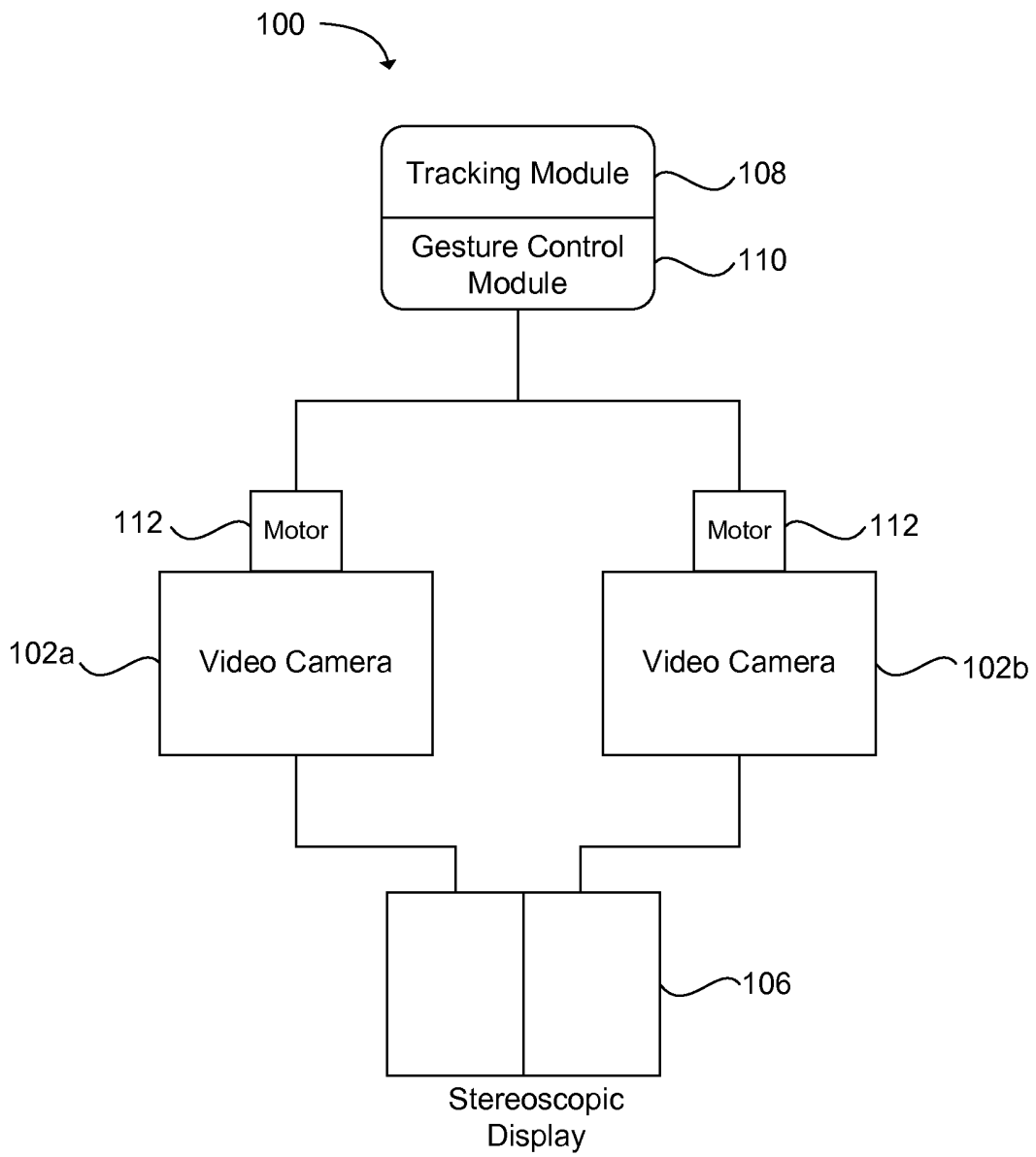


FIG. 1b

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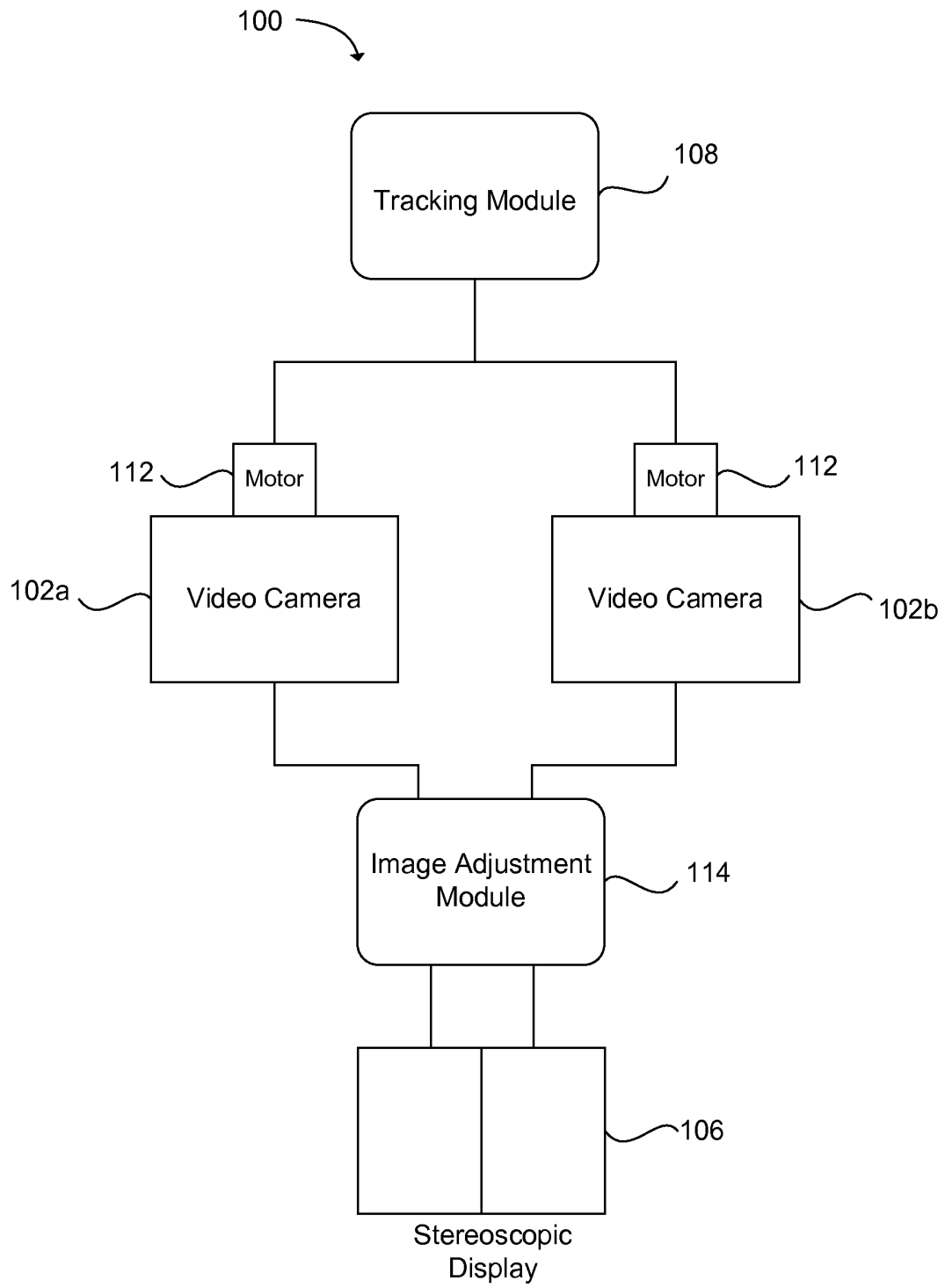


FIG. 1c

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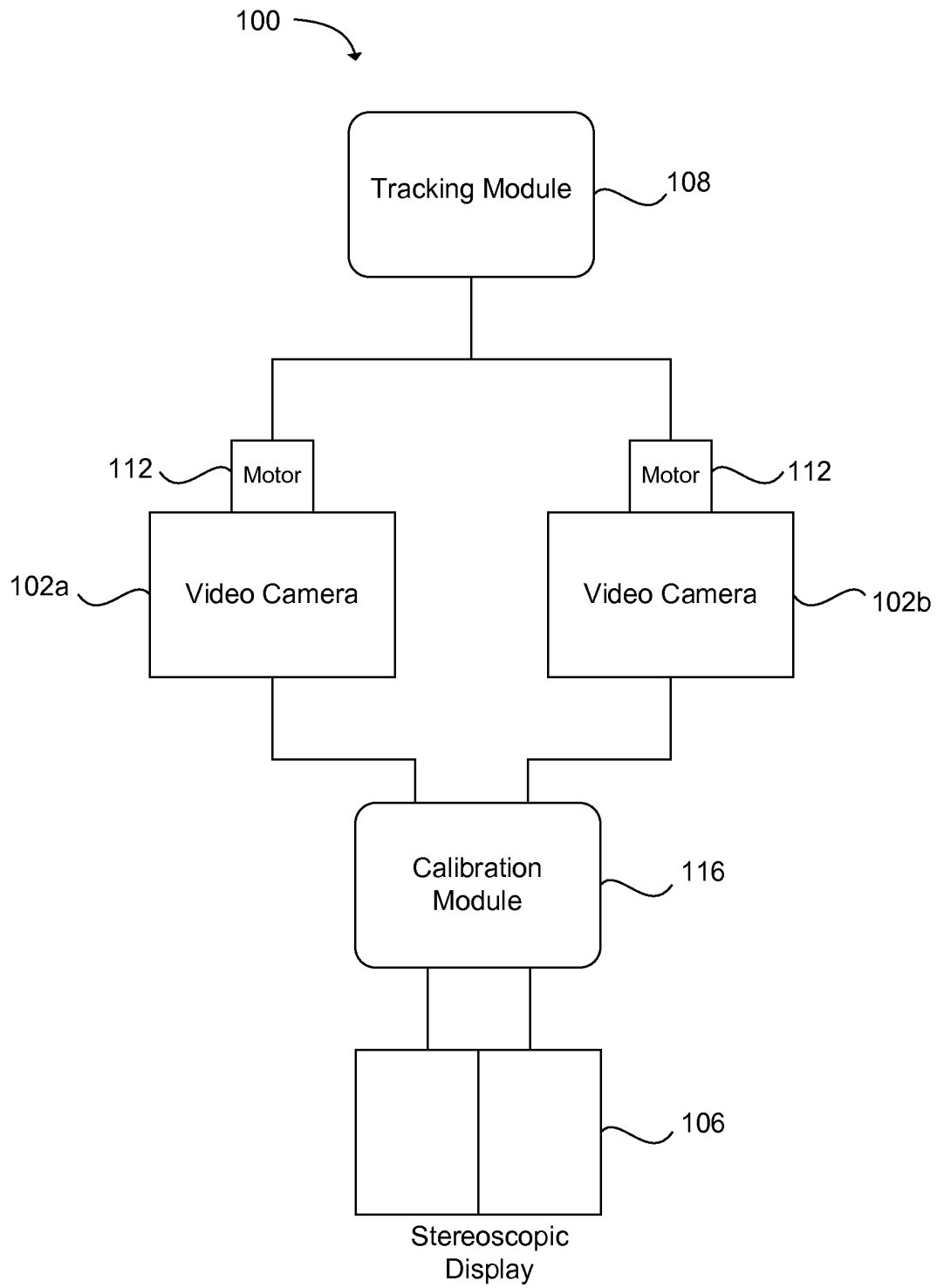


FIG. 1d

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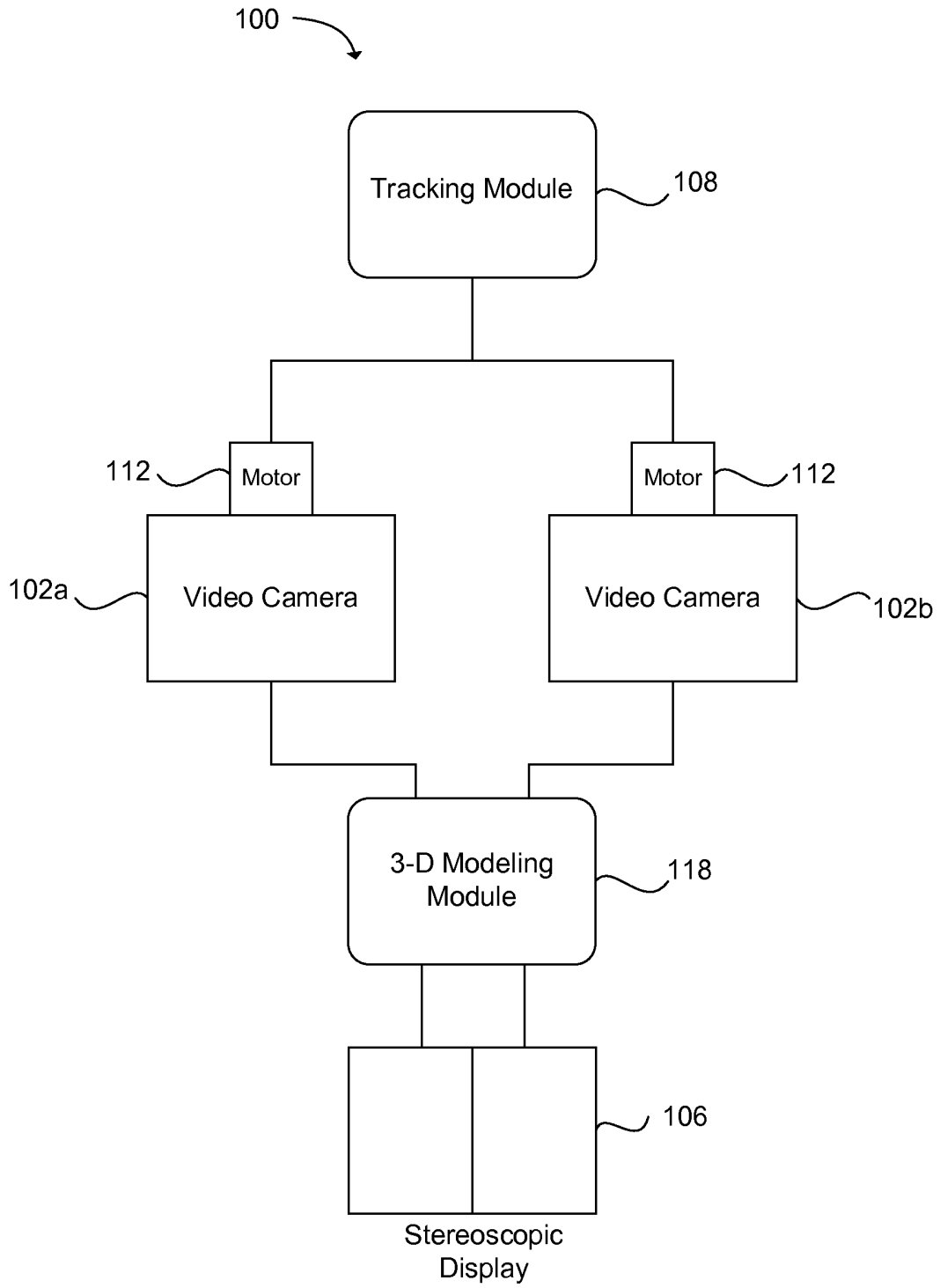


FIG. 1e

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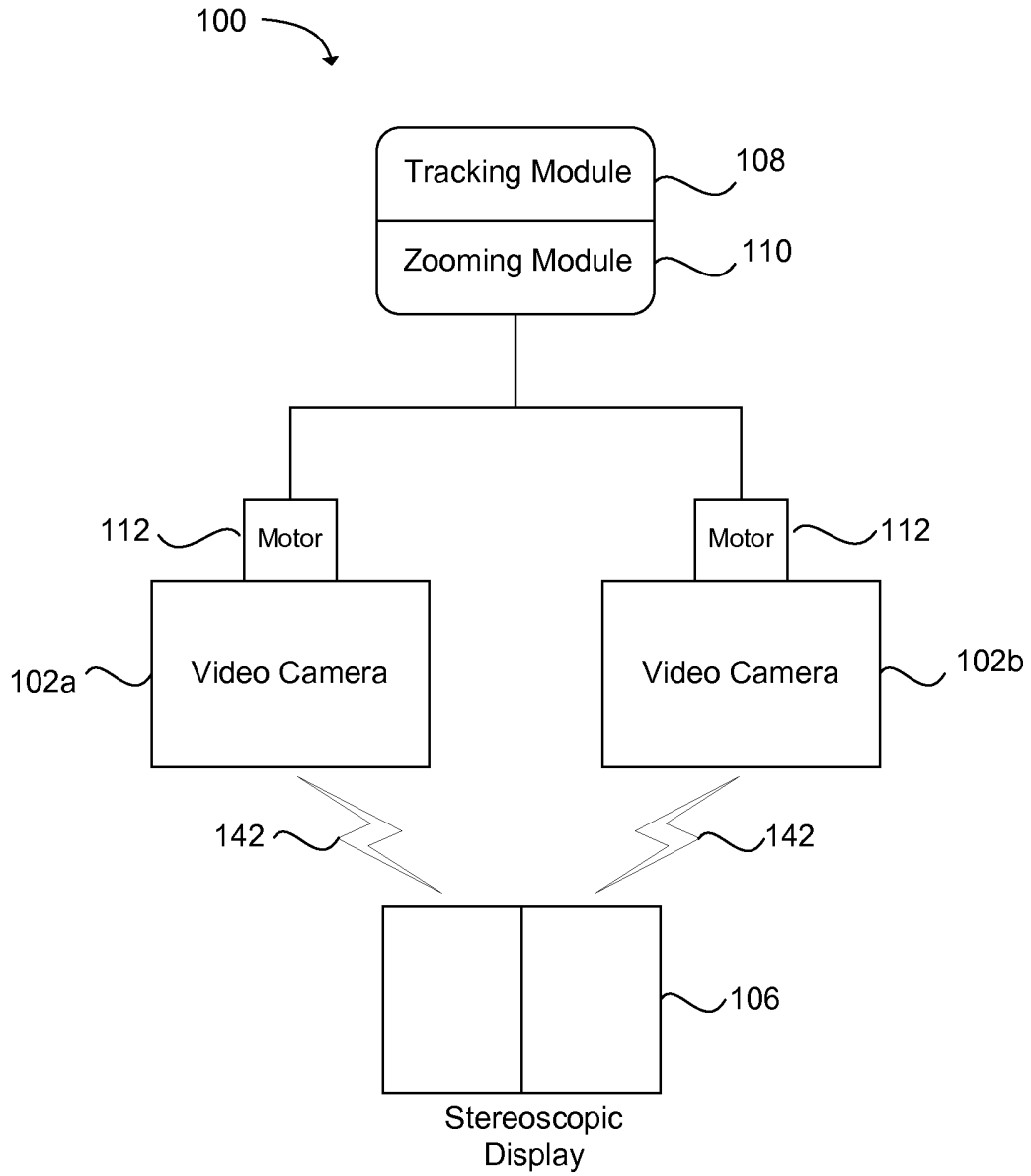


FIG. 1f

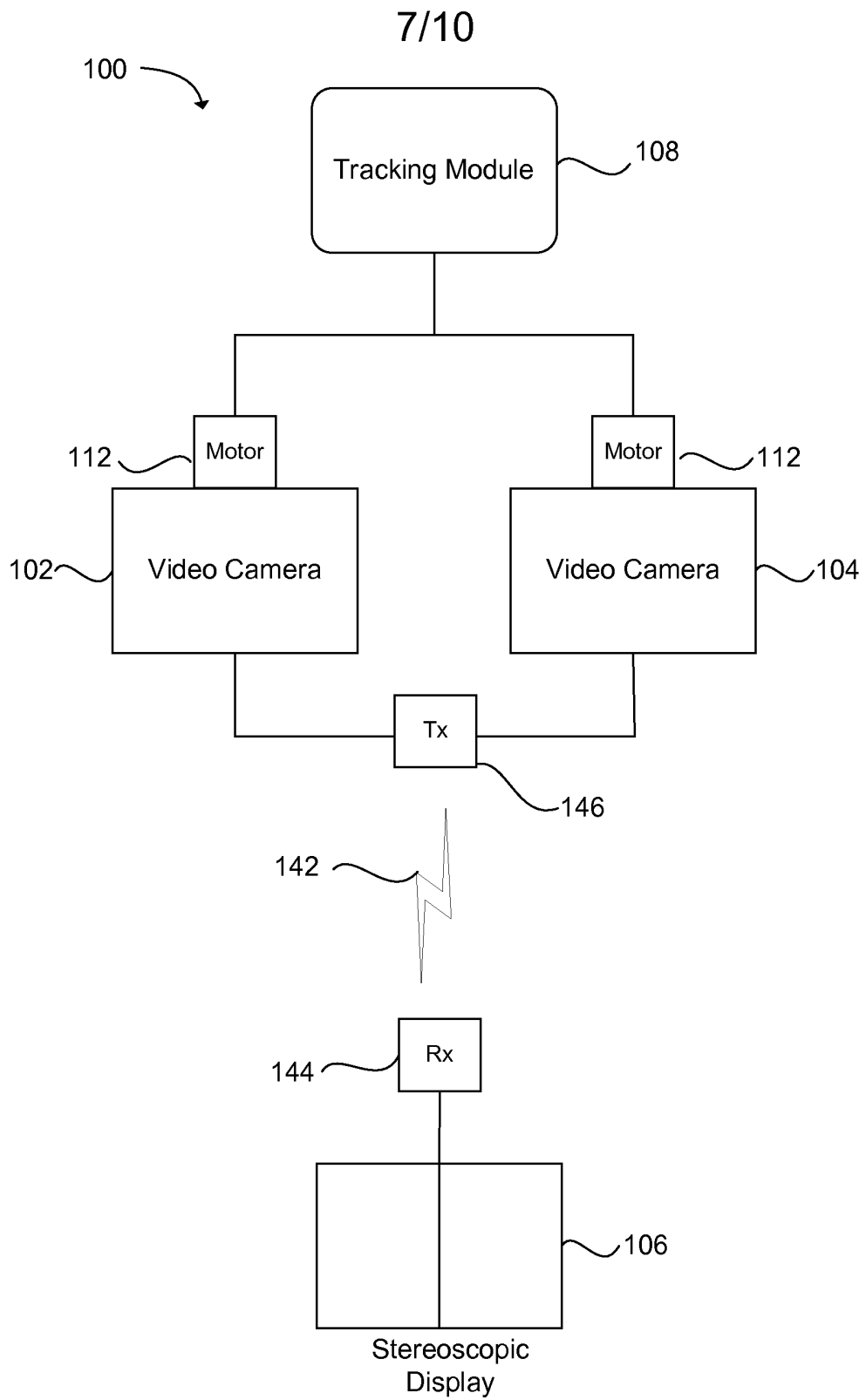


FIG. 1g

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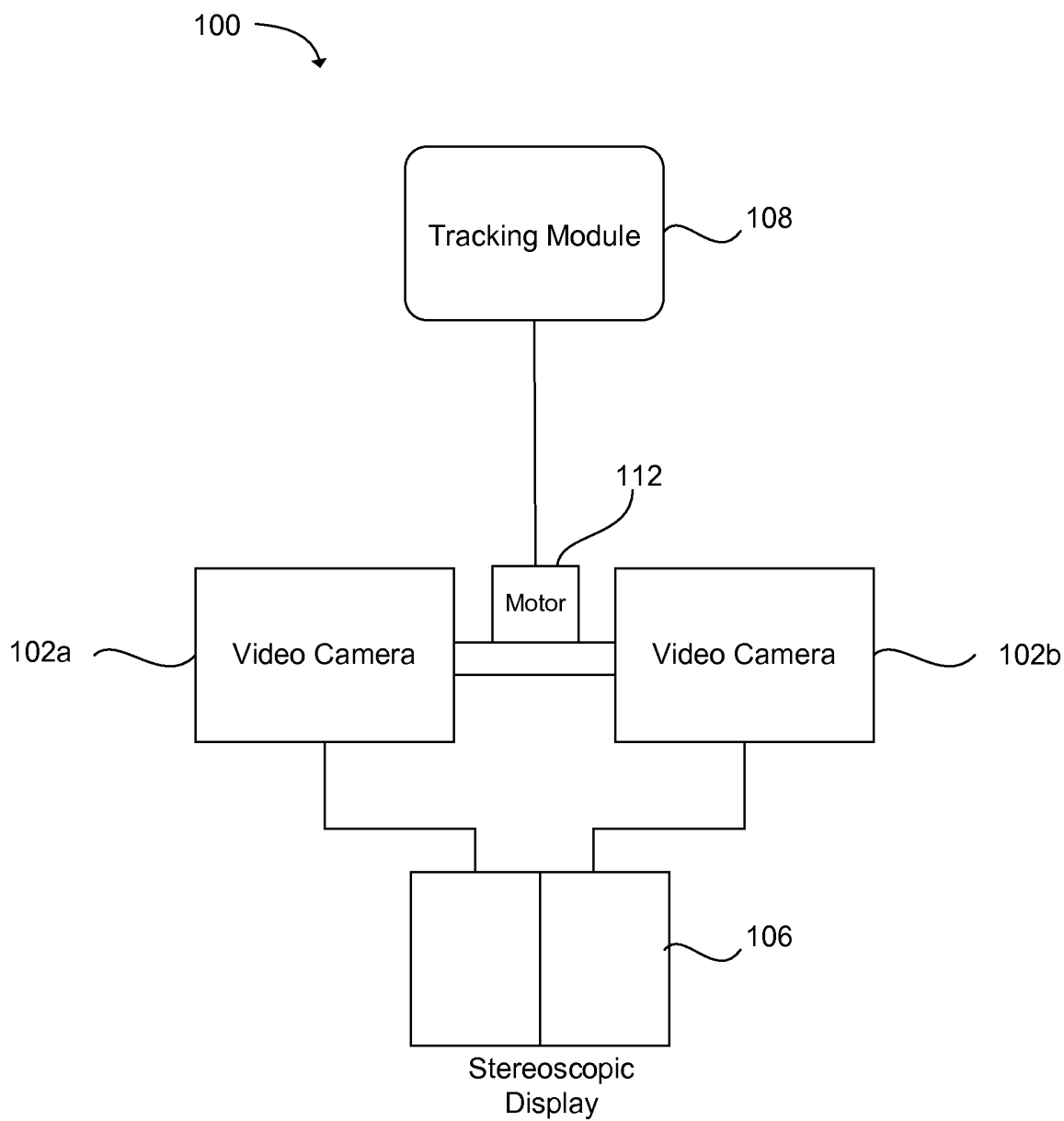


FIG. 1h

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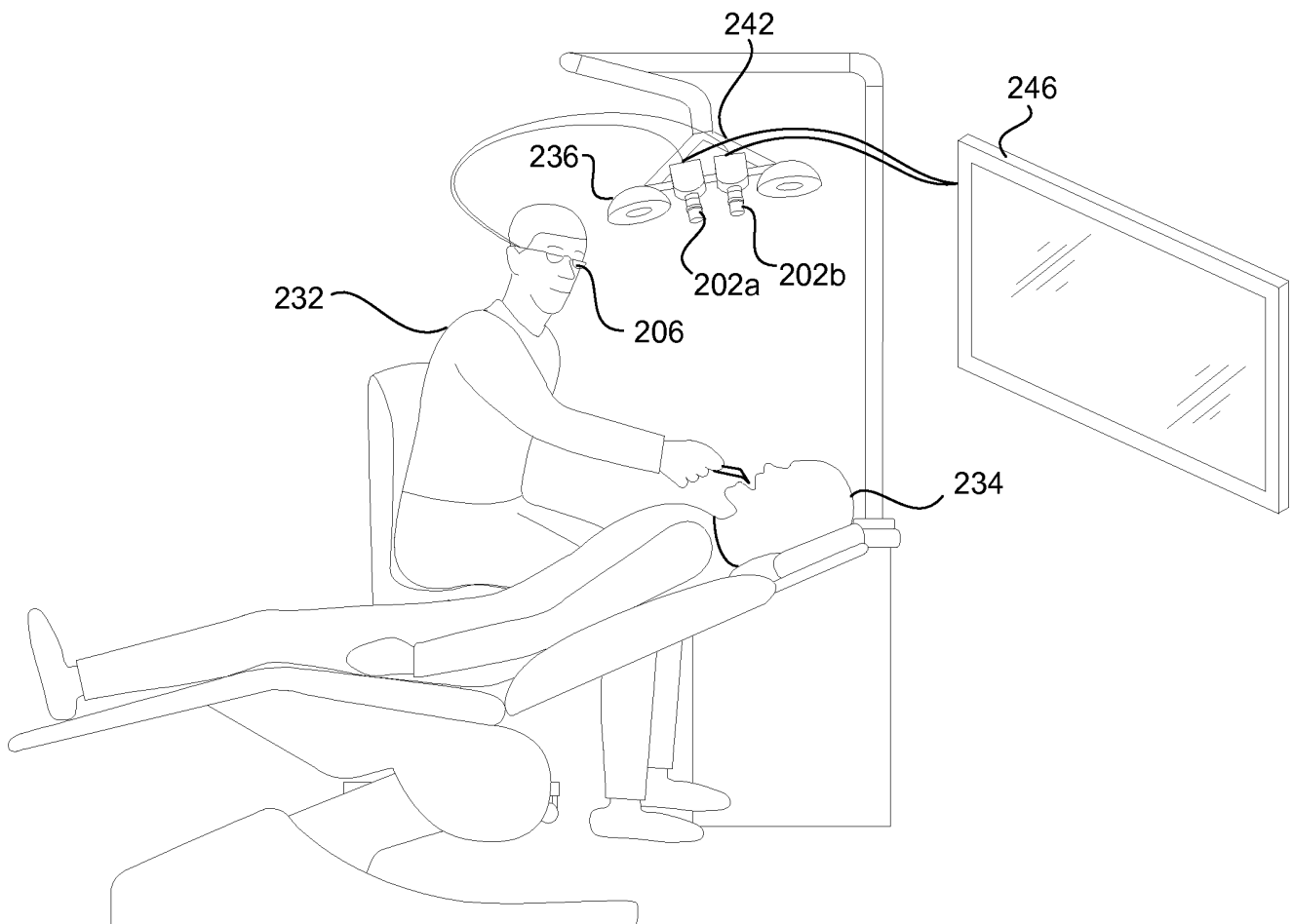


FIG. 2

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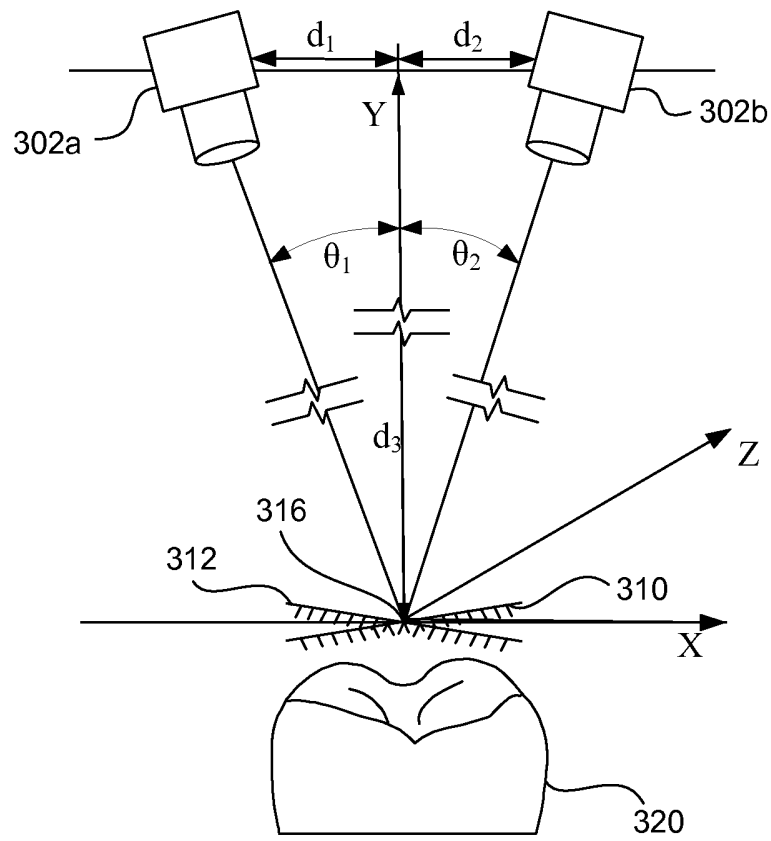


FIG. 3