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(54) **Method and apparatus for colour imaging a three-dimensional structure**

Verfahren und Gerät zur Farbbildformung einer dreidimensionalen Struktur

Procédé et appareil d'imagerie en couleurs d'une structure tridimensionnelle

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EP 1 607 064 B1

Description

FIELD OF THE INVENTION

[0001] The present invention relates to optical scanners, particularly for providing a digital representation of three-dimensional objects including colour. The invention finds particular application in the surveying of the intraoral cavity.

BACKGROUND OF THE INVENTION

[0002] Many methods have been developed for obtaining the three dimensional location of surface points of an object, for a host of applications including, inter alia, the intraoral cavity. Techniques for direct non-contact optical measurement, in particular for direct optical measurement of teeth and the subsequent automatic manufacture of dentures, are known. The term "direct optical measurement" signifies surveying of teeth in the oral cavity of a patient. This facilitates the obtainment of digital constructional data necessary for the computer-assisted design (CAD) or computer-assisted manufacture (CAM) of tooth replacements without having to make any cast impressions of the teeth. Such systems typically include an optical probe coupled to an optical pick-up or receiver such as charge coupled device (CCD) and a processor implementing a suitable image processing technique to design and fabricate virtually the desired product. Such methods include, for example, confocal imaging techniques as described in WO 00/08415 assigned to the present assignee. These methods provide a digital three-dimensional surface model that is inherently monochromatic, i.e., no colour information is obtained in the imaging process.

[0003] Associating colour information with three-dimensional objects is not straightforward, particularly when the position information is obtained by using a three dimensional scanning method, while the colour information is obtained by using a two dimensional scanning method. The problem of conformally mapping the two dimensional colour information onto the three dimensional surface model is difficult and it is common for mismatching of the colour with three-dimensional points to occur. Essentially, where two-dimensional colour detectors are used for obtaining the colour information, it is difficult to accurately associate colour information from the detectors with the correct points on the three dimensional surface model, particularly where relative movement between the object and the device occurs between the acquisition of the three-dimensional topological data and acquisition of the two-dimensional image data.

[0004] EP 837 659 describes a process and device for obtaining a three dimensional image of teeth. Three-dimensional surface data is obtained by first covering the surface with an opaque, diffusely reflecting material, and the object is illuminated with monochromatic light. The image of the object under the layer is obtained by the process described in US 4,575,805 using intensity pattern techniques. In order to obtain a two-dimensional colour image of the object, the reflecting layer has to be removed. The method thus requires the camera to be manually re-aligned so that the two-dimensional colour image should more or less correspond to the same part of the object as the three dimensional image. Then, the three dimensional image may be viewed on a screen as a two-dimensional image, and it is possible to superimpose on this two-dimensional image the two-dimensional colour image of the teeth taken by the camera.

[0005] US 6,594,539 provides an intraoral imaging system that produces images of a dental surface, including three dimensional surface images and also two dimensional colour images, with the same camera.

[0006] In 5,440,393, the shape and dimensions of a dental patients mouth cavity including upper and lower tooth areas and the jaw structure, are measured by an optical scanner using an external radiation source, whose reflected signals are received externally and converted into electronic signals for analysis by a computer. Both surface radiation and reflection from translucent internal surfaces are scanned, and processing of reflections may involve a triangulation system or holograms.

[0007] In US 5,864,640, a scanner is described having a multiple view detector responsive to a broad spectrum of visible light. The detector is operative to develop several images of a three dimensional object to be scanned. The images are taken from several relative angles with respect to the object. The images depict several surface portions of the object to be scanned. A digital processor, coupled to the detector, is responsive to the images and is operative to develop with a computational unit 3-D coordinate positions and related image information of the surface portions of the object, and provides 3-D surface information that is linked to colour information without need to conformally map 2-D colour data onto 3-D surface. Of general background interest, US 4,836,674, US 5,690,486, US 6,525,819, EP 0367647 and US 5,766,006 describe devices for measuring the colour of teeth.

[0008] US 6,205,243 B1 describes a system and a method for collection of data in construction of a computer model based on a multi-resolution mesh to describe surface contours and colour of an object. In said document, the triangulation principle is used in order to collect the data. As an immediate consequence of this approach, however, the X and Y coordinates which are probed on the object deviate from the X and Y coordinates associated with the corresponding data, which leads to the problem of associating the colour information and the three-dimensional information, which are registered as a function of the detector position, and the model, which is based on the XY positions of the probed region of the object itself.

[0009] Consequently, a complicated alignment procedure is necessary.

[0010] This problem is solved by the alternative system and method of the present invention.

SUMMARY OF THE INVENTION

[0011] In accordance with the present invention, a device and method for determining the surface topology and colour of at least a portion of a three dimensional structure is provided. Preferred non-limiting embodiments of the invention are concerned with the imaging of a three-dimensional topology of a teeth segment, optionally including such where one or more teeth are missing. This may allow the generation of data for subsequent use in design and manufacture of, for example, prosthesis of one or more teeth for incorporation into said teeth segment. particular examples are the manufacture of crown, bridges dental restorations or dental filings. The colour and surface data is provided in a form that is highly manipulable and useful in many applications including prosthesis colour matching and orthodontics, among others.

[0012] The determination of the 3D surface topology of a portion of a three-dimensional structure is preferably carried out using a confocal focusing method, comprising:

(a) providing an array of incident light beams propagating in an optical path leading through a focusing optics and a probing face; the focusing optics defining one or more focal planes forward said probing face in a position changeable by said optics, each light beam having its focus on one of said one or more focal plane; the beams generating a plurality of illuminated spots on the structure;

(b) detecting intensity of returned light beams propagating from each of these spots along an optical path opposite to that of the incident light;

(c) repeating steps (a) and (b) a plurality of times, each time changing position of the focal plane relative to the structure; and

(d) for each of the illuminated spots, determining a spot-specific position, being the position of the respective focal plane, yielding a maximum measured intensity of a respective returned light beam; and based on the determined spot-specific positions, generating data representative of the topology of said portion.

[0013] The determination of the spot-specific positions in fact amounts to determination of the in-focus distance. The determination of the spot-specific position may be by measuring the intensity per se, or typically is performed by measuring the displacement (S) derivative of the intensity (I) curve (dI/dS) and determining the relative position in which this derivative function indicates a maximum intensity. The term "spot-specific position (SSP)" will be used to denote the relative in-focus position regardless of the manner in which it is determined. It should be understood that the SSP is always a relative position as the absolute position depends on the position of the sensing face. However the generation of the surface topology does not require knowledge of the absolute position, as all dimensions in the cubic field of view are absolute.

[0014] The SSP for each illuminated spot will be different for different spots. The position of each spot in an **X-Y** frame of reference is known and by knowing the relative positions of the focal plane needed in order to obtain maximum intensity (namely by determining the SSP), the **Z** or depth coordinate can be associated with each spot and thus by knowing the **X-Y-Z** coordinates of each spot the surface topology can be generated.

[0015] In order to determine the **Z** coordinate (namely the SSP) of each illuminated spot the position of the focal plane may be scanned over the entire range of depth or **Z** component possible for the measured surface portion. Alternatively the beams may have components, each of which has a different focal plane. Thus, by independent determination of SSP for the different light components, e.g. 2 or 3 with respective corresponding 2 or 3 focal planes, the position of the focal planes may be changed by the focusing optics to scan only part of the possible depth range, with all focal planes together covering the expected depth range. Alternatively, the determination of the SSP may involve a focal plane scan of only part of the potential depth range and for illuminated spots where a maximum illuminated intensity was not reached, the SSP is determined by extrapolation from the measured values or other mathematical signal processing methods. Thus, in each case, a **Z**-value is obtained for each point along an **X-Y** grid representing a plurality of light beams. In this manner, a three-dimensional (3D) numerical entity E may be crated, comprising a plurality of coordinates (X, Y, Z) representative of the surface topology of the object being scanned.

[0016] Alternatively, any other suitable method may be employed to obtain the 3D entity E.

[0017] According to the present invention, a two dimensional (2D) colour image of the 3D structure that is being scanned is also obtained, but typically within a short time interval with respect to the 3D scan. Further, the 2D colour image is taken at substantially the same angle and orientation with respect to the structure as was the case when the 3D scan was taken. Accordingly, there is very little or no substantial distortion between the **X-Y** plane of 3D scan, and the plane of the image, i.e., both planes are substantially parallel, and moreover substantially the same portion of the structure should be comprised in both the 3D scan and the 2D image. This means that each **X-Y** point on the 2D image substantially corresponds to a similar point on the 3D scan having the same relative **X-Y** values. Accordingly, the same point of the structure being scanned has substantially the same **X-Y** coordinates in both the 2D image and the 3D scan, and thus the colour value at each **X, Y** coordinate of the 2D colour scan may be mapped directly to the spatial coordinates in the 3D scan having the same **X, Y** coordinates, wherein to create a numerical entity I representing the colour and surface topology of the structure being scanned.

[0018] Where the X,Y coordinates of the colour image do not precisely correspond to those of the 3D scan, for example as may arise where one CCD is for the 3D scanning, while another CCD is used for the 2D colour image, suitable interpolation methods may be employed to map the colour data to the 3D spartial data.

[0019] To provide a more accurate mapping, it is possible to construct a 2D image along the **X-Y** plane of the 3D model, and using procedures such as optical recognition, manipulate the colour 2D image to best fit over this 3D image. This procedure may be used to correct for any slight misalignment between the 2D colour scan and the 3D scan. Once the colour 2D image has been suitably manipulated, the colour values of the colour 2D image are mapped onto the adjusted **X-Y** coordinates of the 3D scan.

[0020] Thus the present invention provides a relatively simple and effective way for mapping 2D colour information onto a 3D surface model.

[0021] The present invention thus provides a device and method for obtaining a numerical entity that represents the colour and surface topology of an object. When applied particularly to the intraoral cavity, the device of the invention provides advantages over monochrome 3D scaners, including such scanners that are based on confocal focusing techniques. For example, the 2D colour image capability on its own enables the dental practitioner to identify the area of interest within the oral cavity with a great degree of confidence in order to better aim the device for the 3D scanning. In other words, an improved viewfinder is automatically provided. Further, rendition of a full colour 3D image of the target area can help the practitioner to decide on the spot whether the scan is sufficiently good, or whether there are still parts of the teeth or soft tissues that should have been included, and thus help the practitioner to deciode whether or not to acquire another 3D colour entity.

[0022] Creation of a colour 3D entity that is manipulable by a computer is extremely useful in enabling the practictioner to obtain data from such an entity that is useful for procedures carried out in the dental cavity.

[0023] Thus, according to the present invention, a device according to claim 1 is provided for determining the surface topology and associated colour of at least a portion of a three dimensional structure, comprising:

scanning means adapted for providing depth data of said portion corresponding to a two-dimensional reference array substantially orthogonal to a depth direction;

imaging means adapted for providing two-dimensional colour image data of said portion associated with said reference array;

wherein the device is adapted for maintaining a spatial disposition with respect to said portion that is substantially fixed during operation of said scanning means and said imaging means. In other words, operation of the scanning means and the imaging means is substantially or effectively simultaneous in practical terms, and thus the actual time interval that may exist between operation of the two means is so short that the amplitude of any mechanical vibration of the device or movement of the oral cavity will be so small as can be ignored.

[0024] The device is adapted for providing a time interval between acquisition of said depth data and acquisition of said colour image data such that substantially no significant relative movement between said device and said portion occurs. The time interval may be between about 0 seconds to about 100 milliseconds, for example 5, 10, 20, 30, 40, 50, 60, 70, 80, 90 or 100 milliseconds, and preferably between about 0 to about 50 milliseconds, and more preferably between about 0 and 20 milliseconds.

[0025] The device further comprise processing means for associating said colour data with said depth data for corresponding data points of said reference array. In described embodiments, the operation of said scanning means is based on confocal imaging techniques. Such scanning means comprises:

a probing member with a sensing face;

first illumination means for providing a first array of incident light beams transmitted towards the structure along an optical path through said probing unit to generate illuminated spots on said portion along said depth direction, wherein said first array is defined within said reference array;

a light focusing optics defining one or more focal planes forward said probing face at a position changeable by said optics, each light beam having its focus on one of said one or more focal plane;

a translation mechanism for displacing said focal plane relative to the structure along an axis defined by the propagation of the incident light beams;

a first detector having an array of sensing elements for measuring intensity of each of a plurality of light beams returning from said spots propagating through an optical path opposite to that of the incident light beams;

a processor coupled to said detector for determining for each light beam a spot-specific position, being the position of the respective focal plane of said one or more focal planes yielding maximum measured intensity of the returned light beam, and based on the determined spot-specific positions, generating data representative of the topology of said portion.

[0026] The first array is arranged to provide depth data at a plurality of predetermined spatial coordinates substantially corresponding to the spatial disposition of said incident light beams.

[0027] The first illumination means comprises a source emitting a parent light beam and a beam splitter for splitting the parent beam into said array of incident light beams. The first illumination means may comprise a grating or microlens array.

[0028] The device may comprise a polarizer for polarizing said incident light beams are polarized. Further, the device may comprise a polarization filter for filtering out from the returned light beams light components having the polarization of the incident light beams.

[0029] The illumination unit may comprise at least two light sources and each of said incident beams is composed of light components from the at least two light sources. The at least two light sources emit each a light component of different wavelength. The light directing optics defines a different focal plane for each light component and the detector independently detects intensity of each light components.

[0030] The at least two light sources may be located so as to define optical paths of different lengths for the incident light beams emitted by each of the at least two light sources.

[0031] Typically, the focusing optics operates in a telecentric confocal mode.

[0032] Optionally, the light directing optics comprises optical fibers.

[0033] Typically, the sensing elements are an array of charge coupled devices (CCD). The detector unit may comprise a pinhole array, each pinhole corresponding to one of the CCDs in the CCD array.

[0034] The operation of said imaging means may be based on:

illuminating said portion with three differently- coloured illumination radiations, the said illuminations being combinable to provide white light,

capturing a monochromatic image of said portion corresponding to each said illuminating radiation, and

combining the monochromatic images to create a full colour image,

wherein each said illuminating radiation is provided in the form of a second array of incident light beams transmitted towards the portion along an optical path through said probing unit to generate illuminated spots on said portion along said depth direction, wherein said second array is defined within said reference frame.

[0035] The second array is arranged to provide colour data at a plurality of spatial coordinates substantially corresponding to the spatial coordinates of said first array. The device may comprise colour illumination means adapted for providing three second illuminating radiations, each of a different colour. The colour illumination means comprises second illumination means for providing said three second illuminating radiations, each of a different colour. Alternatively, the colour illumination means comprises second illumination means for providing two said second illuminating radiations, and wherein said first illumination means provides another said second illuminating radiation each said second illuminating radiation being of a different colour. Optionally, each one of said second illumination radiations is a different one of red, green or blue light. The second illumination means may comprise radiation transmission elements that are configured to be located out of the path of said light beams or said returned light beam at least within said light focusing optics. The probing member may be made from a light transmissive material having an upstream optical interface with said light focusing optics and a reflective face for reflecting light between said optical interface and said sensing face. The second illumination means may be optically coupled to said optical interface for selectively transmitting illuminating radiations in at least two colours to said portion via said sensing face. The colour illumination means may comprise second illumination means for providing two said second illuminating radiations, and wherein said first illumination means provides another said second illuminating radiation each said second illuminating radiation being of a different colour. The probing member may comprise a removable sheath having an inner surface substantially complementary to an outer surface of said probing member, and having a window in registry with said sensing face, wherein said sheath is made from a waveguiding material and is adapted to transmit said light from said second illuminating means from an upstream face thereof to a downstream face associated with said window. The second illumination means may be optically coupled to said upstream face for selectively transmitting said second illuminating radiations in at least two colours to said portion via said downstream face. Preferably, the sheath is disposable after use with a patient.

[0036] In another embodiment, the reflective face comprises a dichroic coating, having relatively high reflectivity and low optical transmission properties for a said second illuminating radiation provided by said first illumination means, and relatively low reflectivity and high optical transmission properties for the two said second illuminating radiations provided by said second illumination means.

[0037] The second illumination means may be adapted for providing second illuminating radiations within said light focusing optics. In particular, the second illumination means may be adapted for providing second illuminating radiations at an aperture stop plane of said light focusing optics. The second illumination means may be provided on a bracket having an aperture configured to allow said light beams and said returning light beams to pass therethrough without being optically affected by said bracket.

[0038] Optionally, the device further comprises:

a first polarizing element located just downstream of said illumination means so as to polarize the light emitted therefrom;

a second polarizing element located just upstream of said first detector,

wherein said second polarizing element is crossed with respect to the first polarizing element; and
a quarter waveplate at the downstream end of said device.

[0039] Further optionally the second illumination means are adapted for selective movement in the depth direction.

[0040] The device may comprise a mirror inclined to the optical axis of said light focusing optics and having an aperture configured to allow said light beams and said returning light beams to pass therethrough without being optically affected by said mirror, and wherein said second illumination means comprises at least one white illumination source optically coupled with suitable colour filters, said filters selectively providing illumination radiation in each colour in cooperation with said white illumination source, wherein said mirror is coupled to said white illumination source to direct radiation therefrom along said optical axis. The white illumination source may comprise a phosphorus InGaN LED. The filters may be arranged on sectors of a rotatable disc coupled to a motor, predetermined selective angular motion of said disc selectively couples said white illumination source to each said filter in turn.

[0041] Optionally, the second illumination means are in the form of suitable LED's, comprising at least one LED for providing illumination radiation in each colour. Optionally, the second illumination means are in the form of suitable LED's, comprising at least one white illumination source optically coupled with suitable colour filters, said filters selectively providing illumination radiation in each colour in cooperation with said white illumination source. The white illumination source may comprise a phosphorus InGaN LED. The filters may be arranged on sectors of a rotatable disc coupled to a motor, predetermined selective angular motion of said disc selectively couples said white illumination source to each said filter in turn. The device may further comprise a plurality of optical fibers in optical communication with said filters and with radiation transmission elements comprised in said second illumination means.

[0042] The first detector is adapted for selectively measuring intensity of each said second illuminating radiation after reflection from said portion.

[0043] Alternatively, the operation of said imaging means is based on illuminating said portion with substantially white illumination radiation, and capturing a colour image of said portion, wherein said white illuminating radiation is provided in the form of a second array of incident light beams transmitted towards the portion along an optical path through said probing unit to generate illuminated spots on said portion along said depth direction, wherein said second array is defined within said reference frame. The second array is arranged to provide colour data at a plurality of spatial coordinates substantially corresponding to the spatial coordinates of said first array. The imaging means comprises:-

white illumination radiation means;
second detector having an array of sensing elements for measuring intensity of said white illuminating radiation after reflection from said portion.

[0044] Alternatively, the operation of said imaging means is based on illuminating said portion with substantially white illumination radiation, selectively passing radiation reflected from said portion through a number of colour filters, capturing a monochromatic image of said portion corresponding to each said filter, and combining the monochromatic images to create a full colour image, wherein said illuminating radiation is provided in the form of a second array of incident light beams transmitted towards the portion along an optical path through said probing unit to generate illuminated spots on said portion along said depth direction, wherein said second array is defined within said reference frame. The second array is arranged to provide colour data at a plurality of spatial coordinates substantially corresponding to the spatial coordinates of said first array.

[0045] Alternatively, the operation of said imaging means is based on illuminating said portion with three differently- coloured illumination radiations, capturing a monochromatic image of said portion corresponding to each said illuminating radiation, and combining the monochromatic images to create a full colour image, wherein each said illuminating radiation is provided in the form of a second array of incident light beams transmitted towards the portion along an optical path through said probing unit to generate illuminated spots on said portion along said depth direction, wherein said second array is defined within said reference frame, and wherein said illuminating radiations are provided by said first illumination source. The second array is arranged to provide colour data at a plurality of spatial coordinates substantially corresponding to the spatial coordinates of said first array.

[0046] The device may further comprise a tri- colour sequence generator for controlling the illumination of said portion with said second illuminating radiations.

[0047] The device further comprises a processor coupled to said detector for conformally mapping colour data provided by said imaging means to said depth data provided by said scanning means for each said spatial coordinates of said first array to provide a colour three-dimensional numerical entity comprising a plurality of data points, each data point comprising three-dimensional surface coordinate data and colour data associated therewith. The device may also optionally comprise a unit for generating manufacturing data for transmission to CAD/CAM device based on said entity, and a communication port of a communication medium.

[0048] The device is adapted for determining colour and surface topology of a teeth portion, but may be used for determining colour and surface topology of any suitable surface.

[0049] The present invention is also directed to a method according to claim 30 for determining the surface topology and associated colour of at least a portion of a three dimensional structure, comprising:

(a) providing depth data of said portion corresponding to a two-dimensional reference array substantially orthogonal to a depth direction;
(b) providing two-dimensional image data of said portion associated with said reference array;
(c) ensuring that a spatial disposition with respect to said portion during steps (a) and (b) is substantially fixed;
(d) conformally mapping said colour data to said depth data for said reference array.

[0050] Preferably, in step (c), a minimum time interval is allowed between acquisition of said depth data and acquisition of said image data. The time interval may be between about 0 seconds to about 100 milliseconds, preferably between 0 and 50 milliseconds, and more preferably between 0 and 20 milliseconds.

[0051] In described embodiments, the depth data is provided using confocal imaging techniques. The method comprises :

(i) providing a first array of incident light beams defined within said reference array propagating in an optical path leading through a focusing optics and through a probing face; the focusing optics defining one or more focal planes forward said probing face in a position changeable by said optics, each light beam having its focus on one of said one or more focal plane; the beams generating a plurality of illuminated spots on the structure;
(ii) detecting intensity of returned light beams propagating from each of these spots along an optical path opposite to that of the incident light;
(iii) repeating steps (i) and (ii) a plurality of times, each time changing position of the focal plane relative to the structure;
(iv) for each of the illuminated spots, determining a spot-specific position, being the position of the respective focal plane yielding a maximum measured intensity of a respective returned light beam; and
(v) generating data representative of the topology of said portion.

[0052] Step (ii) may be based on illuminating said portion with at least three differently- coloured illumination radiations, said illumination radiations being combinable to produce white radiation, capturing a monochromatic image of said portion corresponding to each said illuminating radiation, and combining the monochromatic images to create a full colour image, wherein each said illuminating radiation is provided in the form of a second array of incident light beams transmitted towards the portion along an optical path through said probing unit to generate illuminated spots on said portion along said depth direction, wherein said second array is defined within said reference frame. The second array is arranged to provide colour data at a plurality of spatial coordinates substantially corresponding to the spatial coordinates of said first array.

[0053] Optionally, the sources for the at least three coloured illuminations may be located at the confocal system aperture stop, and facing the objective lens of the system. Preferably, the illumination sources are configured to have a relatively low numerical aperture compared with that of the first array of light beams. Further preferably, the confocal system is configured for chromatically dispersing said coloured illuminations therethrough.

[0054] Preferably, the method further comprises providing an improved focus 2D colour image of said structure, comprising:-

(I) sequentially illuminating the structure with each one of a plurality of illuminations, each said illumination having a different wavelength in the visible spectrum;
(II) providing a monochrome image of the structure when illuminated with each illumination in (I);
(III) manipulating image data obtained in (II) to provide a best focus composite image;
(IV) manipulating image data in (II) and (III) to provide a composite focused colour image of the structure.

[0055] Further preferably, the said sources for the coloured illuminations are moveable in the depth direction.

[0056] Optionally, the method of the invention further comprises the steps of:

polarizing the emitted coloured illuminations by means of a first polarizing element;
modifying the said polarized colour illuminations on the way to the structure and on their return therefrom by means of a quarter waveplate;
causing the returning colour illuminations to pass through a second polarizing element located just upstream of said first detector, wherein said second polarizing element is crossed with respect to the first polarizing element.

[0057] Step (ii) may be based on illuminating said portion with substantially white illumination radiation, selectively passing radiation reflected from said portion through a number of colour filters, capturing a monochromatic image of said portion corresponding to each said filter, and combining the monochromatic images to create a full colour image, wherein said illuminating radiation is provided in the form of a second array of incident light beams transmitted towards the portion along an optical path through said probing unit to generate illuminated spots on said portion along said depth direction, wherein said second array is defined within said reference frame. The second array is arranged to provide colour data at a plurality of spatial coordinates substantially corresponding to the spatial coordinates of said first array.

[0058] Step (ii) may be based on illuminating said portion with three differently-coloured illumination radiations, capturing a monochromatic image of said portion corresponding to each said illuminating radiation, and combining the monochromatic images to create a full colour image, wherein each said illuminating radiation is provided in the form of a second array of incident light beams transmitted towards the portion along an optical path through said probing unit to generate illuminated spots on said portion along said depth direction, wherein said second array is defined within said reference frame, and wherein said illuminating radiations are provided by said first illumination source. The second array is arranged to provide colour data at a plurality of spatial coordinates substantially corresponding to the spatial coordinates of said first array.

[0059] The data representative of said topology may be used for constructing an object to be fitted within said structure, or may be converted into a form transmissible through a communication medium to recipient. Typically, the structure is a teeth segment. The structure may be a teeth segment with at least one missing tooth or a portion of a tooth and said object is said at least one missing tooth or the portion of the tooth. Thus, for example, steps (i) to (v) may be repeated for two different surfaces of said structure to provide surface topologies thereof, and the surface topologies may then be combined to obtain colour and topological data representative of said structure.

[0060] The method of the invention, and also the operation of the device of the present invention, may be modified to take account of any possible relative movement between the device and the intra oral cavity, for example as follows:-

(a) providing depth data of said portion corresponding to a two-dimensional reference array substantially orthogonal to a depth direction;
(b) providing two-dimensional image data of said portion associated with said reference array;
(c) repeating step (a);
(d) for each image colour data point obtained in step (b), i.e., for each particular (x, y) point on the array for which a colour value was obtained in step (b), providing an estimated value for depth, based on the depth values obtained in steps (a) and (c) for the same part of the array, i.e. based on the Z-values obtained for the same (x, y) point in steps (a) and (c). The estimated value may be based on a simple arithmetic mean, on a weighted mean, or on any suitable empirical or theoretical formula, algorithm and so on.

[0061] Of course, step (a) may be repeated a number of times consecutively before step (b), and optionally also after step (b), the time intervals between each step being taken. In any case, for each point on the array (x, y), the values of depth Z may be plotted against elapsed time, for steps (a) (single or repeated), through step (b) and steps (c) (single or repeated), and the best estimate of the value of Z corresponding to the time interval when step (b) was carried out can be calculated, using, for example, any suitable interpolation or curve-fitting method.

[0062] Alternatively, the method of the invention, and thus the operation of the device of the present invention, may be modified to take account of any possible relative movement between the device and the intra oral cavity, for example as follows:

(a) providing two-dimensional image data of said portion associated with said reference array;
(b) providing depth data of said portion corresponding to a two-dimensional reference array substantially orthogonal to a depth direction;
(c) repeating step (a);
(d) for each depth data point obtained in step (b), i.e., for each particular (x, y) point on the array for which a depth value was obtained in step (b), providing an estimated value for colour, based on the colour values obtained in steps (a) and (c) for the same part of the array, i.e. based on the C-values obtained for the same (x, y) point in steps (a) and (c). The estimated value may be based on a simple arithmetic mean, on a weighted mean, or on any suitable empirical or theoretical formula, algorithm and so on.

[0063] Of course, step (a) may optionally be repeated a number of times consecutively before step (b), and optionally also after step (b), the time intervals between each step being taken. In any case, for each point on the array (x, y), the values of colour C may be plotted against elapsed time, for steps (a) (single or repeated), through step (b) and steps (c) (single or repeated), and the best estimate of the value of C corresponding to the time interval when step (b) was carried out can be calculated, using, for example, any suitable interpolation or curve-fitting method.

[0064] Optionally, the steps of providing colour values and depth values may be repeated in any sequence, for example in alternate sequence, and a suitable colour value may be associated with a corresponding depth value, similarly to the manner described above.

[0065] The invention also relates to a method for reconstruction of colour and topology of a three-dimensional structure comprising:

determining surface topologies from at least two different positions or angular locations relative to the structure, by the method of the invention described above;
combining the surface topologies to obtain colour and topological data representative of said structure.

[0066] The method may be applied to the reconstruction of topology of a teeth portion, and comprise the steps:

determining surface topologies of at least a buccal surface and a lingual surface of the teeth portion;
combining the surface topologies to obtain data representative of a three-dimensional structure of said teeth portion.

[0067] The method may be applied to obtaining data representative of a three-dimensional structure of a teeth portion with at least one missing tooth or a portion of a tooth.

[0068] The data may be used in a process of designing or manufacturing of a prostheses of said at least one missing tooth or a portion of a tooth. Such a prosthesis may be, for example, a crown, a bridge, a dental restoration or a dental filing.

BRIEF DESCRIPTION OF THE DRAWINGS

[0069] In order to understand the invention and to see how it may be carried out in practice, a number of embodiments will now be described, by way of non-limiting example only, with reference to the accompanying drawings, in which:

Fig. 1 illustrates the main elements of preferred embodiments of the invention.

Figs. 2A, 2B, 2C graphically illustrates the creation of a three dimensional colour entity from a three dimensional monochrome entity and a two dimensional colour entity.

Fig. 3 graphically illustrates an alignment procedure according to the invention for aligning the X-Y coordinates of a three dimensional monochrome entity with corresponding coordinates of a two dimensional colour entity.

Figs. 4A and 4B schematically illustrate the main elements of a portion of the invention used for providing a three dimensional monochrome entity.

Figs. 5A, 5B, 5C illustrate in plan view, side view and isometric view, respectively, a probe used in first embodiment of the invention to provide a two dimensional colour entity.

Fig. 6 illustrates in side view a sheath for a probe used in second embodiment of the invention to provide a two dimensional colour entity.

Fig. 7A illustrates in side view a probe used in third embodiment of the invention to provide a two dimensional colour entity. **Fig. 7B** illustrates the transmission and reflection characteristics of a typical dichroic coating used in the probe of Fig. 7A.

Fig. 8 illustrates in side view the general arrangement of the main elements used in fourth embodiment of the invention to provide a two dimensional colour entity.

Fig. 9 illustrates an LED arrangement used with the embodiment of Fig. 8.

Fig. 10 illustrates an alternative illumination arrangement used with the embodiment of Figure 8. Fig. 10A illustrates details of the tri- colour disc used with the illumination arrangement of Fig. 10.

Fig. 11 illustrates in side view the general arrangement of the main elements used in fifth embodiment of the invention to provide a two dimensional colour entity.

Fig. 12 illustrates in side view the general arrangement of the main elements used in sixth embodiment of the invention to provide a two dimensional colour entity.

Fig. 13 illustrates in side view the general arrangement of the main elements used in seventh embodiment of the invention to provide a two dimensional colour entity.

DETAILED DESCRIPTION

[0070] Reference is first being made to Fig. 1 which illustrates the general relationship between the various elements of the device of the invention, generally designated with the numeral **100,** according to the embodiments described herein.

[0071] The device **100** comprises a main illumination source **31** for illuminating the object of interest **26,** typically a part of the intraoral cavity, and is optically coupled to main optics **41** to provide depth **Z** values for an array range of **X-Y** points (according to a knoum frame of reference) along the surface of the object **26.** Detection optics 60 comprises an image sensor, typically a CCD, that is preferably monochromatic to maximise the resolution of the device, and which typically defines the X-Y frame of reference. Alternatively, the CCD may be adapted to receive colour images. The detection optics **60** receives image data from the main optics **41** and the image processor **24** determines the depth **Z** values for each **X-Y** point illuminated on the object **26** based on this image data. In this manner, a manipilable three-dimensional numerical entity **E** comprising the surface coordinates of the object **26.**

[0072] The device **100** further comprises colour illuminating means, such as for example a tri- colour sequence generator **74,** for selectively illuminating the object **26** with suitable colours, typically Green, Red and Blue, and for each such monochromatic illumination, a two dimensional image of the object **26** is captured by the detection optics **60.** The processor **24** then processes the three differently coloured monochromatic images and combines the same to provide a full colour 2D image of the object. The device **100** is configured for providing colour data for an array of X-Y points that is according to the same frame of reference as the X-Y array used for obtaining the 3D entity.

[0073] The processor **24** aligns the 2D colour image with the 3D entity previously created, and then provides colour values to this entity by mapping colour values to the entity at aligned **X-Y** points. Such alignment is straightforward because both the 3D data and the 2D colour data are treferenced to the same X-Y frame of reference. Referring to Figs. 2A, 2B, 2C, the mapping procedure is performed as follows. A three-dimensional numerical entity **E** is obtained by determining depth Z-values for a grid of **X-Y** points, illuminated via main optics **41** and determined by image processor **24.** The entity **E** thus comprises an array of (**X, Y, Z**) points, as illustrated in Fig. 2A. The **X-Y** plane of entity **E** is substantially parallel to the sensing face of the image sensing means of the detection optics **60,** typically a CCD. Almost concurrently, i.e., either just before or just after the readings for determining the 3D entity **E** are obtained by the detection optics **60,** a 2D colour image of the object **26** is taken using the same detection optics **60,** at substantially the same relative spatial disposition between the detection optics **60** and the object **26,** Fig. 2B. If a monochromatic CCD is used, the 2D colour image obtained is a composite created from three separate monochromatic images, each provided by illuminating the object **26** with a different colour, such as for example red, green and blue. The 2D colour image thus corresponds to another entity **N** comprised of the location and colour value of each pixel forming this image, **(X', Y', C).** The **X'-Y'** coordinates of the pixels are on a plane substantially parallel to the **X-Y** plane of the entity **E,** and furthermore these coordinates represent substantially the same part of the object **26** as the **X-Y** coordinates of entity **E.** The reason for this is that the optical information that is used for creating both the 3D entity **E** and the colour 2D entity **N** are obtained almost simultaneously with a very small time interval therebetween, and typically there is insufficient time for any significant relative movement between the image plane of the detection optics **60** and the object **26** to have occurred between the two scans. Thus, similar **X-Y** and **X'-Y'** coordinates in the entities **E** and **N,** resepectively, will substantially represent the same part of the object **26.** Accordingly, the colour value **C** of each pixel of entity **N** can be mapped to the data point of entity **E** having **X-Y** coordinates that are the same as the **X'-Y'** coordinates of the pixel, whereby to create another entity **I** comprising surface coordinate and colour data, **(X, Y, Z, C),** as illustrated in Fig. 2C.

[0074] Were the relative angle and disposition between the plane of the sensing face of the detection optics **60** with respect to the object **26** change significantly between the 2D and the 3D scans, then the **X-Y** coordinates of entity **E** having similar values to the **X'-Y'** coordinates of entity **N** could correspond to different parts of the object **26**, and thus it may then be difficult to map the colour values of entity **N** to entity **E**. However, if only a small movement between the detection optics **60** with respect to the object **26** occurs, particularly involving a relative translation or a rotation about the depth direction (Z), but substantially no change in the angular disposition between detection optics **60** and the object **26** about the **X** or **Y** axes, it may still be posible to map the colour values of entity **N** to entity **E,** but first an alignment procedure must be followed.

[0075] Referring to Fig. 3, such an alignment procedure may be based on optical character recognition (OCR) techniques. In the **X-Y** plane, the **X-Y** coordinates of entity **E** can be divided up into two groups, one group comprising **Z** values corresponding to the depth of the object, and a second group for which no reasonable **Z** value was found, and this group corresponds to the background relative to object **26.** The profiles of shapes represented by the **X-Y** coordinates of the first group of entity **E,** herein referred to as another entity **E',** are then optically compared with profiles of shapes corresponding to the **X'-Y'** coordinates of entity **N,** herein referred to as another entity **N'.** Accordingly, entity **E'** is translated or rotated (coplanarly) with respect to entity **N'** until a best fit between the optical shapes between the two entities is obtained, using OCR techniques that are well known in the art. Typically, the image processor, or another computer, will attempt to align the outer border of the object **26** as seen along the Z-axis and encoded in entity **E** with optical elements in the 2D colour image encoded in entity **N**. Thereafter, the colour value **C** of each **X'-Y'** coordinate of entity **N** is mapped to the appropriate data point of entity **E** having the aligned **X-Y** coordinates corresponding thereto. The colour mapping operation to create entity **I** may be executed by any suitable microprocessor means, typically processor **24** of the device **100** (Fig. 4B).

[0076] The main optics **41,** main illumination source **31,** detection optics **60** and image processor **24** are now described with reference to Figs. 4A and 4B which illustrate, by way of a block diagram an embodiment of a system **20** for confocal imaging of a three dimensional structure according to WO 00/08415 assigned to the present assignee, the contents of which are incorporated herein. Alternatively, any suitable confocal imaging arrangement may be used in the present invention.

[0077] The system **20** comprises an optical device **22** coupled to a processor **24.** Optical device **22** comprises, in this specific embodiment, a semiconductor laser unit **28** emitting a laser light, as represented by arrow **30.** The light passes through a polarizer **32** which gives rise to a certain polarization of the light passing through polarizer **32.** The light then enters into an optic expander **34** which improves the numerical aperture of the light beam **30.** The light beam **30** then passes through a module **38,** which may, for example, be a grating or a micro lens array which splits the parent beam **30** into a plurality of incident light beams **36,** represented here, for ease of illustration, by a single line. The operation principles of module **38** are known per se and the art and these principles will thus not be elaborated herein.

[0078] The optical device **22** further comprises a partially transparent mirror **40** having a small central aperture. It allows transfer of light from the laser source through the downstream optics, but reflects light travelling in the opposite direction. It should be noted that in principle, rather than a partially transparent mirror other optical components with a similar function may also be used, e.g. a beam splitter. The aperture in the mirror **40** improves the measurement accuracy of the apparatus. As a result of this mirror structure the light beams will yield a light annulus on the illuminated area of the imaged object as long as the area is not in focus; and the annulus will turn into a completely illuminated spot once in focus. This will ensure that a difference between the measured intensity when out-of- and in-focus will be larger. Another advantage of a mirror of this kind, as opposed to a beam splitter, is that in the case of the mirror internal reflections which occur in a beam splitter are avoided, and hence the signal-to-noise ratio improves.

[0079] The unit further comprises a confocal optics **42,** typically operating in a telecentric mode, a relay optics **44,** and an endoscopic probing member **46.** Elements **42, 44** and **46** are generally as known per se. It should however be noted that telecentric confocal optics avoids distance-introduced magnification changes and maintains the same magnification of the image over a wide range of distances in the **Z** direction (the **Z** direction being the direction of beam propagation). The relay optics enables to maintain a certain numerical aperture of the beam's propagation.

[0080] The endoscopic probing member **46** typically comprises a rigid, light-transmitting medium, which may be a hollow object defining within it a light transmission path or an object made of a light transmitting material, e.g. a glass body or tube. At its end, the endoscopic probe typically comprises a mirror of the kind ensuring a total internal reflection and which thus directs the incident light beams towards the teeth segment **26.** The endoscope **46** thus emits a plurality of incident light beams **48** impinging on to the surface of the teeth section.

[0081] Incident light beams **48** form an array of light beams arranged in an **X-Y** plane, in the Cartesian frame **50,** propagating along the **Z** axis. As the surface on which the incident light beams hits is an uneven surface, the illuminated spots **52** are displaced from one another along the **Z** axis, at different (X_i,Y_i) locations. Thus, while a spot at one location may be in focus of the optical element **42,** spots at other locations may be out-of-focus. Therefore, the light intensity of the returned light beams (see below) of the focused spots will be at its peak, while the light intensity at other spots will be off peak. Thus, for each illuminated spot, a plurality of measurements of light intensity are made at different positions along the Z-axis and for each of such (X_i,Y_i) location, typically the derivative of the intensity over distance (Z) will be made, the Z_i yielding maximum derivative, Z_0, will be the in-focus distance. As pointed out above, where, as a result of use of the punctured mirror **40,** the incident light forms a light disk on the surface when out of focus and a complete light spot only when in focus, the distance derivative will be larger when approaching in-focus position thus increasing accuracy of the measurement.

[0082] The light scattered from each of the light spots includes a beam travelling initially in the **Z**-axis along the opposite direction of the optical path traveled by the incident light beams. Each returned light beam **54** corresponds to one of the incident light beams **36.** Given the unsymmetrical properties of mirror **40,** the returned light beams are reflected in the direction of the detection optics **60.** The detection optics **60** comprises a polarizer **62** that has a plane of preferred polarization oriented normal to the plane polarization of polarizer **32.** The returned polarized light beam **54** pass through an imaging optic **64,** typically a lens or a plurality of lenses, and then through a matrix **66** comprising an array of pinholes. CCD camera has a matrix or sensing elements each representing a pixel of the image and each one corresponding to one pinhole in the array **66.**

[0083] The CCD camera is connected to the image-capturing module **80** of processor unit **24.** Thus, each light intensity measured in each of the sensing elements of the CCD camera is then grabbed and analyzed, in a manner to be described below, by processor **24.**

[0084] Unit **22** further comprises a control module **70** connected to a controlling operation of both semi-conducting laser **28** and a motor **72.** Motor **72** is linked to telecentric confocal optics **42** for changing the relative location of the focal plane of the optics **42** along the Z-axis. In a single sequence of operation, control unit **70** induces motor **72** to displace the optical element **42** to change the focal plane location and then, after receipt of a feedback that the location has changed, control module **70** will induce laser **28** to generate a light pulse. At the same time, it will synchronize image-capturing module **80** to grab data representative of the light intensity from each of the sensing elements. Then in subsequent sequences the focal plane will change in the same manner and the data capturing will continue over a wide focal range of optics **44.**

[0085] Image capturing module **80** is connected to a CPU **82,** which then determines the relative intensity in each pixel over the entire range of focal planes of optics **42, 44.** As explained above, once a certain light spot is in focus, the measured intensity will be maximal. Thus, by determining the Z_i corresponding to the maximal light intensity or by determining the maximum displacement derivative of the light intensity, for each pixel, the relative position of each light spot along the **Z**-axis can be determined. Thus, data representative of the three-dimensional pattern of a surface in the teeth segment, can be obtained. This three-dimensional representation may be displayed on a display **84** and manipulated for viewing, e.g. viewing from different angles, zooming-in or out, by the user control module **86** (typically a computer keyboard).

[0086] The device **100** further comprises means for providing a 2D colour image of the same object **26,** and any suitable technique may be used for providing the colour image. A number of such techniques are described below.

[0087] The first technique is based on illuminating the object **26** sequentially with three different coloured lights such as red, green and blue, and capturing a monochromatic image corresponding to each colour via CCD **68** and the image capture device **80** (see Figs. 4A, 4B). Referring to Fig. 1, tri- colour light sources **71,** i.e., one or more light sources that provide illuminating radiations to the object **26** in a plurality of different colours, are coupled to a tri- colour sequence generator **74,** which are suitably controlled by the processing unit **24** to provide the three coloured illuminations via delivery optics **73** in a predetermined sequence. The coloured illuminations are provided at a relative short time interval, typically in the range of about 0 to 100 milliseconds, in some cases being in the order of 50 milliseconds or 20 milliseconds, for example, with respect to the 3D scan, directly before or after the same. Suitable processing software **82** combines the three images to provide a 2D colour image comprising an array of data points having location **(X,Y)** and colour **(C)** information for each pixel of the 2D colour image.

[0088] According to a first embodiment of the device **100,** the delivery optics **73** is integral with endoscope **46,** which is in the form of a probing member **90,** as illustrated in Figs. 5A, 5B and 5C. The probing member **90** is made of a light transmissive material, typically glass and is composed of an anterior segment **91** and a posterior segment **92,** tightly glued together in an optically transmissive manner at **93.** Slanted face **94** is covered by a totally reflective mirror layer **95.** Glass disk 96 defining a sensing surface 97 may be disposed at the bottom in a manner leaving an air gap 98. The disk is fixed in position by a holding structure which is not shown. Three light rays are 99 from the main optics 42 are represented schematically. As can be seen, they bounce at the walls of the probing member at an angle in which the walls are totally reflective and finally bounce on mirror 95 and reflected from there out through the sensing face 97. The light rays focus on focusing plane 101, the position of which can be changed by the focusing optics (not shown in this figure). The probe member 90 comprises an interface 78 via which optical communication is established with the relay optics 44 and the remainder of the device 100. The probe 90 further comprises a plurality of tri- colour LED's 77, for providing the coloured illumination to the object **26.**

[0089] The LED's 77 typically comprise different LED's for providing blue radiation and green radiation when red illuminating radiation is used as the illumination source 31 for the main optics 41 when creating the 3D entity. Alternatively, if a blue illuminating radiation is used as the illumination source 31, the LED's 77 may comprise green and red LED's, and if a green illuminating radiation is used as the illumination source 31, LED's 77 may comprise blue and red LED's.

[0090] The tri- colour LED's 77 are each capable of providing an illumination radiation in one of three colours, typically red, green or blue, as controlled via the tri- colour sequence generator. Alternatively, a plurality of LED's in three groups, each group providing illumination in one of the desired colours, may be provided. The LED's 77 are located at the periphery of the interface 78 such that the LED's do not interfere with the other optical operations of the device 100. In particular such operations include the transmission of the illuminating radiation for the confocal focusing operations, and also the transmission of reflected light from the object **26** to the main optics **41** to provide the 3D entity or the 2D colour entity. The LED's are mounted substantially orthogonally with respect to the interface **78,** and thus, as illustrated in Fig. 5C, light from each of the LED's **77** is transmitted by internal reflection with respect to the walls of the probe **90,** to the user interface end **79** of the probe.

[0091] Preferably, the device **100** according to a variation of the first embodiment is further adapted for providing improved precision of the colour data obtained therewith, in a similar manner to that described herein for the fourth embodiment.

[0092] According to a second embodiment of the device **100,** the endoscope **46,** is also in the form of a probing member **90,** substantially as described with respect to the first embodiment, but with the difference that there are no LED's directly mounted thereon at the interface **78,**. In the second embodiment the delivery optics **73** is in the form of a disposable sleeve, shroud or sheath **190** that covers the outer surface the probing member **90,** as illustrated in Fig. 6. The sheath **190** is made from a waveguiding material, such as an acrylic polymer for example, capable of transmitting an illuminating radiation from the upstream face **191** of the sheath **190** therethrough and to the downstream face **192** thereto. The upstream face **191** is in the form of a peripheral surface around the interface **78.** The downstream face **192** is formed as a peripheral projection surrounding a window **193** comprised in said sheath **190.** The window **193** is in registry with the user interface end **79** of the probe **90.** A plurality of tri- colour LED's 177 for providing the coloured illumination to the object **26** are mounted on the device **100** just upstream of the sheath **190.** The tri-colour LED's **177** are each capable of providing an illumination radiation in one of three colours, typically red, green or blue, as controlled via the tri- colour sequence generator **74.** Alternatively, a plurality of LED's in three groups, each group providing one coloured illumination, may be provided. The LED's 177 are located outside of the main optics of the device **100,** and thus the LED's do not interfere with the other optical operations of the device **100** in particular including the transmission of the illuminating radiation for the confocal focusing operations, or in the transmission of reflected light from the object **26** to provide the 3D entity or the 2D colour entity. The LED's are mounted substantially opposite to the upstream face **191,** and thus, as illustrated in Fig. 6, light from each of the LED's **177** is transmitted by the waveguiding sheath **190** to downstream face **192** and thence to the object 26. In this embodiment, the sheath **190** is particularly useful in maintaining hygienic conditions between one patient and the next, and avoids the need for sterilizing the probe **90,** since the sheath may be discarded after being used with one patient, and replaced with another sterilised sheath before conducting an intra-oral cavity survey with the next patient.

[0093] Preferably, the device **100** according to a variation of the second embodiment is further adapted for providing improved precision of the colour data obtained therewith, in a similar manner to that described herein for the fourth embodiment.

[0094] In either one of the first or second embodiments, or variations thereof, a red laser may be used as the illumination source **28** for the main optics when creating the 3D entity. As such, this illumination means may also be used to obtain the red monochromatic image for the creation of the 2D colour image, by illuminating the object **26** and recording the image with the optical detector **60.** Accordingly, rather than tri- colour LED's or LED's or three different colours, it is only necessary to provide LED's adapted to provide only the remaining two colours, green and blue. A similar situation arises if the illumination source for the main optics **41** is a green or blue laser, wherein illuminating radiations in only the remaining two colours need to be provided.

[0095] In these embodiments, the positioning of the illumination sources at the upstream end of the probe **90** where there is ample room rather than at the patient interface end **79** where space is tight.

[0096] According to a third embodiment of the device **100,** the endoscope **46** is also in the form of a probing member **90,** substantially as described with respect to the second embodiment with the following differences. As illustrated in Fig. 7A, in the third embodiment the delivery optics **73** comprises a plurality of LED's **277** for providing the coloured illumination to the object **26.** In this embodiment, a red laser is used as the illumination source for the main optics when creating the 3D entity. As such, this illumination means is also used to obtain the red monochromatic image for the creation of the 2D colour image. Thus, the LED's **277** are each capable of providing an illumination radiation in either green or blue, as controlled via the tri- colour sequence generator **74.** The LED's **277** are located on the outer side of slanted face **94,** and thus the LED's do not interfere with the other optical operations of the device **100** in particular including the transmission of the illuminating radiation for the confocal focusing operations, or in the transmission of reflected light from the object **26** to provide the 3D entity or the 2D colour entity. The slanted face **94** comprises a dichroic coating **278** on the outer side thereof, which has relatively high reflectivity and low transmission properties with respect to red light, while having substantially high transmission characteristics for blue light and green light, as illustrated in Fig. 7B. Thus, as illustrated in Fig. 7A, light from each of the blue or green LED's **277** is transmitted, in turn, through the dichroic coating to interface **79** and thence to the object **26,** as controlled by the generator **74.** At the same time the dichroic coating permits internal reflection of the red radiation from the main optics **41** to the interface **79** and object **26,** and thus allows the 3D scan to be completed, as well as allowing the red monochromatic image of the object **26** to be taken by the device **100.** Optionally, rather than employing blue and green LED's, tri colour LED's may be used, and properly synchronized to illuminate with either green or blue light as controlled by generator **74.** Alternatively, the illumination source for the main optics **41** may be a green or blue laser, in which case the LED's are each capable of providing illumination in the remaining two colours, and in such cases the dichroic coating is adapted for allowing transmission of these remaining two colours while providing substantially high reflection for the illuminating laser of the main optics, in a similar manner to that described above for the red laser.

[0097] In a fourth embodiment of the device **100,** and referring to Fig. 8, tri-colour illumination is provided within the main focal optics **42,** in particular at the confocal system aperture stop, and facing the objective lens of the system. An advantage provided by this form of illumination is that the tri- colour illumination illuminates the object **26** through the downstream objective lens **142** in nearly collimated light, and thus the object illumination is highly uniform. The tri- colour light sources **377** may be mounted statically on the physical aperture stop at the aperture stop plane **150,** or alternatively they may be mounted on a retracting aperture stop, which also serves to stop down the system aperture in preview mode. In this embodiment, by placing the tri- colour light sources **377** at the aperture stop plane, wherein the light beam from the illumination source **31** narrows to a minimum within the main optics **41,** the external dimensions of the device 100 may still remain relatively compact.

[0098] Referring to Fig. 9, the tri- colour light sources **377** may comprise, for example, a plurality of tri- colour LED's **385** mounted onto a bracket **380.** The bracket **380** is typically annular, having a central aperture to allow illumination light from the illuminating unit **31** to pass therethrough and to the object **26,** and to allow light coming from the object **26** to pass therethrough and to the detection optics **60,** without being affected by the bracket **380.** At the same time, the bracket **380** positions the LED's in the required location upstream of objective lens **166.** The LED's are arranged in a spaced radial and circumferential manner as illustrated in Fig. 9 to provide the most uniform illumination of the object **26** possible with this arrangement. Typically, a red laser is used as the illumination source **31** for the main optics **41** when creating the 3D entity. As such, and as in other embodiments, this illumination means is also used to obtain the red monochromatic image for the creation of the 2D colour image. Thus, the LED's **385** are each capable of providing an illumination radiation in either green or blue, as controlled via the tri- colour sequence generator **74.** Alternatively, the illumination source for the main optics **41** may be a green or blue laser, in which case the LED's **385** are each capable of providing illumination in the remaining two colours, in a similar manner to that described above for the red laser, *mutatis mutandis*. Optionally, rather than employing blue and green LED's. tri colour LED's may be used, and properly synchronized to illuminate with either green or blue light as controlled by generator **74.** Further optionally, the LED's **385** may be used to provide, sequentially, all the required coloured illuminations, typically red, green and blue. Alternatively, the LED's **385** each provide illumination in one of at least three colours. Thus, some of the LED's **385** provide a blue illumination, while other LED's **385** provide green illumination, while yet other LED's **385** provide red illumination.

[0099] Preferably, the device **100** according to a variation of the fourth embodiment is further adapted for providing improved precision of the colour data obtained therewith. In this connection, the device **100** according to this variation of the fourth embodiment is adapted such that the tri- colour light sources **377** each illuminate the object **26** with as wide a depth of field as possible, i.e., at a low numerical aperture. Thus, each set of light sources **377** of the same colour, for example blue, illuminates a particular depth of the object **26** in the z-direction while substantially in focus. In contrast, the numerical aperture of the confocal system itself is relatively high to maximize accuracy of the depth measurements, and thus provides a relatively narrower depth of field.

[0100] Advantageously, the optical system downstream of the light sources **377,** in this embodiment the objective lens **166,** is chromatic, and in particular maximizes the chromatic dispersion therethrough. Alternatively or additionally, a chromatic dispersion element, for example an optically refractive block of suitable refractive index, may be provided along the optical path between the light sources **377** and the object **26.** Thus, each one of the different- coloured light sources **377** illuminates a different portion of the object **26** along the z-direction. The light sources **377** providing the blue illumination illuminate in focus a portion of the object **26** closest to the device **100,** and the light sources **377** providing the red illumination illuminate in focus a portion of the object **26** furthest from the device **100.** At the same time, the light sources **377** providing the green illumination illuminate in focus a portion of the object **26** intermediate the blue and red portions, and a non-illuminated gap may exists between the red and green, and between the green and blue illuminated portions, the depth of these gaps depending on the dispersion characteristics of the downstream optics. Advantageously, the light sources **377** are also adapted for providing illumination in colours intermediate in wavelengths such as to illuminate the aforesaid gaps in focus. Thus, the LED's **385** may be adapted for providing both such additional coloured illumination, or some of the LED's **385** may be adapted to provide coloured illumination at a first intermediate wavelength, while another set of LED's **385** may be adapted to provide coloured illumination at a second intermediate wavelength. For example, the first intermediate wavelength provides an illumination in aqua, and thus illuminates in focus at least a part of the gaps between the blue and green illuminated focused zones of the object **2**6, while the second intermediate wavelength provides an illumination in amber, and thus illuminates in focus at least a part the gaps between the green and red illuminated focused zones. Of course, additional light sources may be used to provide further intermediate wavelengths and thus provide further depth cover illumination, in focus, of the object.

[0101] While the device **100** is used as a viewfinder, typically prior to taking a depth and colour scan of the object **26,** the above arrangement using at least five different coloured illuminations at a low numerical aperture, enables a much clearer and focused real-time colour image of the object **26** to be obtained. Thus when in operation in viewfinder mode (also known as "aiming mode", prior to the 3D scan event, while the dental practitioner is in the process of aiming the scanner onto the target dental surface, for example) the device **100** according to this variation of the fourth embodiment repeatedly illuminates the object **26** in cycles, wherein in each cycle the object **26** is separately illuminated in each of the five colours blue, aqua, green, amber, red, in quick succession, and each time a monochromatic image is obtained by the monochromatic image sensor in 60. Each set of five monochromatic images is then analysed to provide a composite colour image, and this image is then displayed in substantially real time in the viewfinder display window in the control software, so that the succession of such composite images gives the appearance of a substantially real-time colour video feed of the object **26.**

[0102] Each of the monochrome images in any particular set corresponds to a particular illumination colour or wavelength, and thus the zone(s) of the object **26** within the depth of field corresponding to this illumination will be in focus, while the other parts of the object **26** will appear out of focus. Thus, each such image in the aforesaid set of images will contain a portion which has high precision focused image of a part of the object, for the particular illumination wavelength.

[0103] In forming a composite image for each set of images, the images are combined in such a way as to maximize the precision of the focused image and corresponding colour thereof. Thus, for example, suitable algorithms may be applied to each of the five images of a set to distinguish between the focused and unfocused the areas thereof. Such algorithms may employ, for example, techniques which apply FFT techniques to areas of the images, and which search for high frequency portions which correspond to focused areas. In any case, such algorithms, as well as software and hardware to accomplish the same are well known in the art. Then, the focused areas of each of the five images are merged to provide a monochrome composite substantially focused image of the object. Next, the images obtained using the red, green and blue illuminations are combined and converted to a corresponding luminescence/chroma (Y/C) image, and techniques for doing so are well known in the art. Finally, the luminescence component of the luminescence/chroma (Y/C) image is replaced with the aforesaid corresponding composite focus image, and the resulting new luminescence/chroma image is then transmitted to the display in the viewfinder.

[0104] For each set of images, prior to combining the corresponding red, green and blue images, these are preferably first scaled to compensate for magnification effects of the different wavelengths. Thus, the green image, and more so the blue image, needs to be scaled up to match the red image.

[0105] When the user is ready to take a depth and colour scan of the object 26, having steered the device **100** into position with the aid of the viewfinder, the device **100** takes a depth scan in the z-direction as described herein, and either before or after the same, but in quick succession one with the other, takes a colour scan in a similar manner to that described above for the viewfinder mode. Subsequently, the colour data and the depth data of the two scans can be combined to provide the full spatial and colour data for the surface scanned.

[0106] Advantageously, one or more colour scans may also be taken during the depth scan, and/or at the beginning and at the end of the depth scan. In one mode of operation, the depth scan is obtained by displacing the objective lends **166** along the z-direction in a continuous or stepped motion. Multiple colour scans can then be obtained by associating the colour sources **377** with the objective lens, so that these are also displaced along the z-direction. Accordingly, as the light sources **377** are moved in the z-direction towards the object **26** during the depth scan, at each different z-position in which a set of images is taken (concurrently with or alternately with the depth scan), each one of the coloured illuminations - red, green, blue and intermediate wavelengths - illuminates a progressively deeper part of the object along the z-direction. Of course, in some cases it is possible that at the downstream end of the depth scan the green and red illuminations completely overshoot the object **26,** and the corresponding images may be discarded or otherwise manipulated to provide a composite colour image at this station. Thus, a plurality of colour images can be obtained, each based on a different z-position, so that each illumination wavelength is used to illuminate in focus a different part (depth) of the object **26.** Advantageously, suitable algorithms may be used to form a composite colour image of the set of colour images associated with a particular z-scan of the object **26** to provide even more precise and accurate colour image, than can then be combined with the depth data.

[0107] Alternatively, and referring to Fig. 10, the tricolour light sources **377** may be replaced with a rotating filter illumination system **400.** The system **400** comprises a while light source **410,** such as for example white phosphorus InGaN LED's, and the light therefrom is focused onto an optical fiber bundle **420** by means of condenser optics **430.** Between the condenser optics **430** and the fiber bundle **420** is provided a rotating tri- colour filter **450.** As best seen in Fig. 10A, the filter **450** is divided into three coloured sections, comprising blue, green and red filters on adjacent sectors therein. The fiber bundle **420** is flared at the downstream end **470** to form the desired illumination pattern. Optionally, the downstream end **470** of the fibers may be mounted onto an annular bracket similar to bracket **380** illustrated in Fig. 9, at the aperture stop plane of the confocal optics. A suitable motor **460,** typically a stepper motor for example, drives the rotating filter such as to sequentially present each coloured filter to the light passing from the condenser optics **430** to the fiber bundle **420,** as synchronized with the sequence generator **74** (Fig. 1) to enable the detection optics **60** to capture images of the object 26 when selectively illuminated with each of the three colours. Optionally, if a red, blue or green illuminating radiation is used as the illumination source **31** for the main optics **41** when creating the 3D entity, then the rotating filter **450** only requires to comprise the remaining two colours, as discussed above for similar situations regarding the LED's.

[0108] Preferably, the device **100** according to this variation of the fourth embodiment may be further adapted for providing improved precision of the colour data obtained therewith, in a similar manner to that described herein for another variation of fourth embodiment. In particular, the filter **450** is divided into five (or more if desired) coloured sections, comprising blue, aqua, green, amber and red filters on adjacent sectors therein.

[0109] A fifth embodiment of system **100** is substantially similar to the fourth embodiment as described herein, with the following difference. In the fifth embodiment, and referring to Fig. 11, polarizers are provided at two locations in order to increase the image contrast. A first polarizing element **161** is located just downstream of the light sources **377** so as to polarize the light emitted from the light sources **377.** A second polarizing element **162** is located just upstream of the image sensor of the detection optics **60,** and is crossed with respect to the first polarizing element **161.** Further, a quarter waveplate **163** is provided just upstream of the object **26,** i.e. at the downstream end of the endoscope **46** (Fig. 4A). The first polarizing element **161** is typically annular, having a central aperture to allow illumination light from the illuminating unit **31** to pass therethrough and to the object, and to allow light coming from the object **26** to pass therethrough and to the detection optics **60,** without being affected by the polarizing element **161.** However, light that is reflected from the object **26** returns to the main confocal optics **42** in a crossed polarization state due to the effect of the quarter waveplate **163,** and thus reaches the detection optics **60** at substantially full intensity. However, any light reflected from the objective lens **166** of the confocal optics **42** is reflected at the same polarization state, and is therefore filtered out by the crossed polarizing element **162.** This arrangement serves as an effective signal to ghost enhancement system.

[0110] Preferably, the device **100** according to a variation of the fifth embodiment is further adapted for providing improved precision of the colour data obtained therewith, in a similar manner to that described herein for the fourth embodiment.

[0111] A sixth embodiment of the system **100** is substantially as described for the fourth embodiment, with the following difference. In the sixth embodiment, and referring to Fig. 12, the tri- colour light sources **377** are replaced with a rotating filter illumination system **500.** The system **500** comprises a while light source **510,** such as for example white phosphorus InGaN LED's, and the light therefrom is focused onto a mirror **520** by means of condenser optics **530.** Between the condenser optics **530** and the mirror **520** is provided a rotating tri- colour filter **550,** which is similar to the filter **450** illustrated in Fig. 11, and thus comprises three coloured sections, comprising blue, green and red filters on adjacent sectors therein, and is actuated by motor **560.** The optical axis **OA** of the confocal optics **41** is orthogonal to the optical axis **OA'** of the light source **510** and condenser optics **530.** The mirror **520** is mounted between the aperture stop plane and the objective lens **166** of the confocal optics, and at an angle to the optical axis **OA** thereof and to the optical axis **OA'** of the light source **510** and condenser optics **530.** The mirror **520** is typically annular, having a central aperture aligned with optical axis **OA** to allow illumination light from the illuminating unit **31** to pass therethrough and to the object **26,** and to allow light coming from the object **26** to pass therethrough and to the detection optics **60,** without being affected by the mirror **520.** At the same time, the mirror **520** has sufficient reflecting surface to reflect light from the source **510** via objective lens **166** and to the object **26.** Optionally, if a red, blue or green illuminating radiation is used as the illumination source **31** for the main optics **41** when creating the 3D entity, then the rotating filter **550** only requires the remaining two colours, as discussed above for similar situations.

[0112] Preferably, the device **100** according to a variation of the sixth embodiment is further adapted for providing improved precision of the colour data obtained therewith, in a similar manner to that described herein for the fourth embodiment.

[0113] According to a second technique for providing the aforesaid 2D colour image, the object **26** is illuminated with a white light, and a colour CCD is used for receiving the light reflected from the object **26.** Thus, a seventh embodiment of the system **100** comprises a white light illumination system **600,** illustrated in Fig. 13. The system **600** comprises a while light source **610,** such as for example white phosphorus InGaN LED's, and the light therefrom is directed onto a flip mirror **620** via a polarizing beam splitter **650** by means of condenser optics **630.** The optical axis **OA** of the confocal optics **41** is orthogonal to the optical axis **OA"** of the light source **610** and condenser optics **630.** The mirror **620** is mounted between the aperture stop plane **155** and the objective lens **166** of the confocal optics, and at an angle to the optical axis **OA** thereof and to the optical axis **OA"** of the light source **610** and condenser optics **630.**

[0114] The mirror **620** is adapted to flip away from optical axis **OA** when the device **100** is being used for obtaining the 3D entity E. This allows illumination light from the illuminating unit **31** to pass therethrough and to the object **26,** and to allow light coming from the object **26** to pass therethrough and to the detection optics **60**, without being affected by the mirror **620.** When it is desired to take a 2D colour image, the mirror **620** is flipped down to the position shown in Fig. 13. Polarizing beam splitter **650** that polarizes white light from the source **610** and allows the same to pass therethrough and to mirror **620,** and thence to the object **26** via the confocal objective **166** and broadband quarter wave plate **163.** Light that is reflected from the object **26** returns to the mirror **620** in a crossed polarization state due to the effect of the quarter waveplate **163,** and thus reaches the colour CCD **660** (and associated detection optics - not shown) at substantially full intensity. However, any light reflected from the objective lens **166** of the confocal optics **42** is reflected at the same polarization state, and is therefore filtered out by a crossed polarizing element **662** just upstream of the CCD **660.** This arrangement serves as an effective signal to ghost enhancement system.

[0115] Alternatively, the CCD of the detection optics **60** is a colour CCD and is also used for the 2D scan. In such a case, flipping mirror **620** is replaced with a fixed mirror having a central aperture similar to mirror **520,** having a central aperture, as described for the sixth embodiment, mutatis mutandis.

[0116] In the seventh embodiment, the image capture device **80** and processing software **82** (Fig. 4b) automatically provide a 2D colour image comprising an array of data points having location **(X,Y)** and colour **(C)** information for each pixel of the image.

[0117] According to a third technique for providing the 2D colour image, the object is illuminated with a white light, and the light reflected from the object **26** is passed sequentially through one of three different coloured filters such as red, green ad blue. Each time a monochromatic image corresponding to each colour is captured via CCD **68** and the image capture device **80** (see Figs. 4A, 4B). Suitable processing software **82** combines the three images to provide a 2D colour image comprising an array of data points having location **(X,Y)** and colour **(C)** information for each pixel of the image.

[0118] According to a fourth technique for providing the colour image, the main illumination source **31** of device **100** comprises suitable means for providing the three different coloured illuminations. In one embodiment, the illumination source **31** comprises three different lasers, each one providing an illumination radiation at a different desired colour, red green or blue. In another embodiment, a suitable white light illumination means is provided, coupled to a suitable rotating tri- colour filter, similar to the filters described above. In each case, suitable control means are provided, adapted to illuminate the object **26** with each coloured radiation in turn, and the 2D coloured image is obtained in a similar fashion to that described above. The object is also illuminated with one of the coloured illuminations in order to provide the 3D surface topology data.

[0119] In each of the embodiments described herein, the illumination radiation that is used for obtaining the 2D colour image is injected into the optical axis OA of the confocal optics **42** without affecting the operation thereof or degrading the 3D image capture.

[0120] The endoscope **46,** the illumination unit **31,** the main optics **41,** colour illumination **71** and tri- colour sequence genetrator are preferably included together in a unitary device, typically a hand-held device. The device preferably includes also the detector optics **60,** though the latter may be connected to the remainder of the device via a suitable optical link such as a fibre optics cable.

[0121] For all embodiments, the data representative of the surface topology and colour, i.e., entity **I,** may be transmitted through an appropriate data port, e.g. a modem **88** (Fig. 4B), through any communication network, e.g. telephone line **90,** to a recipient (not shown) e.g. to an off-site CAD/CAM apparatus (not shown).

[0122] By capturing, in this manner, an image from two or more angular locations around the structure, e.g. in the case of a teeth segment from the buccal direction, from the lingual direction and optionally from above the teeth, an accurate colour three-dimensional representation of the teeth segment may be reconstructed. This may allow a virtual reconstruction of the three-dimensional structure in a computerized environment or a physical reconstruction in a CAD/CAM apparatus.

[0123] While the present invention has been described in the context of a particular embodiment of an optical scanner that uses confocal focusing techniques for obtaining the 3D entity, the device may comprise any other confocal focusing arrangement, for example as described in WO 00/08415. In fact, any suitable means for providing 3D scanning can be used so long as the 3D scan and the colour 2D scan correspond substantially to the same object or portion thereof being scanned, and the same frames of references are maintained. Typically the scans are executed in relatively quick succession, and by the same or different image capturing means such as CCD's that are arranged such that the colour 2D image substantially corresponds to the 3D entity. This enables colour values at particular x, y coordinates of the 2D colour image to be matched to the same x, y coordinates of the 3D image which also have a z coordinate.

[0124] The embodiments illustrated herein are particularly useful for determining the three-dimensional structure of a teeth segment, particularly a teeth segment where at least one tooth or portion of tooth is missing for the purpose of generating data of such a segment for subsequent use in design or manufacture of a prosthesis of the missing at least one tooth or portion, e.g. a crown, or a bridge, or a dental restoration or a filing. It should however be noted, that the invention is not limited to this embodiment and applies also to a variety of other applications of imaging of three-dimensional structure of objects, e.g. for the recordal or archeological objects, for imaging of a three-dimensional structure of any of a variety of biological tissues, etc.

[0125] While there has been shown and disclosed exemplary embodiments in accordance with the invention, it will be appreciated that many changes may be made therein without departing from the claimed subject matter of the invention.

[0126] In the method claims that follow, alphabetic characters and Roman numerals used to designate claim steps are provided for convenience only and do not imply any particular order of performing the steps.

[0127] Finally, it should be noted that the word "comprising" as used throughout the appended claims is to be interpreted to mean "including but not limited to".

Claims

1. Device (100) for determining the surface topology and associated colour of at least a portion of a three dimensional structure, comprising:

scanning means for performing a three-dimensional scan and adapted for providing depth data of said portion, said depth data being in a Cartesian X, Y, Z frame depth Z values for an array range of X, Y points and corresponding to a two-dimensional reference array substantially orthogonal to a depth direction, wherein said operation of said scanning means is based on confocal imaging techniques, and wherein said scanning means comprises:

a probing member (90) with a sensing face (97);

first illumination means for providing a first array of incident light beams (48) transmitted towards the structure along an optical path through said probing member (90) and, arranged in an X, Y plane, propagating in the depth Z direction, along the Z axis, towards the structure to generate illuminated spots (52) on said portion at different X_i, Y_i locations along said depth direction, wherein said first array is defined within said reference array;

a light focusing optics (42) defining one or more focal planes forward said sensing face at a position changeable by said optics, each light beam having its focus on one of said one or more focal plane;

a translation mechanism for displacing said focal plane relative to the structure along said Z axis defined by the propagation of the incident light beams (48);

a first detector (68) having an array of sensing elements for measuring intensity of each of a plurality of light beams returning from said spots (54) propagating through an optical path opposite to that of the incident light beams (48);

a processor (82) coupled to said detector for determining for each light beam that generates a said spot, for each said X_i, Y_i location, a spot-specific position Z_i, being the position of the respective focal plane of said one or more focal planes yielding maximum measured intensity of the returned light beam (54), and based on the determined spot-specific positions, generating data representative of the topology of said portion as a three-dimensional numerical entity comprising an array of X, Y Z points;

characterised in that the device (100) further comprises imaging means adapted for providing, for an array of X, Y points two-dimensional colour image data of said portion associated with said reference array; said two-dimensional colour image data being taken at substantially the same angle and orientation with respect to the structure as was the case when the three-dimensional scan was taken, such that accordingly, each X, Y point on the two-dimensional colour image substantially corresponds to a similar point on the three-dimensional scan having the same relative X, Y values and accordingly, the same point of the structure being scanned has substantially the same X, Y coordinates in both the two-dimensional colour image and the three-dimensional scan, and thus the colour value at each X, Y coordinate of the two-dimensional colour scan may be mapped directly to the spatial coordinates in the three-dimensional scan having the same X, Y coordinates, wherein to create a numerical entity representing the colour and surface topology of the structure being scanned;
wherein the device (100) is adapted for maintaining a spatial disposition with respect to said portion that is substantially fixed during operation of said scanning means and said imaging means.

2. Device (100) according to claim 1, wherein said device (100) is adapted for providing a time interval between acquisition of said depth data and acquisition of said colour image data such that substantially no significant relative movement between said device and said portion occurs.

3. Device (100) according to claim 2, wherein said time interval is between about 0 seconds to about 100 milliseconds, preferably between 0 and 50 milliseconds, and more preferably between 0 and 20 milliseconds.

4. Device (100) according to claim 1, further comprising processing means for associating said colour data with said depth data for corresponding data points of said reference array.

5. Device (100) according to claim 1, wherein said first array is arranged to provide depth data at a plurality of predetermined spatial coordinates substantially corresponding to the spatial disposition of said incident light beams (48).

6. Device (100) according to claim 5, wherein said imaging means are configured to:

- illuminate said portion with three differently-coloured illumination radiations, the said illuminations being combinable to provide white light,
- capture a monochromatic image of said portion corresponding to each said illuminating radiation, and
- combine the monochromatic images to create a full colour image,

wherein each said illuminating radiation is provided in the form of a second array of incident light beams (48) transmitted towards the portion along an optical path through said probing unit to generate illuminated spots on said portion along said depth direction, wherein said second array is defined within said reference frame.

7. Device (100) according to claim 6, wherein said second array is arranged to provide colour data at a plurality of spatial coordinates substantially corresponding to the spatial coordinates of said first array.

8. Device (100) according to claim 7, comprising colour illumination means adapted for providing three second illuminating radiations, each of a different colour.

9. Device (100) according to claim 8, wherein said colour illumination means comprises any one of the following:

- second illumination means for providing said three second illuminating radiations, each of a different colour;
- second illumination means for providing two said second illuminating radiations, and wherein said first illumination means provides another said second illuminating radiation each said second illuminating radiation being of a different colour.

10. Device (100) according to claim 9, wherein said second illumination means comprise radiation transmission elements that are configured to be located out of the path of said light beams or said returned light beam at least within said light focusing optics.

11. Device (100) according to claim 10, wherein said probing member (90) is made from a light transmissive material having an upstream optical interface with said light focusing optics (42) and a reflective face for reflecting light between said optical interface and said sensing face (97).

12. Device (100) according to claim 11, wherein said second illumination means are optically coupled to said optical interface for selectively transmitting illuminating radiations in at least two colours to said portion via said sensing face (97).

13. Device (100) according to claim 11, wherein said colour illumination means comprises second illumination means for providing two said second illuminating radiations, and wherein said first illumination means provides another said second illuminating radiation each said second illuminating radiation being of a different colour.

14. Device (100) according to claim 13, wherein said probing member (90) comprises a removable sheath (190) having an inner surface substantially complementary to an outer surface of said probing member (90), and having a window (93) in registry with said sensing face (97), wherein said sheath (190) is made from a waveguiding material and is adapted to transmit said light from said second illuminating means from an upstream face (91) thereof to a downstream face (92) associated with said window (93).

15. Device (100) according to claim 14, wherein said second illumination means are optically coupled to said upstream face (91) for selectively transmitting said second illuminating radiations in at least two colours to said portion via said downstream face (92).

16. Device (100) according to claim 11, wherein said reflective face comprises a dichroic coating (278), having relatively high reflectivity and low optical transmission properties for a said second illuminating radiation provided by said first illumination means, and relatively low reflectivity and high optical transmission properties for the two said second illuminating radiations provided by said second illumination means.

17. Device (100) according to claim 10, wherein said second illumination means are adapted for providing second illuminating radiations within said light focusing optics (42).

18. Device (100) according to claim 17, wherein said second illumination means are adapted for providing second illuminating radiations at an aperture stop plane (150) of said light focusing optics (42).

19. Device (100) according to claim 17, further comprising:

- a first polarizing element (161) located just downstream of said illumination means so as to polarize the light emitted therefrom;
- a second polarizing element (162) located just upstream of said first detector, wherein said second polarizing element (162) is crossed with respect to the first polarizing element (161); and
- a quarter waveplate (163) at the downstream end of said device.

20. Device (100) according to claim 17, wherein said illumination means are adapted for selective movement in the depth direction.

21. Device (100) according to claim 17, comprising a mirror inclined to the optical axis of said light focusing optics (42), said mirror having an aperture configured to allow said light beams and said returning light beams to pass therethrough without being optically affected by said mirror, and wherein said second illumination means comprises at least one white illumination source optically coupled with suitable colour filters, said filters selectively providing illumination radiation in each colour in cooperation with said white illumination source, wherein said mirror is coupled to said white illumination source to direct radiation therefrom along said optical axis.

22. Device (100) according to claim 10, wherein said second illumination means are in the form of any one of the following :

- suitable LED's, comprising at least one LED for providing illumination radiation in each colour;
- suitable LED's, comprising at least one white illumination source optically coupled with suitable colour filters, said filters selectively providing illumination radiation in each colour in cooperation with said white illumination source.

23. Device (100) according to claim 8, wherein said first detector is adapted for selectively measuring intensity of each said second illuminating radiation after reflection from said portion.

24. Device (100) according to claim 5, wherein said imaging means is configured to operate based on any one of the following:

- illuminating said portion with substantially white illumination radiation, and capturing a colour image of said portion, wherein said white illuminating radiation is provided in the form of a second array of incident light beams (48) transmitted towards the portion along an optical path through said probing unit to generate illuminated spots on said portion along said depth direction, wherein said second array is defined within said reference frame;

- illuminating said portion with substantially white illumination radiation, selectively passing radiation reflected from said portion through a number of colour filters, capturing a monochromatic image of said portion corresponding to each said filter, and combining the monochromatic images to create a full colour image, wherein said illuminating radiation is provided in the form of a second array of incident light beams transmitted towards the portion along an optical path through said probing unit to generate illuminated spots on said portion along said depth direction, wherein said second array is defined within said reference frame;

- illuminating said portion with three differently-coloured illumination radiations, capturing a monochromatic image of said portion corresponding to each said illuminating radiation, and combining the monochromatic images to create a full colour image, wherein each said illuminating radiation is provided in the form of a second array of incident light beams transmitted towards the portion along an optical path through said probing unit to generate illuminated spots on said portion along said depth direction, wherein said second array is defined within said reference frame, and wherein said illuminating radiations are provided by said first illumination source.

25. Device (100) according to claim 24, wherein said second array is arranged to provide colour data at a plurality of spatial coordinates substantially corresponding to the spatial coordinates of said first array.

26. Device (100) according to claim 25, wherein said imaging means comprise:-

- white illumination radiation means;
- a second detector (660) having an array of sensing elements for measuring intensity of said white illuminating radiation after reflection from said portion.

27. Device (100) according to claim 8, further comprising a tri-colour sequence generator (74) for controlling the illumination of said portion with said second illuminating radiations.

28. Device (100) according to claim 27, further comprising at least one of

- a tri-colour sequence generator (74) for controlling the illumination of said portion with said second illuminating radiations;
- processor coupled to said first detector (68) for conformally mapping colour data provided by said imaging means to said depth data provided by said scanning means for each said spatial coordinates of said first array to provide a colour three-dimensional numerical entity comprising a plurality of data points, each data point comprising three-dimensional surface coordinate data and colour data associated therewith;
- a unit for generating manufacturing data based on said numerical entity for transmission to CAD/CAM device based on said entity
- a communication port of a communication medium.

29. Device (100) according to claim 28, adapted for determining colour and surface topology of a teeth portion.

30. Method for determining the surface topology and associated colour of at least a portion of a three dimensional structure, comprising;

(a) providing, in a three-dimensional scan, depth data of said portion, said depth data being in a Cartesian X, Y, Z frame depth Z values for an array range of X, Y points and corresponding to a two-dimensional reference array substantially orthogonal to a depth direction;

(b) providing two-dimensional colour image data of said portion associated with said reference array;

(c) ensuring that a spatial disposition with respect to said portion during steps (a) and (b) is substantially fixed;

(d) conformally mapping said colour data to said depth data for said reference array, wherein step (a) comprises:

(i) providing a first array of incident light beams (48) defined within said reference array propagating in an optical path leading through a focusing optics (42) and through a sensing face (97), and, arranged in an X, Y plane, propagating in the depth Z direction, along the Z axis, towards the structure; the focusing optics (42) defining one or more focal planes forward said sensing face in a position changeable by said optics, each light beam having its focus on one of said one or more focal plane; the beams generating a plurality of illuminated spots (52) on the structure at different X_i,Y_i locations;

(ii) detecting intensity of returned light beams (54) propagating from each of these spots along an optical path opposite to that of the incident light;

(iii) repeating steps (i) and (ii) a plurality of times, each time changing position of the focal plane relative to the structure along the Z axis;

(iv) for each of the illuminated spots, for each said X_i, Y_i location, determining a spot-specific position Z_i, being the position of the respective focal plane yielding a maximum measured intensity of a respective returned light beam; and

(v) generating, based on the determined spot-specific positions, data representative of the topology of said portion as a three-dimensional numerical entity comprising an array of X, Y, Z points, and

characterised in that step (b) comprises:

providing, for an array of X, Y points two-dimensional colour image data of said portion associated with said reference array; said two-dimensional colour image data being taken at substantially the same angle and orientation with respect to the structure as was the case when the three-dimensional scan was taken, such that accordingly, each X, Y point on the two-dimensional colour image substantially corresponds to a similar point on the three-dimensional scan having the same relative X, Y values and accordingly, the same point of the structure being scanned has substantially the same X, Y coordinates in both the two-dimensional colour image and the three-dimensional scan, and thus the colour value at each X, Y coordinate of the two-dimensional colour scan may be mapped directly to the spatial coordinates in the three-dimensional scan having the same X, Y coordinates, wherein to create a numerical entity representing the colour and surface topology of the structure being scanned.

31. Method according to claim 30, wherein in step (c), a minimum time interval is allowed between acquisition of said depth data and acquisition of said image data.

32. Method according to claim 31, wherein said time interval is between about 0 seconds to about 100 milliseconds, preferably between 0 and 50 milliseconds, and more preferably between 0 and 20 millisecondes.

33. Method according to claim 30, wherein said depth data is provided using confocal imaging techniques.

34. Method according to claim 30, wherein step (ii) is based on any one of the following:

(A) illuminating said portion with three differently-coloured illumination radiations, said illumination radiations being combinable to produce white radiation, capturing a monochromatic image of said portion corresponding to each said illuminating radiation, and combining the monochromatic images to create a full colour image, wherein each said illuminating radiation is provided in the form of a second array of incident light beams (48) transmitted towards the portion along an optical path through said probing unit to generate illuminated spots on said portion along said depth direction, wherein said second array is defined within said reference frame;

(B) illuminating said portion with substantially white illumination radiation, selectively passing radiation reflected from said portion through a number of colour filters, capturing a monochromatic image of said portion corresponding to each said filters, and combining the monochromatic images to create a full colour image, wherein said illuminating radiation is provided in the form of a second array of incident light beams transmitted towards the portion along an optical path through said probing unit to generate illuminated spots on said portion along said depth direction, wherein said second array is defined within said reference frame;

(C) illuminating said portion with three differently-coloured illumination radiations, capturing a monochromatic image of said portion corresponding to each said illuminating radiation, and combining the monochromatic images to create a full colour image, wherein each said illuminating radiation is provided in the form of a second array of incident light beams (48) transmitted towards the portion along an optical path through said probing unit to generate illuminated spots on said portion along said depth direction, wherein said second array is defined within said reference frame, and wherein said illuminating radiations are provided by said first illumination source.

35. Method according to claim 34, wherein said second array is arranged to provide colour data at a plurality of spatial coordinates substantially corresponding to the spatial coordinates of said first array.

36. Method according to claim 30, further comprising at least one of the following steps:-

(A1) using the virtual three-dimensional and colour model corresponding to said portion for constructing an object to be fitted within said structure;

(B1) converting the virtual three-dimensional and colour model corresponding to said portion into a form transmissible through a communication medium to recipient;

37. Method according to claim 36, wherein in step (A1) said structure is a teeth segment with at least one missing tooth or a portion of a tooth and said object is said at least one missing tooth or the portion of the tooth.

38. Method according to claim 30, comprising repeating steps (i) to (v) for two different surfaces of said structure to provide surface topologies thereof; and combining the surface topologies to obtain colour and topological data representative of said structure.

39. Method according to claim 37, for reconstruction of topology of a teeth portion, comprising:

determining surface topologies of at least a buccal surface and a lingual surface of the teeth portion;
combining the surface topologies to obtain data representative of a three-dimensional structure of said teeth portion.

Patentansprüche

1. Einrichtung (100) zum Bestimmen der Oberflächentopologie und assoziierter Farbe von zumindest einem Teil einer dreidimensionalen Struktur, umfassend:

Abtastmittel zur Durchführung einer dreidimensionalen Abtastung und dazu ausgelegt, Tiefendaten dieses Teils bereitzustellen, wobei die Tiefendaten in einem kartesischen X, Y, Z-Rahmen Z-Werte für einen Arraybereich von X,Y-Punkten sind und einem zweidimensionalen Referenzarray im Wesentlichen orthogonal zu einer Tiefenrichtung entsprechen, wobei der Vorgang der Abtastmittel auf konfokalen Bildformungstechniken beruht, und wobei die Abtastmittel Folgendes umfassen:

ein Sondenglied (90) mit einer Fühlseite (97);
erste Beleuchtungsmittel zur Bereitstellung eines ersten Arrays einfallender Lichtstrahlen (48), die in Richtung der Struktur entlang eines Lichtwegs durch das Sondenglied (90) übertragen werden und, in einer X,Y-Ebene angeordnet, sich in die Z-Tiefenrichtung entlang der Z-Achse in Richtung der Struktur ausbreiten, um beleuchtete Flecken (52) auf dem Teil an unterschiedlichen X_i, Y_i-Stellen entlang der Tiefenrichtung zu erzeugen, wobei das erste Array innerhalb des Referenzarrays definiert ist;
eine lichtfokussierende Optik, die eine oder mehr Brennebenen vor der Fühlfläche an einer von der Optik veränderbaren Position definiert, wobei jeder Lichtstrahl seinen Fokus auf einer der einen oder mehr Brennebenen hat;
einen Translationsmechanismus zum Verschieben der Brennebene relativ zur Struktur entlang der Z-Achse, die durch die Ausbreitung der einfallenden Lichtstrahlen (48) definiert wird;
einen ersten Detektor (68) mit einem Array Fühlelemente zur Messung der Intensität jedes mehrerer Lichtstrahlen, die von den Flecken (54) zurückkehren und sich durch einen Lichtweg ausbreiten, der dem der einfallenden Lichtstrahlen (48) gegenüber liegt;
ein Prozessor (82), der mit dem Detektor verbunden ist, zum Bestimmen für jeden Lichtstrahl, der einen besagten Fleck erzeugt, für jede X_i, Y_i-Stelle, eine fleckenspezifische Position Z_i, die die Position der jeweiligen Brennebene der einen oder mehr Brennebenen ist, die die gemessene Maximalintensität des zurückkehrenden Lichtstrahls (54) ergibt, und zum Erzeugen, aufgrund der bestimmten fleckenspezifischen Positionen, von Daten, die für die Topologie des Teils repräsentativ sind, als eine dreidimensionale numerische Entität, die ein Array von X, Y, Z-Punkten umfasst;

dadurch gekennzeichnet, dass die Einrichtung (100) weiterhin Folgendes umfasst:

ein Bildformungsmittel, das dazu ausgelegt ist, für ein Array von X, Y-Punkten zweidimensionale Farbbilddaten des zu dem Referenzarray gehörigen Teils bereitzustellen; wobei die zweidimensionalen Farbbilddaten unter dem im Wesentlichen gleichen Winkel und Orientierung hinsichtlich der Struktur genommen wurden, wie es der Fall war, als die dreidimensionale Abtastung vorgenommen wurde, so dass dementsprechend jeder X,Y-Punkt auf dem zweidimensionalen Farbbild im Wesentlichen einem ähnlichen Punkt auf dem dreidimensionalen Abtastbild mit den gleichen relativen X,Y-Werten entspricht, und dementsprechend der gleiche Punkt der abgetasteten Struktur im Wesentlichen die gleichen X,Y-

Koordinaten sowohl im zweidimensionalen Farbbild als auch im dreidimensionalen Abtastbild aufweist, und folglich der Farbwert jeder X,Y-Koordinate des zweidimensionalen Farbabtastbilds direkt auf die Raumkoordinaten im dreidimensionalen Abtastbild mit den gleichen X,Y-Koordinaten abgebildet wird, um darin eine numerische Entität, repräsentierend die Farbe und die abgetastete Oberflächentopologie der Struktur, zu erzeugen.
wobei die Einrichtung (100) dazu ausgelegt ist, eine räumliche Anordnung in Bezug auf den Teil beizubehalten, der im Wesentlichen während des Betriebs der Abtastmittel und der Bildformungsmittel festgelegt ist.

2. Einrichtung (100) nach Anspruch 1, wobei die Einrichtung (100) dazu ausgelegt ist, ein Zeitintervall zwischen der Erfassung der Tiefendaten und der Erfassung der Farbbilddaten bereitzustellen, so dass im Wesentlichen keine erhebliche Relativbewegung zwischen der Einrichtung und dem Teil auftritt.

3. Einrichtung (100) nach Anspruch 2, wobei das Zeitintervall zwischen ungefähr 0 Sekunden und ungefähr 100 Millisekunden, bevorzugt zwischen 0 und 50 Millisekunden und besonders bevorzugt zwischen 0 und 20 Millisekunden, liegt.

4. Einrichtung (100) nach Anspruch 1, weiterhin umfassend Verarbeitungsmittel zum Assoziieren der Farbdaten mit den Tiefendaten für entsprechende Datenpunkte des Referenzarrays.

5. Einrichtung (100) nach Anspruch 1, wobei das erste Array so angeordnet ist, um Tiefendaten an mehreren vorbestimmten Raumkoordinaten bereitzustellen, die im Wesentlichen der räumlichen Anordnung der einfallenden Lichtstrahlen (48) entsprechen.

6. Einrichtung (100) nach Anspruch 5, wobei die Bildformungsmittel dazu konfiguriert sind:

- den Teil mit drei Beleuchtungsstrahlungen mit unterschiedlichen Farben zu beleuchten, wobei die Beleuchtungen zu weißem Licht kombiniert werden können,
- entsprechend der Beleuchtungsstrahlungen ein monochromatisches Bild des Teils zu erfassen, und
- die monochromatischen Bilder zur Erzeugung eines Vollfarbbilds zu kombinieren,

wobei die Beleuchtungsstrahlungen in Form eines zweiten Arrays einfallender Lichtstrahlen (48) bereitgestellt werden, die in Richtung des Teils entlang einem Lichtweg durch die Sondeneinheit übertragen werden, um beleuchtete Flecken auf dem Teil entlang der Tiefenrichtung zu erzeugen, wobei das zweite Array innerhalb des Referenzarrays definiert ist.

7. Einrichtung (100) nach Anspruch 6, wobei das zweite Array angeordnet ist, um Farbdaten an mehreren Raumkoordinaten bereitzustellen, die im Wesentlichen den Raumkoordinaten des ersten Arrays entsprechen.

8. Einrichtung (100) nach Anspruch 7, umfassend Farbbeleuchtungsmittel, die dazu ausgelegt sind, drei zweite Beleuchtungsstrahlungen jeweils unterschiedlicher Farbe bereitzustellen.

9. Einrichtung (100) nach Anspruch 8, wobei die Farbbeleuchtungsmittel Folgendes umfassen:

- zweite Beleuchtungsmittel zum Bereitstellen der drei zweiten Beleuchtungsstrahlungen jeweils unterschiedlicher Farbe; oder
- zweite Beleuchtungsmittel zum Bereitstellen von zwei der zweiten Beleuchtungsstrahlungen, und wobei die ersten Beleuchtungsmittel eine weitere der zweiten Beleuchtungsstrahlungen bereitstellen, wobei jede der zweiten Beleuchtungsstrahlungen unterschiedlicher Farbe ist.

10. Einrichtung (100) nach Anspruch 9, wobei die zweiten Beleuchtungsmittel Strahlungsübertragungselemente umfassen, die dazu konfiguriert sind, zumindest innerhalb der lichtfokussierenden Optik außerhalb des Wegs der Lichtstrahlen oder des zurückkommenden Lichtstrahls zu liegen.

11. Einrichtung (100) nach Anspruch 10, wobei das Sondenglied (90) aus einem lichtdurchlässigen Material hergestellt ist, das eine vorgeordnete optische Grenzfläche mit der lichtfokussierenden Optik (42) und eine reflexive Fläche zum Reflektieren von Licht zwischen der optischen Grenzfläche und der Fühlseite (97) aufweist.

12. Einrichtung (100) nach Anspruch 11, wobei die zweiten Beleuchtungsmittel optisch mit der optischen Grenzfläche verbunden sind, um selektiv Beleuchtungsstrahlungen in mindestens zwei Farben zu dem Teil über die Fühlfläche (97) zu übertragen.

13. Einrichtung (100) nach Anspruch 11, wobei die Farbbeleuchtungsmittel zweite Beleuchtungsmittel zur Bereitstellung von zwei der zweiten Beleuchtungsstrahlungen umfassen, und wobei die ersten Beleuchtungsmittel eine weitere der zweiten Beleuchtungsstrahlungen bereitstellen, wobei jede der zweiten Beleuchtungsstrahlungen unterschiedlicher Farbe ist.

14. Einrichtung (100) nach Anspruch 13, wobei das Sondenglied (90) eine entfernbare Umhüllung (190) umfasst, die eine Innenfläche aufweist, die im Wesentlichen zu einer Außenfläche des Sondenglieds (90) komplementär ist, und ein Fenster (93) aufweist, das im Register mit der Fühlfläche (97) ist, wobei die Umhüllung (190) aus einem Wellenleitermaterial hergestellt ist und dazu ausgelegt ist, das Licht von den zweiten Beleuchtungsmitteln von einer vorgeordneten Fläche (91) davon an eine mit dem Fenster (93) assoziierte nachgeordnete Fläche (92) zu übertragen.

15. Einrichtung (100) nach Anspruch 14, wobei die zweiten Beleuchtungsmittel optisch mit der vorgeordneten Fläche (91) verbunden sind, um selektiv die zweiten Beleuchtungsstrahlungen in mindestens zwei Farben an den Teil über die nachgeordnete Fläche (92) zu übertragen.

16. Einrichtung (100) nach Anspruch 11, wobei die reflexive Fläche einen dichroitischen Überzug (278) umfasst, der eine relativ hohe Reflektivität und niedrige optische Transmissionseigenschaften für eine zweite Beleuchtungsstrahlung, die von den ersten Beleuchtungsmitteln bereitgestellt wird, und relativ niedrige Reflektivität und hohe optische Transmissionseigenschaften für die zwei zweiten Beleuchtungsstrahlungen aufweist, die von den zweiten Beleuchtungsmitteln bereitgestellt werden.

17. Einrichtung (100) nach Anspruch 10, wobei die zweiten Beleuchtungsmittel dazu ausgelegt sind, zweite Beleuchtungsstrahlungen innerhalb der lichtfokussierenden Optik (42) bereitzustellen.

18. Einrichtung (100) nach Anspruch 17, wobei die zweiten Beleuchtungsmittel dazu ausgelegt sind, zweite Beleuchtungsstrahlungen an einer Aperturenblendenebene (150) der lichtfokussierenden Optik (42) bereitzustellen.

19. Einrichtung (100) nach Anspruch 17, weiterhin Folgendes umfassend:

- ein erstes Polarisierungselement (161), das sich den Beleuchtungsmitteln gerade nachgeordnet befindet, um das davon emittierte Licht zu polarisieren;
- ein zweites Polarisierungselement (162), das sich dem ersten Detektor gerade vorgeordnet befindet, wobei das zweite Polarisierungselement (162) mit Bezug auf das erste Polarisierungselement (161) gekreuzt ist; und
- ein Viertelwellenlängenplättchen (163) am nachgeordneten Ende der Einrichtung.

20. Einrichtung (100) nach Anspruch 17, wobei die Beleuchtungsmittel für selektive Bewegung in die Tiefenrichtung ausgelegt sind.

21. Einrichtung (100) nach Anspruch 17, umfassend einen Spiegel, der zur optischen Achse der lichtfokussierenden Optik (42) geneigt ist, wobei der Spiegel eine Apertur aufweist, die dazu konfiguriert ist, die Lichtstrahlen und die zurückkommenden Lichtstrahlen **dadurch** laufen zu lassen, ohne optisch von dem Spiegel beeinträchtigt zu werden, und wobei die zweiten Beleuchtungsmittel mindestens eine weiße Beleuchtungsquelle umfassen, die optisch mit geeigneten Farbfiltern verbunden ist, wobei die Filter selektiv Beleuchtungsstrahlung in jeder Farbe in Zusammenarbeit mit der weißen Beleuchtungsquelle bereitstellen, wobei der Spiegel mit der weißen Beleuchtungsquelle verbunden ist, um Strahlung davon entlang der optischen Achse zu richten.

22. Einrichtung (100) nach Anspruch 10, wobei die zweiten Beleuchtungsmittel in Form eines der Folgenden vorliegen:

- geeignete LEDs, umfassend mindestens eine LED zur Bereitstellung von Beleuchtungsstrahlung in jeder Farbe; oder
- geeignete LEDs, umfassend mindestens eine weiße Beleuchtungsquelle, die optisch mit geeigneten Farbfiltern verbunden ist, wobei die Filter selektiv Beleuchtungsstrahlung in jeder Farbe in Zusammenarbeit mit der weißen Beleuchtungsquelle bereitstellen.

23. Einrichtung (100) nach Anspruch 8, wobei der erste Detektor dazu ausgelegt ist, selektiv die Intensität jeder der zweiten Beleuchtungsstrahlungen nach Reflexion von dem Teil zu messen.

24. Einrichtung (100) nach Anspruch 5, wobei die Bildformungsmittel dazu konfiguriert sind, aufgrund eines der Folgenden zu arbeiten:

- Beleuchten des Teils mit im Wesentlichen weißer Beleuchtungsstrahlung, und Erfassen eines Farbbilds des Teils, wobei die weiße Beleuchtungsstrahlung in Form eines zweiten Arrays einfallender Lichtstrahlen (48) bereitgestellt wird, die in Richtung des Teils entlang einem Lichtweg durch die Sondeneinheit übertragen werden, um beleuchtete Flecken auf dem Teil entlang der Tiefenrichtung zu erzeugen,

wobei das zweite Array innerhalb des Referenzrahmens definiert ist;

- Beleuchten des Teils mit im Wesentlichen weißer Beleuchtungsstrahlung, selektives Laufen von von dem Teil reflektierter Strahlung durch mehrere Farbfilter, Erfassen eines jeweils jedem Filter entsprechenden monochromatischen Bilds des Teils, und Kombinieren der monochromatischen Bilder, um ein Vollfarbbild zu erzeugen, wobei die Beleuchtungsstrahlung in Form eines zweiten Arrays einfallender Lichtstrahlen bereitgestellt wird, die in Richtung des Teils entlang einem Lichtweg durch die Sondeneinheit übertragen werden, um beleuchtete Flecken auf dem Teil entlang der Tiefenrichtung zu erzeugen, wobei das zweite Array innerhalb des Referenzrahmens definiert ist;
- Beleuchten des Teils mit drei Beleuchtungsstrahlungen unterschiedlicher Farbe, Erfassen eines jeweils jeder Beleuchtungsstrahlung entsprechenden monochromatischen Bilds des Teils, und Kombinieren der monochromatischen Bilder, um ein Vollfarbbild zu erzeugen, wobei die Beleuchtungsstrahlung jeweils in Form eines zweiten Arrays einfallender Lichtstrahlen bereitgestellt wird, die in Richtung des Teils entlang einem Lichtweg durch die Sondeneinheit übertragen werden, um beleuchtete Flekken auf dem Teil entlang der Tiefenrichtung zu erzeugen, wobei das zweite Array innerhalb des Referenzrahmens definiert ist, und wobei die Beleuchtungsstrahlungen von der ersten Beleuchtungsquelle bereitgestellt werden.

25. Einrichtung (100) nach Anspruch 24, wobei das zweite Array angeordnet ist, um Farbdaten an mehreren Raumkoordinaten bereitzustellen, die im Wesentlichen den Raumkoordinaten des ersten Arrays entsprechen.

26. Einrichtung (100) nach Anspruch 25, wobei die Bildformungsmittel Folgendes umfassen:

- weiße Beleuchtungsstrahlungsmittel;
- einen zweiten Detektor (660) mit einem Array von Fühlelementen zum Messen der Intensität der weißen Beleuchtungsstrahlung nach Reflexion von dem Teil.

27. Einrichtung (100) nach Anspruch 8, weiterhin umfassend einen Dreifarbensequenzgenerator (74) zum Steuern der Beleuchtung des Teils mit den zweiten Beleuchtungsstrahlungen.

28. Einrichtung (100) nach Anspruch 27, weiterhin umfassend:

- einen Dreifarbensequenzgenerator (74) zum Steuern der Beleuchtung des Teils mit den zweiten Beleuchtungsstrahlungen; und/oder
- Prozessor, der mit dem ersten Detektor (68) verbunden ist, um Farbdaten konform abzubilden, die von den Bildformungsmitteln bereitgestellt sind, auf die Tiefendaten, die von den Abtastmitteln für jede der Raumkoordinaten des ersten Arrays bereitgestellt sind, um eine farbige dreidimensionale numerische Entität bereitzustellen, die mehrere Datenpunkte umfasst, wobei jeder Datenpunkt dreidimensionale Oberflächenkoordinatendaten und damit assoziierte Farbdaten umfasst; und/oder
- eine Einheit zum Erzeugen von Herstellungsdaten aufgrund der numerischen Entität zur Übertragung an eine auf der Entität basierenden CAD/CAM-Einrichtung; und/oder
- einen Kommunikationsanschluss eines Kommunikationsmediums.

29. Einrichtung (100) nach Anspruch 28, zur Bestimmung von Farbe und Oberflächentopologie eines Zahnteils ausgelegt.

30. Verfahren zum Bestimmen der Oberflächentopologie und assoziierter Farbe von zumindest einem Teil einer dreidimensionalen Struktur, umfassend:

(a) Bereitstellen, in einer dreidimensionalen Abtastung, von Tiefendaten dieses Teils, wobei die Tiefendaten in einem kartesischen X,Y,Z-Rahmen Z-Werte für einen Arraybereich von X,Y-Punkten sind und einem zweidimensionalen Referenzarray im Wesentlichen orthogonal zu einer Tiefenrichtung entsprechen;
(b) Bereitstellen zweidimensionaler Farbbildformungsdaten des Teils, der mit dem Referenzarray assoziiert ist;
(c) Sicherstellen, dass eine räumliche Anordnung in Bezug auf den Teil während der Schritte (a) und (b) im Wesentlichen festgelegt ist;
(d) konformes Abbilden der Farbdaten auf die Tiefendaten für das Referenzarray, wobei Schritt (a) Folgendes umfasst:

(i) Bereitstellen eines ersten Arrays einfallender Lichtstrahlen (48), das innerhalb des Referenzarrays definiert ist, die sich in einem Lichtweg ausbreiten, der durch eine fokussierende Optik (42) und durch eine Fühlfläche (97) führt; und, in einer X,Y-Ebene angeordnet, sich in der Z-Tiefenrichtung ausbreiten, entlang der Z-Achse, in Richtung der Struktur; wobei die fokussierende Optik (42) eine oder mehr Brennebenen vor der Fühlfläche an einer von der Optik veränderbaren Position definiert, wobei jeder Lichtstrahl seinen Fokus auf einer der einen oder mehr Brennebenen hat; wobei die Strahlen mehrere beleuchtete Flecken (52) auf der Struktur an unterschiedlichen X_i, Y_i-Stellen erzeugen;

(ii) Detektieren der Intensität zurückkommender Lichtstrahlen (54), die sich von jedem dieser Flecken entlang einem Lichtweg gegenüber dem des einfallenden Lichts ausbreiten;

(iii) mehrfaches Wiederholen von Schritten (i) und (ii), wobei jedes Mal die Position der Brennebene relativ zur Struktur entlang der Z-Achse geändert wird;

(iv) für jeden der beleuchteten Flecken, für jede der X_i, Y_i-Stellen, Bestimmen einer fleckenspezifischen Position Z_i, die die Position der jeweiligen Brennebene ist, die die gemessene Maximalintensität des jeweiligen zurückkehrenden Lichtstrahls ergibt; und

(v) Erzeugen, aufgrund der bestimmten fleckenspezifischen Positionen, von Daten, die für die Topologie des Teils repräsentativ sind, als eine dreidimensionale numerische Entität, die ein Array von X,Y,Z-Punkten umfasst, und

dadurch gekennzeichnet, dass Schritt (b) Folgendes umfasst:

Bereitstellen, für ein Array von X,Y-Punkten, von zweidimensionalen Farbbilddaten des zu dem Referenzarray gehörigen Teils; wobei die zweidimensionalen Farbbilddaten unter dem im Wesentlichen gleichen Winkel und Orientierung hinsichtlich der Struktur aufgenommen wurden, wie es der Fall war, als die dreidimensionale Abtastung vorgenommen wurde, so dass dementsprechend jeder X,Y-Punkt auf dem zweidimensionalen Farbbild im Wesentlichen einem ähnlichen Punkt auf dem dreidimensionalen Abtastbild mit den gleichen relativen X,Y-Werten entspricht, und dementsprechend der gleiche Punkt der abgetasteten Struktur im Wesentlichen die gleichen X,Y-Koordinaten sowohl im zweidimensionalen Farbbild als auch im dreidimensionalen Abtastbild aufweist, und folglich der Farbwert jeder X,Y-Koordinate des zweidimensionalen Farbabtastbilds direkt auf die Raumkoordinaten im dreidimensionalen Abtastbild mit den gleichen X,Y-Koordinaten abgebildet werden kann, um darin eine numerische Entität, repräsentierend die Farbe und die abgetastete Oberflächentopologie der Struktur, zu erzeugen.

31. Verfahren nach Anspruch 30, wobei in Schritt (c) ein Mindestzeitintervall zwischen Erfassung von Tiefendaten und Erfassung von Bilddaten gestattet ist.

32. Verfahren nach Anspruch 31, wobei das Zeitintervall zwischen ungefähr 0 Sekunden und ungefähr 100 Millisekunden, bevorzugt zwischen 0 und 50 Millisekunden und besonders bevorzugt zwischen 0 und 20 Millisekunden, liegt.

33. Verfahren nach Anspruch 30, wobei die Tiefendaten mit Hilfe konfokaler Bildformungstechniken bereitgestellt werden.

34. Verfahren nach Anspruch 30, wobei Schritt (ii) auf Folgendem basiert:

(A) Beleuchten des Teils mit drei Beleuchtungsstrahlungen unterschiedlicher Farbe, wobei die Beleuchtungsstrahlungen zur Erzeugung weißer Strahlung kombiniert werden können, Erfassen eines jeweils jeder Beleuchtungsstrahlung entsprechenden monochromatischen Bilds des Teils, und Kombinieren der monochromatischen Bilder, um ein Vollfarbbild zu erzeugen, wobei die Beleuchtungsstrahlung jeweils in Form eines zweiten Arrays einfallender Lichtstrahlen (48) bereitgestellt wird, die in Richtung des Teils entlang einem Lichtweg durch die Sondeneinheit übertragen werden, um beleuchtete Flecken auf dem Teil entlang der Tiefenrichtung zu erzeugen, wobei das zweite Array innerhalb des Referenzrahmens definiert ist; oder

(B) Beleuchten des Teils mit im Wesentlichen weißer Beleuchtungsstrahlung, selektives Laufen von von dem Teil reflektierter Strahlung durch mehrere Farbfilter, Erfassen eines jeweils jedem Filter entsprechenden monochromatischen Bilds des Teils, und Kombinieren der monochromatischen Bilder, um ein Vollfarbbild zu erzeugen, wobei die Beleuchtungsstrahlung in Form eines zweiten Arrays einfallender Lichtstrahlen bereitgestellt wird, die in Richtung des Teils entlang einem Lichtweg durch die Sondeneinheit übertragen werden, um beleuchtete Flecken auf dem Teil entlang der Tiefenrichtung zu erzeugen, wobei das zweite Array innerhalb des Referenzrahmens definiert ist; oder

(C) Beleuchten des Teils mit drei Beleuchtungsstrahlungen unterschiedlicher Farbe,. Erfassen eines jeweils jeder Beleuchtungsstrahlung entsprechenden monochromatischen Bilds des Teils, und Kombinieren der monochromatischen Bilder, um ein Vollfarbbild zu erzeugen, wobei die Beleuchtungsstrahlung jeweils in Form eines zweiten Arrays einfallender Lichtstrahlen (48) bereitgestellt wird, die in Richtung des Teils entlang einem Lichtweg durch die Sondeneinheit übertragen werden, um beleuchtete Flecken auf dem Teil entlang der Tiefenrichtung zu erzeugen, wobei das zweite Array innerhalb des Referenzrahmens definiert ist, und wobei die Beleuchtungsstrahlungen von der ersten Beleuchtungsquelle bereitgestellt werden.

35. Verfahren nach Anspruch 34, wobei das zweite Array angeordnet ist, um Farbdaten an mehreren Raumkoordinaten bereitzustellen, die im Wesentlichen den Raumkoordinaten des ersten Arrays entsprechen.

36. Verfahren nach Anspruch 30, weiterhin die folgenden Schritte umfassend:

(A1) Verwendung des virtuellen dreidimensionalen und Farbmodells entsprechend dem Teil zum Konstruieren eines in die Struktur einzupassenden Objekts; und/oder
(B1) Umwandeln des virtuellen dreidimensionalen und Farbmodells entsprechend dem Teil in eine durch ein Kommunikationsmedium an einen Empfänger übertragbare Form.

37. Verfahren nach Anspruch 36, wobei in Schritt (A1) die Struktur ein Zahnsegment mit mindestens einem fehlenden Zahn oder ein Teil eines Zahns ist und das Objekt mindestens ein fehlender Zahn oder der Teil des Zahns ist.

38. Verfahren nach Anspruch 30, umfassend das Wiederholen der Schritte (i) bis (v) für zwei unterschiedliche Oberflächen der Struktur, um Oberflächentopologien davon bereitzustellen; und Kombinieren der Oberflächentopologien, um Farb- und topologische Daten zu erhalten, die für die Struktur repräsentativ sind.

39. Verfahren nach Anspruch 37, zur Rekonstruierung der Topologie eines Zahnteils, umfassend:

Bestimmen von Oberflächentopologien mindestens einer bukkalen Oberfläche und einer lingualen Oberfläche des Zahnteils;
Kombinieren der Oberflächentopologien, um Daten zu erhalten, die für eine dreidimensionale Struktur des Zahnteils repräsentativ sind.

Revendications

1. Dispositif (100) pour déterminer la topologie de surface et la couleur associée à au moins une partie d'une structure tridimensionnelle comprenant :

- un moyen de balayage pour effectuer un balayage tridimensionnel et ce moyen est adapté pour fournir des données de profondeur de cette partie, les données de profondeur étant des valeurs de profondeur Z en coordonnées cartésiennes X, Y, Z pour une répartition de X, Y points et correspondant à une répartition de référence bidimensionnelle pratiquement orthogonale à la direction de profondeur, le fonctionnement du moyen de balayage étant fondé sur des techniques d'imagerie confocales et le moyen de balayage comprend :
- un élément d'essai (90) avec une face de détection (97),
- un premier moyen d'illumination pour fournir un premier réseau de faisceaux de lumière incidente (48) transmis à la structure suivant un chemin optique à travers l'élément d'essai (90) et réparti dans un plan X, Y, se propageant dans la direction de la profondeur Z le long de l'axe Z en direction de la structure pour générer des points éclairés (52) sur la partie en différents endroits X_i Y_i suivant la direction de la profondeur, le premier réseau étant défini dans le réseau de référence;
- des optiques de focalisation de lumière (42) pour définir un ou plusieurs plans focaux vers la face de détection dans une position modifiable par les moyens optiques, chaque faisceau lumineux ayant son foyer dans l'un ou dans plusieurs plans focaux,
- un mécanisme de translation pour déplacer le plan focal par rapport à la structure suivant l'axe Z défini par la propagation des faisceaux de lumière incidente (48),
- un premier détecteur (68) ayant un réseau d'éléments de détection pour mesurer l'intensité de chacun des ensembles des faisceaux lumineux renvoyés par les points (54) et elle est fose propageant à travers le chemin optique opposé à celui des faisceaux lumineux incidents (48),
- un processeur (82) couplé au détecteur déterminé pour chaque faisceau lumineux qui génère le point, pour chacune des positions X_i, Y_i, une position spécifique au point Z_i étant la position du plan focal respectif parmi un ou plusieurs plans focaux donnant la mesure d'intensité maximale du faisceau de lumière renvoyée (54) et elle est fondée sur les positions déterminées spécifiques des points, générant des données représentant la topologie de cette partie comme entité numérique tridimensionnelle comprenant un réseau de points X, Y, Z,

caractérisé en ce que
le dispositif (100) comprend en outre,
un moyen d'imagerie permettant de fournir pour chaque réseau de, points X, Y, des données d'image couleur en deux dimensions de la partie associée au réseau de référence; les données d'image couleur en deux dimensions étant prises pratiquement suivant le même angle et la même orientation par rapport à la structure comme si cela eut été le cas s'il y avait eu un balayage tridimensionnel de sorte

qu'ainsi, chaque point X, Y, de l'image couleur à deux dimensions correspond pratiquement à un point similaire du balayage tridimensionnel ayant les mêmes valeurs relatives X, Y et ainsi le même point de la structure balayée a pratiquement les mêmes coordonnées X, Y à la fois dans l'image couleur bidimensionnelle et dans le balayage tridimensionnel et ainsi les valeurs de couleur de chaque coordonnée X, Y du balayage couleur bidimen-sionnel peuvent être associées sur une carte, directement aux coordonnées spatiales dans le balayage tridimensionnel ayant les mêmes coordonnées X, Y pour créer une entité numérique représentant la couleur et la topologie de surface de la structure à scanner,
le dispositif (100) étant adapté pour maintenir une disposition spatiale par rapport à cette partie qui est pratiquement fixe pendant le fonctionnement du moyen de balayage et du moyen d'imagerie.

2. Dispositif (100) selon la revendication 1, dans lequel
le dispositif (100) est adapté pour fournir un intervalle de temps entre l'acquisition des données de profondeur et l'acquisition des données d'image en couleur de façon à n'avoir pratiquement pas de mouvement relatif significatif entre le dispositif et cette partie.

3. Dispositif (100) selon la revendication 2, selon lequel
l'intervalle de temps est compris entre 0 seconde et environ 100 millisecondes et de préférence entre 0 et 50 millisecondes et d'une manière encore plus préférentielle, entre 0 et 20 millisecondes.

4. Dispositif (100) selon la revendication 1, comprenant en outre un moyen de traitement pour associer les données de couleur aux données de profondeur pour les points de données correspondants du réseau de référence.

5. Dispositif (100) selon la revendication 1, selon lequel
le premier réseau est conçu pour fournir une donnée de profondeur en un ensemble de coordonnées spatiales prédéterminées, correspondant pratiquement à la disposition spatiale des faisceaux lumineux incidents (48)

6. Dispositif (100) selon la revendication 5, selon lequel
les moyens d'imagerie sont configurés de façon à :

- éclairer la partie avec un faisceau d'éclairage en trois couleurs différentes, les éclairages pouvant être combinés pour donner de la lumière blanche,
- saisir d'une image monochromatique de la partie correspondant à chacun des rayonnements d'éclairage, et
- combiner des images monochromatiques pour créer une image couleur pleine,

chaque radiation d'illumination se présentant sous la forme d'un second réseau de faisceaux lumineux incidents (48) transmis vers la partie suivant un chemin optique traversant l'élément d'essai pour générer des points éclairés sur la partie dans la direction de la profondeur, le second réseau étant défini dans la trame de référence.

7. Dispositif (100) selon la revendication 6, dans lequel
le second réseau est prévu pour fournir des données de couleur pour un ensemble de coordonnées spatiales correspondant pratiquement aux coordonnées spatiales du premier réseau.

8. Dispositif (100) selon la revendication 7, comprenant des moyens d'illumination en couleur adaptés pour fournir trois secondes radiations d'illumination, chacune d'une couleur différente.

9. Dispositif (100) selon la revendication 8, dans lequel
le moyen d'illumination en couleur comprend l'un des moyens suivants:

- des seconds moyens d'illumination pour fournir trois secondes radiations d'illumination chacune d'une couleur différente,
- des seconds moyens d'illumination pour fournir deux des secondes radiations d'illumination, et le premier moyen d'illumination fournit une autre seconde radiation d'illumination, chaque seconde radiation d'illumination étant de couleur différente.

10. Dispositif (100) selon la revendication 9, selon lequel
les seconds moyens d'illumination comprennent même des moyens de transmission de radiation configurés pour être situés en dehors du chemin des faisceaux lumineux ou du faisceau lumineux renvoyé au moins dans les optiques de focalisation de lumière.

11. Dispositif (100) selon la revendication 10, selon lequel
l'élément d'essai (90) est en une matière transmettant la lumière ayant en amont une interface optique avec les optiques de focalisation de lumière (42) et une face réfléchissante pour réfléchir la lumière entre l'interface optique et la face de détection (97).

12. Dispositif (100) selon la revendication 11, selon lequel
les seconds moyens d'illumination sont couplés op-

tiquement à l'interface optique pour transmettre sélectivement des radiations d'illumination dans au moins deux couleurs de la partie par l'intermédiaire de la face de détection (97).

13. Dispositif (100) selon la revendication 11, selon lequel les moyens d'illumination en couleur comprennent des seconds moyens d'illumination pour fournir deux secondes radiations d'illumination, et les premiers moyens d'illumination fournissent une autre seconde radiation d'illumination, chacune de ces secondes radiations d'illumination étant de couleur différente.

14. Dispositif (100) selon la revendication 13, selon lequel l'élément d'essai (90) comporte une gaine amovible (190) ayant une surface intérieure pratiquement complémentaire à la surface extérieure de l'élément (90) et une fenêtre (93) correspondant à la face de détection (97), la gaine (190) étant en une matière guide d'onde et elle est adaptée à transmettre la lumière du second moyen d'illumination à partir de la face amont (91) vers la face aval (92) associée à cette fenêtre (93).

15. Dispositif (100) selon la revendication 14, selon lequel les seconds moyens d'illumination sont couplés optiquement à la face amont (91) pour transmettre sélectivement les secondes radiations d'illumination dans au moins deux couleurs à la partie par l'intermédiaire de la face aval (92).

16. Dispositif (100) selon la revendication 11, selon lequel la face réfléchissante comporte un revêtement dichroïque (278) ayant des propriétés de réflectivité relativement élevées et des propriétés de transmission optique faibles pour une seconde radiation d'illumination fournie par le premier moyen d'illumination et des propriétés de réflectivité relativement faibles et des propriétés de transmission optique élevées pour les secondes radiations d'illumination fournies par le second moyen d'illumination.

17. Dispositif (100) selon la revendication 10, selon lequel les seconds moyens d'illumination sont adaptés pour fournir des secondes radiations d'illumination dans les optiques de focalisation de lumière (42).

18. Dispositif (100) selon la revendication 17, selon lequel les seconds moyens d'illumination sont conçus pour fournir des secondes radiations d'illumination dans un plan d'arrêt d'ouverture (150) des optiques de focalisation (42).

19. Dispositif (100) selon la revendication 17, comprenant en outre :

- un premier élément de polarisation (161) situé directement en aval du moyen d'illumination de façon à polariser la lumière qu'il émet,
- un second élément de polarisation (162) situé directement en amont du premier détecteur, le second élément de polarisation (162) étant croisé par rapport au premier élément de polarisation (161), et
- une plaque quart d'onde (163) à l'extrémité aval du dispositif.

20. Dispositif (100) selon la revendication 17, selon lequel les moyens d'illumination sont destinés à un mouvement sélectif dans la direction de la profondeur.

21. Dispositif (100) selon la revendication 17, comprenant un miroir incliné par rapport à l'axe optique des optiques de focalisation de lumière (42), le miroir ayant une ouverture configurée pour autoriser les faisceaux lumineux et les faisceaux lumineux de retour à le traverser sans être influencés optiquement par le miroir et les seconds moyens d'illumination comprennent au moins une source d'illumination blanche couplée optiquement à des filtres couleurs appropriés, ces filtres fournissant sélectivement une radiation d'illumination pour chaque couleur en coopération avec la source d'illumination blanche, le miroir étant couplé à la source d'illumination blanche pour diriger sa radiation suivant l'axe optique.

22. Dispositif (100) selon la revendication 10, selon lequel les seconds moyens d'illumination ont l'une des formes suivantes :

- des diodes LED appropriées comprenant au moins une diode LED pour générer le rayonnement d'illumination dans chaque couleur,
- des diodes LED appropriées comportant au moins une source d'éclairage blanche couplée optiquement à des filtres couleur appropriés, ces filtres fournissant sélectivement la radiation d'illumination dans chaque couleur en coopération avec la source d'illumination blanche.

23. Dispositif (100) selon la revendication 8, selon lequel le premier détecteur permet de mesurer sélectivement l'intensité de chaque seconde radiation d'illumination après réflexion par cette partie.

24. Dispositif (100) selon la revendication 5,

selon lequel
le moyen d'imagerie est configuré de façon à travailler seulement en fonction de l'un des éléments suivants :

- illumination de la partie avec une radiation d'illumination pratiquement blanche et saisie d'une image en couleur de cette partie, la radiation d'illumination blanche étant faite sous la forme, d'un second réseau de faisceaux lumineux incidents (48) transmis vers la partie suivant un chemin optique traversant l'unité d'échantillon pour générer des points éclairés sur la partie le long de la direction de profondeur, le second réseau étant défini dans une trame de référence;
- illumination de la partie avec une radiation d'illumination pratiquement blanche, passage sélectif de la radiation réfléchie par la partie à travers un certain nombre de filtres couleur, saisie d'une image monochromatique de la partie correspondant à chacun des filtres et combinaison des images monochromatiques pour créer une image en couleur pleine, la radiation d'illumination se présentant sous la forme d'un second réseau de faisceaux lumineux incidents transmis vers la partie le long d'un chemin optique traversant l'élément d'essai pour générer des points illuminés sur cette partie suivant la direction de profondeur, le second réseau étant défini dans la trame de référence;
- illumination de la partie avec trois radiations d'illumination de couleurs différentes, saisie d'une image monochromatique de la partie correspondant à chacune des radiations d'illumination et combinaison des images monochromatiques pour créer une image en couleur pleine, chaque radiation d'illumination se présentant sous la forme d'un second réseau de faisceaux de lumière incidente transmis vers la partie le long d'un chemin optique traversant l'unité d'échantillon pour générer des points illuminés sur cette partie le long de la direction de profondeur, le second réseau étant défini dans la trame de référence et les radiations d'illumination étant assurées par la première source d'illumination.

25. Dispositif (100) selon la revendication 24,
selon lequel
le second réseau est prévu pour fournir des données de couleur à un ensemble de coordonnées spatiales correspondant pratiquement aux coordonnées spatiales du premier réseau.

26. Dispositif (100) selon la revendication 25,
selon lequel
les moyens d'imagerie comprennent :

- des moyens de radiation d'illumination,
- un second détecteur (660) comportant un réseau d'éléments de détection pour mesurer l'intensité de la radiation d'illumination blanche après réflexion par la partie.

27. Dispositif (100) selon la revendication 18, comprenant en outre un générateur (74) de séquence en trois couleurs pour commander l'illumination de la partie avec les secondes radiations d'illumination.

28. Dispositif (100) selon la revendication 27, comprenant en outre au moins l'un des moyens suivants :

- un générateur séquentiel trichrome (74) pour commander l'illumination de la partie avec des secondes radiations d'illumination,
- un processeur couplé au premier détecteur (68) pour réaliser la carte des données couleurs conformes, fournie par le moyen d'imagerie pour les données de profondeur résultant du moyen de balayage de chaque coordonnée spatiale du premier réseau pour avoir une entité numérique tridimensionnelle en couleur, formée d'un ensemble de points de données, chaque point de données ayant des données de coordonnées de surface tridimensionnelles et des données de couleurs associées,
- une unité pour générer des données de fabrication fondées sur l'entité numérique pour la transmission vers le dispositif CAD/CAM fondé sur cette entité,
- un port de communication pour un milieu de communication.

29. Dispositif (100) selon la revendication 28, adapté pour déterminer la couleur et la topologie de surface d'une portion de dent.

30. Procédé pour déterminer la topologie de surface et la couleur associée sur au moins une partie de la structure tridimensionnelle comprenant les étapes suivantes :

(a) fourniture par un balayage tridimensionnel de données de profondeur de la partie, ces données de profondeur étant des valeurs de profondeur Z dans un système de coordonnées cartésiennes X, Y, Z, pour un réseau de points X, Y et correspondant à un réseau de référence à deux dimensions pratiquement orthogonales à la direction correspondant à la profondeur,
(b) fourniture de données d'images couleurs en deux dimensions de la partie associée au réseau de référence,
(c) s'assurer qu'une disposition spatiale par rapport à la partie au cours des étapes (a) et (b) est pratiquement fixe,
(d) faire une carte conforme des données cou-

leurs de cette donnée de profondeur pour le réseau de référence, l'étape (a) comprenant :

(i) la fourniture d'un premier réseau de faisceaux lumineux incidents (48) définis dans le réseau de référence et se développant dans un chemin optique conduisant à des moyens optiques de focalisation (42) et à travers une face de détection (97); disposition dans un plan X, Y, propagation dans la direction de profondeur Z, suivant l'axe Z vers la structure; les moyens optiques de focalisation (42) définissant un ou plusieurs plans focaux vers la face de détection dans une position que les moyens optiques peuvent modifier, chaque faisceau lumineux ayant son foyer dans l'un ou plusieurs plans focaux; les faisceaux générant un ensemble de points éclairés (52) sur la structure en différents endroits X_i, Y_i ;
(ii) détection de l'intensité des faisceaux lumineux renvoyés (54) se propageant à partir de chacun des points suivant un chemin optique opposé à celui de la lumière incidente;
(iii) répétition des étapes (i) et (ii) un ensemble de fois, chaque fois en changeant la position du plan focal par rapport à la structure suivant l'axe Z;
(iv) pour chacun des points illuminés, pour chacune des positions X_i, Yi, on détermine une position spécifique de points Z_i qui est la position du plan focal respectif donnant l'intensité maximale mesurée du faisceau lumineux respectif renvoyé, et
(v) on génère en fonction des positions spécifiques de points déterminés, les données représentant la topologie de cette partie d'une entité numérique tridimensionnelle comprenant un réseau de X, Y, Z points, et

caractérisé en ce que
l'étape (b) comprend :

la fourniture pour un réseau de X, Y points de données image en couleur à deux dimensions de la partie associées aux réseaux de référence, ces données image en couleur, en deux dimensions étant prises sensiblement suivant le même angle et la même orientation par rapport à la structure que s'il s'agissait d'un balayage en trois dimensions de sorte que chaque point X, Y dans l'image couleur à deux dimensions correspond pratiquement à un point similaire d'un balayage en trois dimensions ayant les mêmes valeurs X, Y relatives et en conséquence le même point de la structure est balayé comme ayant pratiquement les mêmes coordonnées X, Y à la fois dans le balayage de l'image couleur à deux dimensions et de l'image couleur à trois dimensions et ainsi la valeur de couleur de chaque coordonnée X, Y du balayage couleur à deux dimensions peut être tracée sur une carte directement pour les coordonnées spatiales dans le balayage tridimensionnel ayant les mêmes coordonnées X, Y, pour créer une entité numérique représentant la couleur et la topologie de surface de la structure balayée.

31. Procédé selon la revendication 30,
selon lequel
dans l'étape (c), un intervalle de temps minimum est autorisé entre l'acquisition des données de profondeur et l'acquisition des données d'image.

32. Procédé selon la revendication 31,
selon lequel
l'intervalle de temps est compris entre 0 seconde et environ 100 millisecondes et de préférence entre 0 et 50 millisecondes et encore d'une manière préférentielle entre 0 et 20 millisecondes.

33. Procédé selon la revendication 30,
selon lequel
les données de profondeur sont obtenues en utilisant des techniques d'imagerie confocales.

34. Procédé selon la revendication 30,
selon lequel
l'étape (ii) est fondée sur l'un quelconque des points suivants :

(A) illumination de la partie avec des radiations d'illumination par trois couleurs différentes, ces radiations d'illumination pouvant être combinées pour donner une radiation blanche, on saisit une image monochromatique de la partie correspondant à chaque radiation d'illumination et on combine les images monochromatiques pour créer une image en couleur pleine, chacune des radiation d'illumination étant prévue sous la forme d'un second réseau de faisceaux de lumière incidente (48) transmis vers la partie suivant un chemin optique traversant l'unité d'échantillon pour générer des points éclairés sur la partie suivant la direction de profondeur, le second réseau étant défini dans la trame de référence.
(B) on illumine cette partie avec une radiation d'illumination pratiquement blanche, on fait passer sélectivement la radiation réfléchie par la partie à travers un certain nombre de filtres couleurs, on saisit une image monochromatique de la partie correspondant à chaque filtre et on combine les images monochromatiques pour créer une image couleur complète, la radiation d'illumination étant fournie sous la forme d'un

second réseau de faisceaux lumineux incidents transmis vers la partie suivant un chemin optique traversant l'élément d'essai pour générer des points illuminés sur la partie suivant la direction de profondeur, le second réseau étant défini dans cette trame de référence;
(C) on illumine la partie avec des radiations d'illumination de trois couleurs différentes, on saisit une image monochromatique de la partie correspondant à chacune des radiations d'illumination et on combine les images monochromatiques pour créer une image couleur complète,

chaque radiation d'illumination se présentant sous la forme d'un second réseau de faisceaux de lumière incidente (48) transmis vers la partie suivant un chemin optique traversant l'élément d'essai pour générer des points illuminés sur la partie le long de la direction de profondeur, le second réseau étant défini dans la trame de référence et les radiations d'illumination étant fournies par la source d'illumination.

35. Procédé selon la revendication 34,
selon lequel
il est prévu un second réseau pour fournir des données couleurs à un ensemble de coordonnées spatiales correspondant pratiquement aux coordonnées spatiales du premier réseau.

36. Procédé selon la revendication 30, comprenant en outre au moins l'un des étapes suivantes :

(A1) on utilise le modèle couleur tridimensionnel virtuel correspondant à la partie pour construire un objet qui s'adapte dans la structure,
(B1) on convertit l'image tridimensionnelle virtuelle et le modèle couleur correspondant à cette partie en une forme transmissible à travers un milieu de communication vers le récepteur.

37. Procédé selon la revendication 36,
selon lequel
dans l'étape (A1) la structure est un segment avec des dents et au moins une dent manquante ou une partie de dent manquante et l'objet est cette dent manquante ou la partie de la dent.

38. Procédé selon la revendication 30, comprenant la répétition des étapes (i) jusqu'à (v) pour deux surfaces différentes de la structure pour avoir des topologies de surface et on combine les topologies de surface pour obtenir des données de couleur et de topologie représentant la structure

39. Procédé selon la revendication 37, pour reconstruire la topologie d'une partie de dent comprenant les opérations suivantes :

- on détermine les topologies de surface d'au moins une surface buccale et d'une surface linguale de la partie de dent,
- on combine les topologies de surface pour obtenir des données représentant la structure tridimensionnelle de la partie de dent.

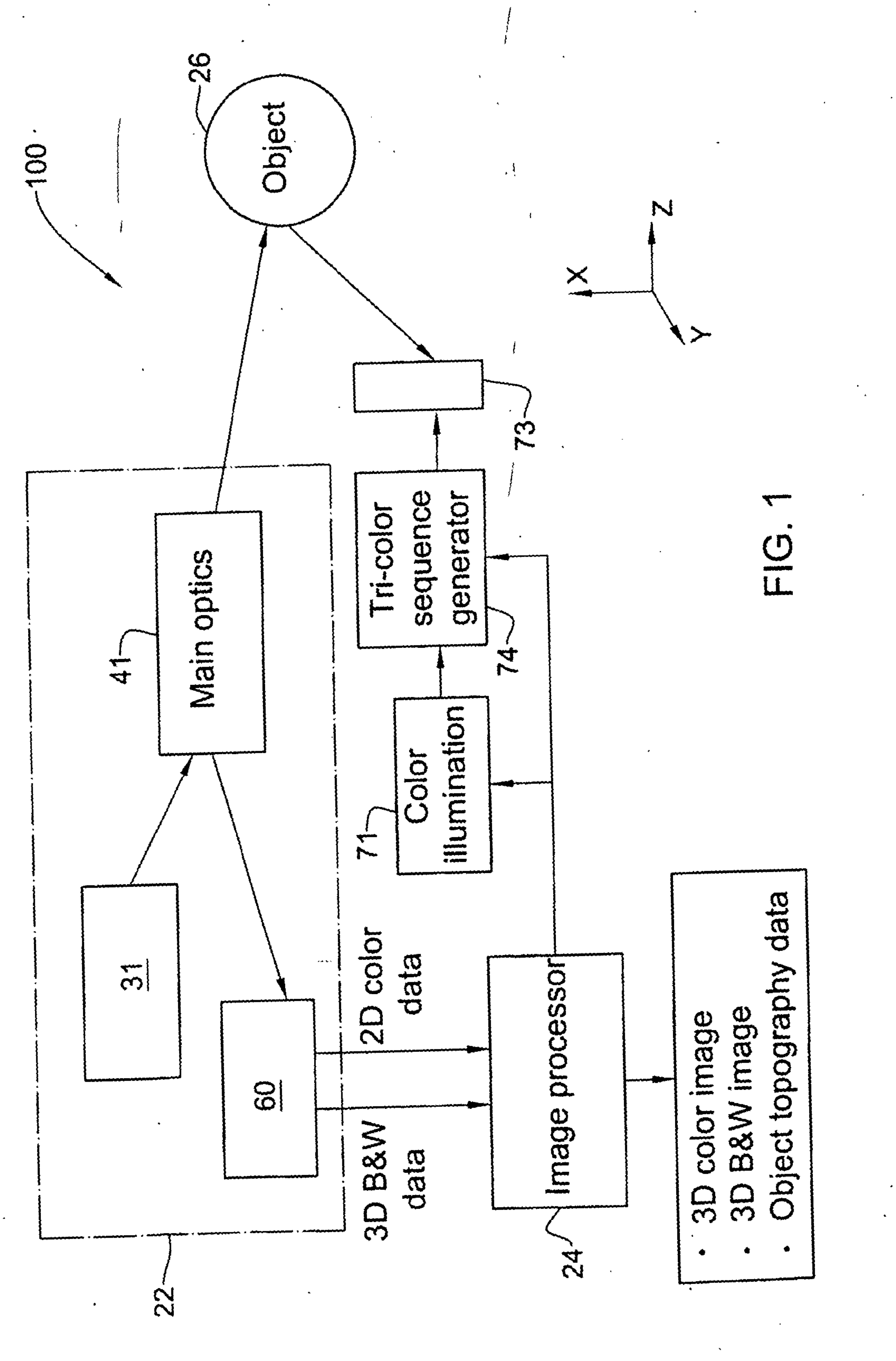
100
26
Object
Z
X
Y
22
41
Main optics
31
60
73
Tri-color sequence generator
74
71
Color illumination
2D color data
3D B&W data
Image processor
24
· 3D color image
· 3D B&W image
· Object topography data

FIG. 1

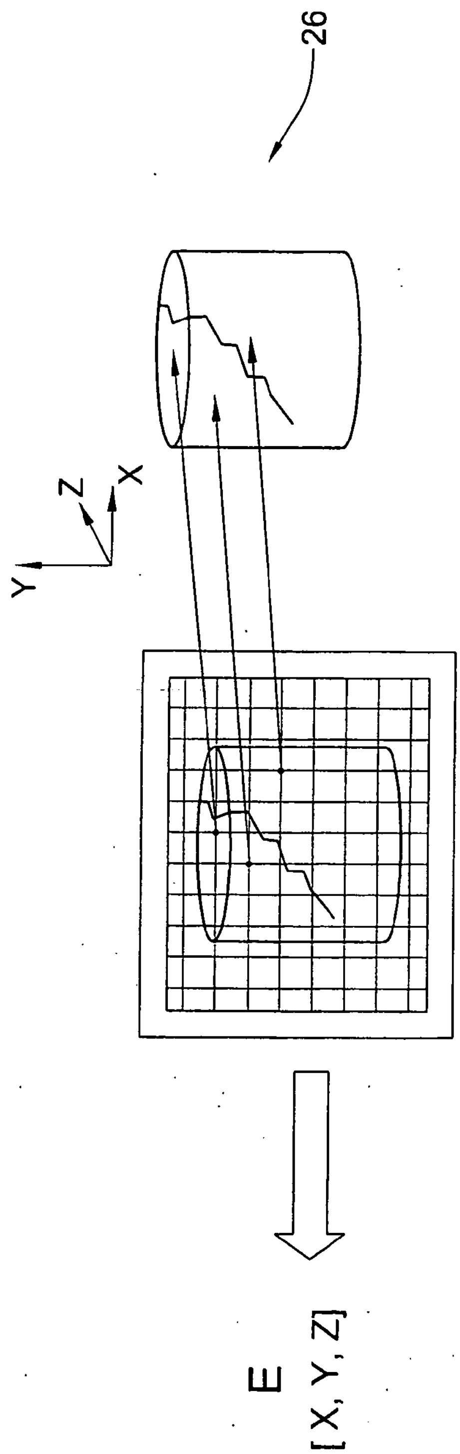

FIG. 2A

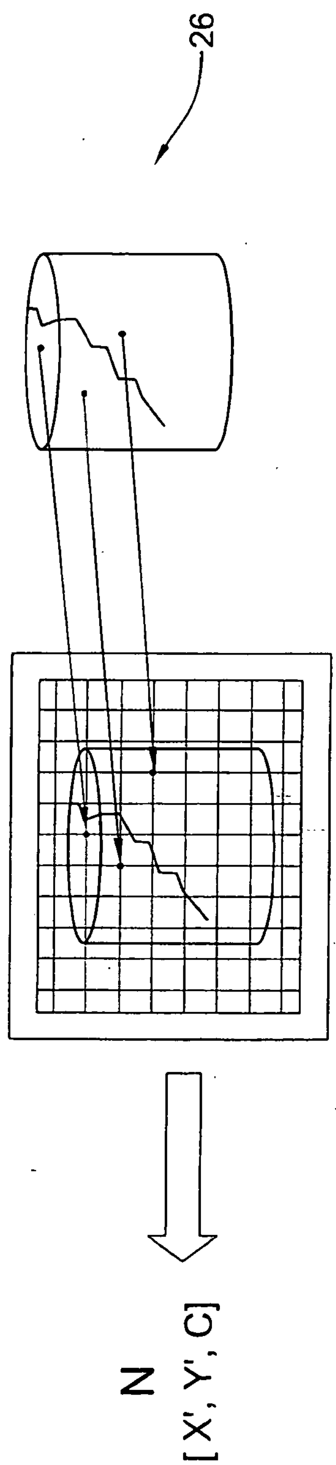

FIG. 2B

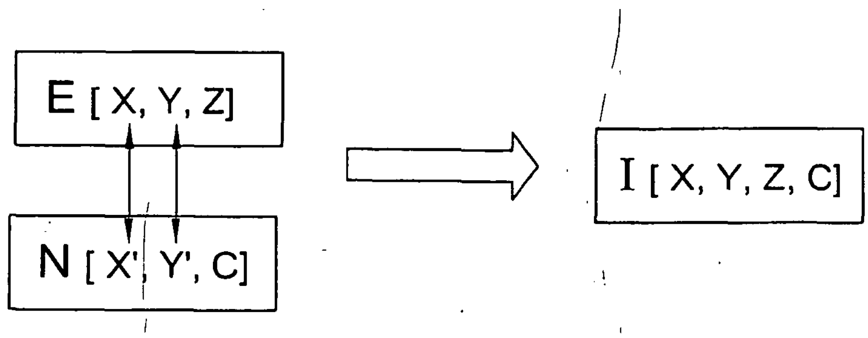

FIG. 2C

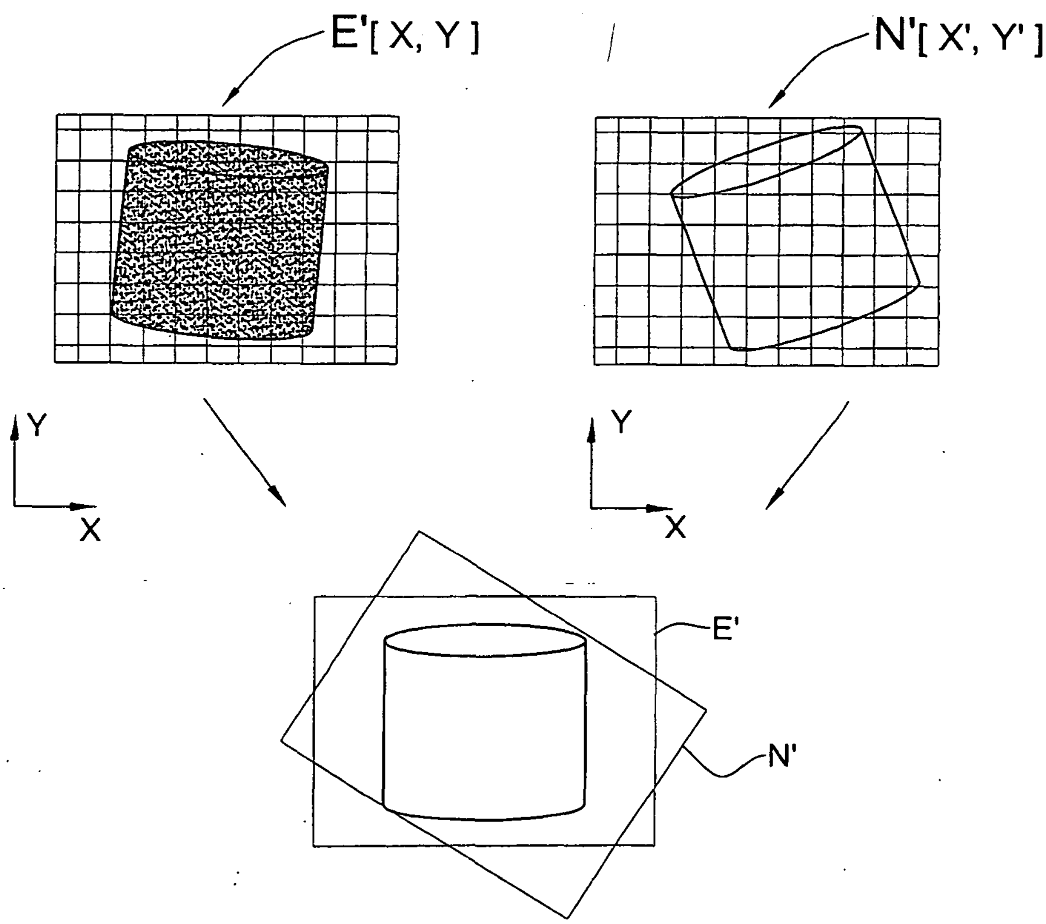

FIG. 3

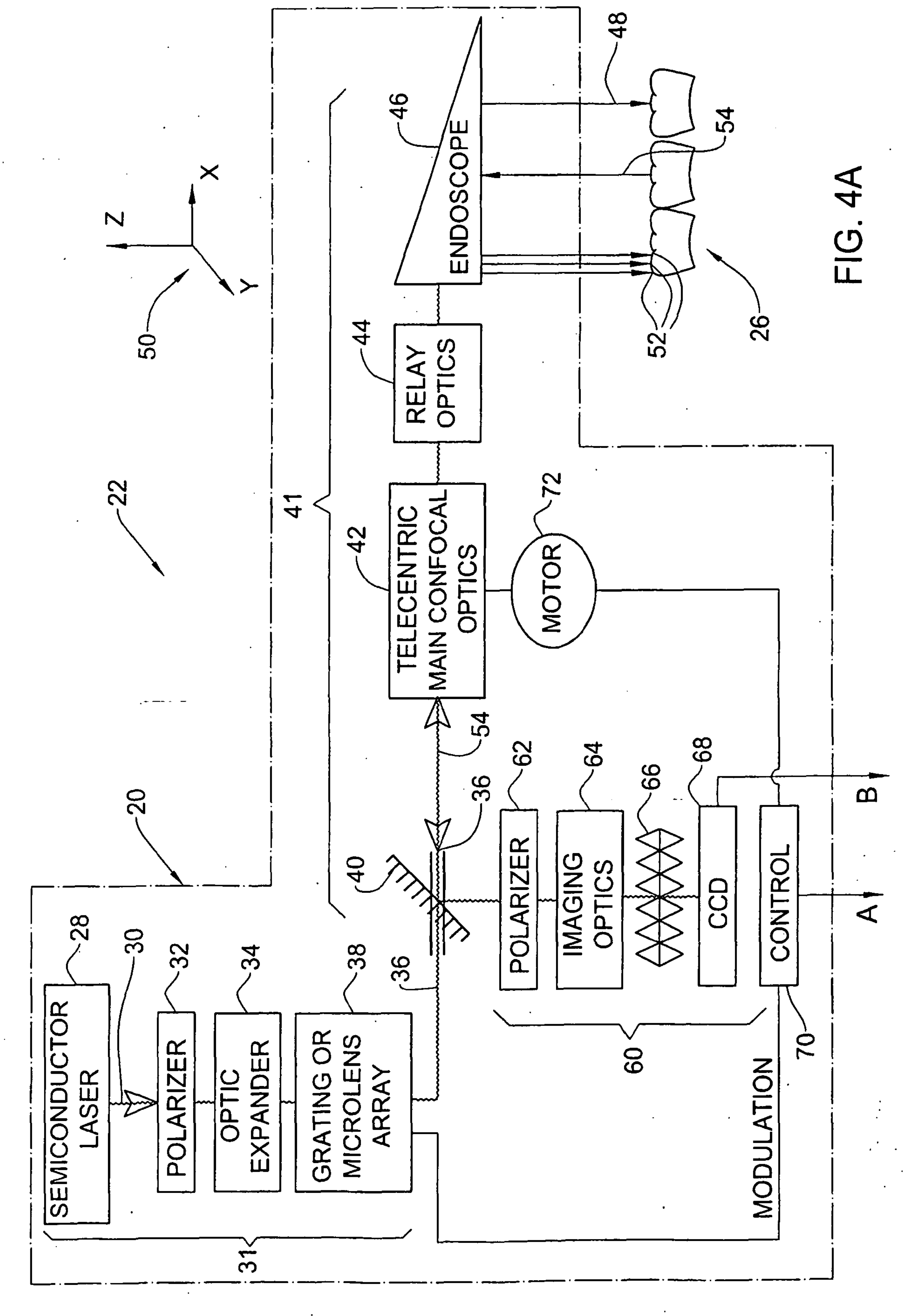
SEMICONDUCTOR LASER
POLARIZER
OPTIC EXPANDER
GRATING OR MICROLENS ARRAY
TELECENTRIC MAIN CONFOCAL OPTICS
RELAY OPTICS
ENDOSCOPE
MOTOR
POLARIZER
IMAGING OPTICS
CCD
CONTROL
MODULATION
A
B
X
Y
Z
20
22
26
28
30
31
32
34
36
38
40
41
42
44
46
48
50
52
54
60
62
64
66
68
70
72

FIG. 4A

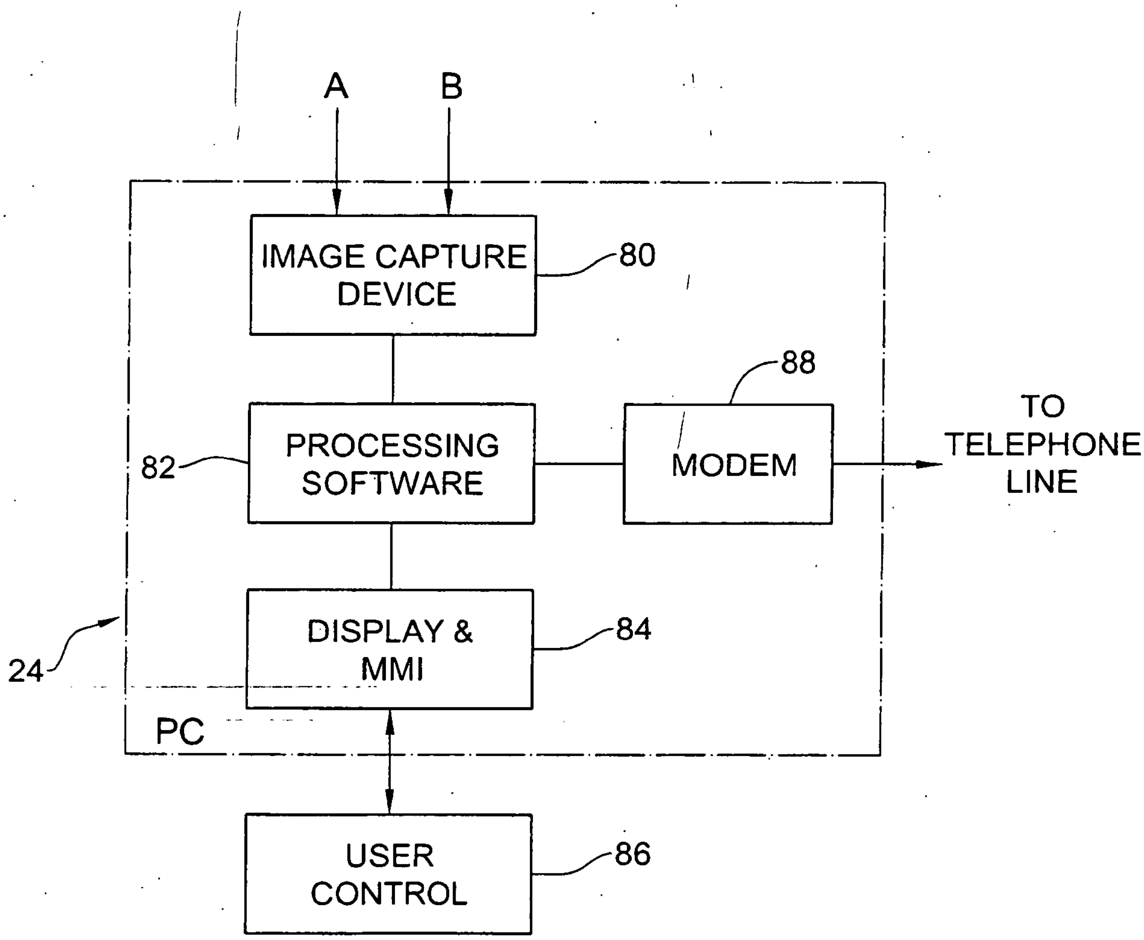
A
B
IMAGE CAPTURE DEVICE
80
88
PROCESSING SOFTWARE
MODEM
TO TELEPHONE LINE
82
DISPLAY & MMI
84
24
PC
USER CONTROL
86

FIG. 4B

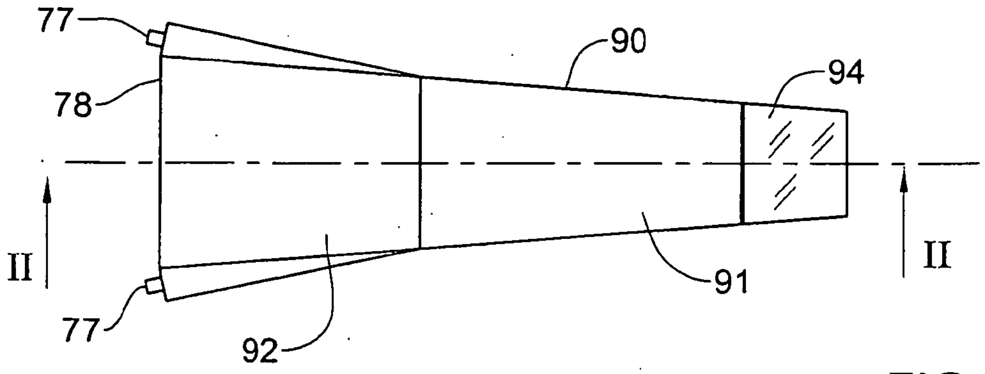

FIG. 5A

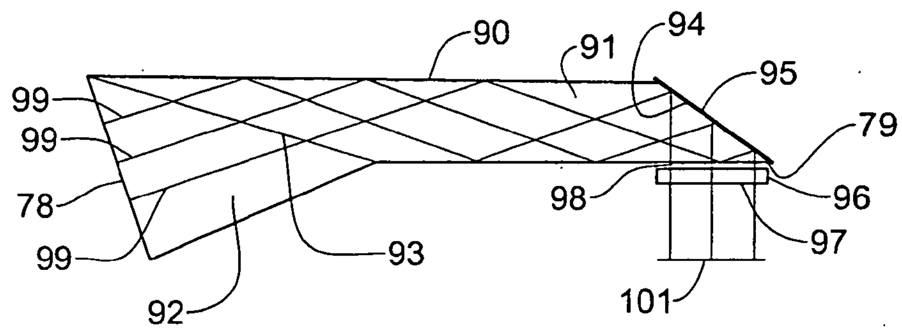

FIG. 5B

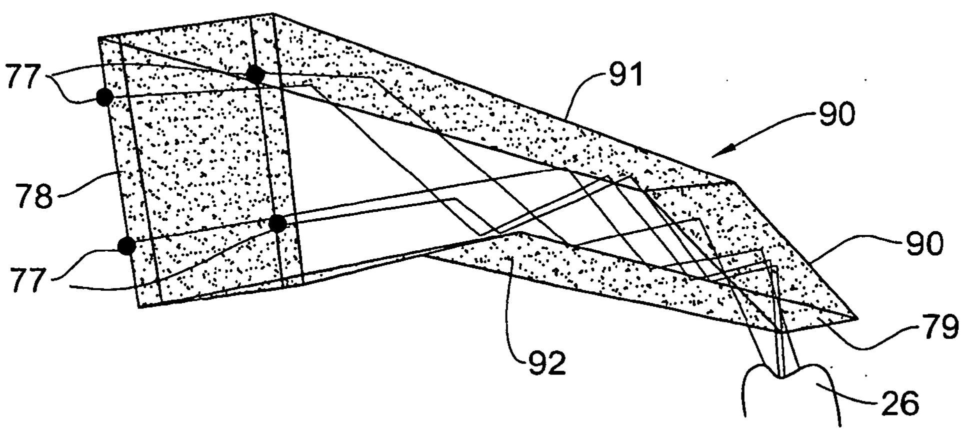

FIG. 5C

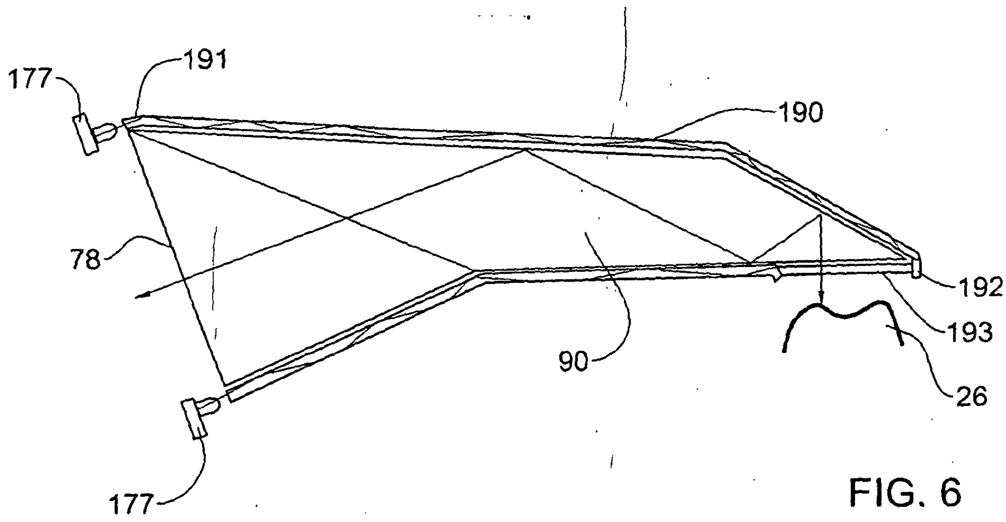

FIG. 6

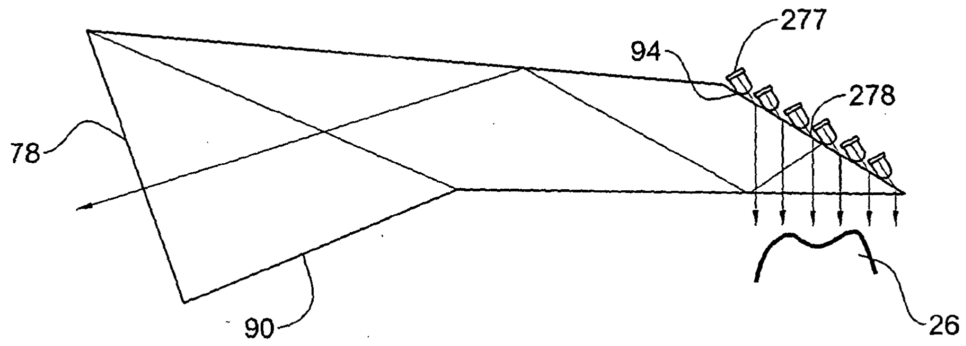

FIG. 7A

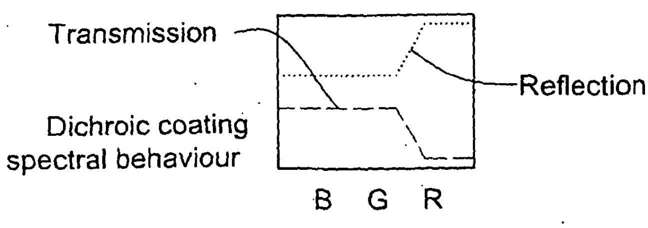

FIG. 7B

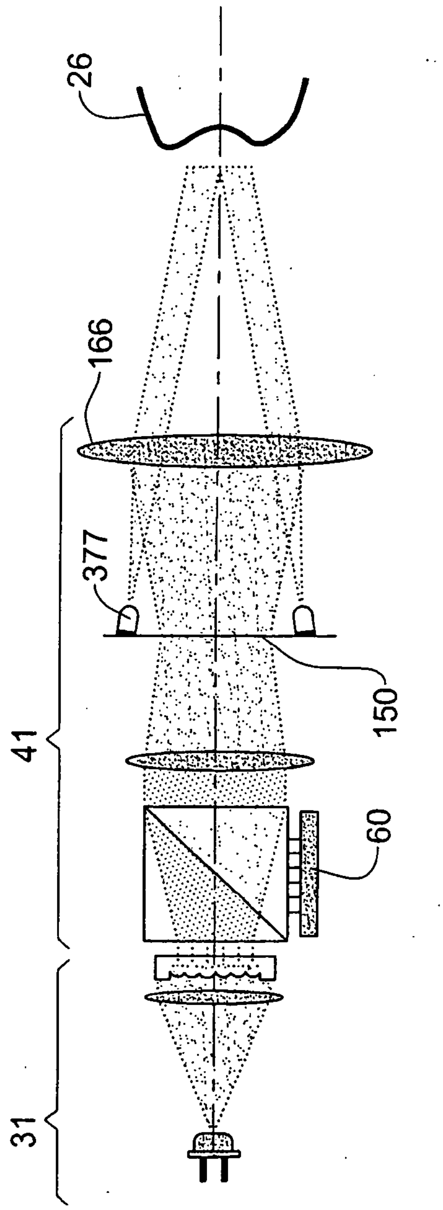

FIG. 8

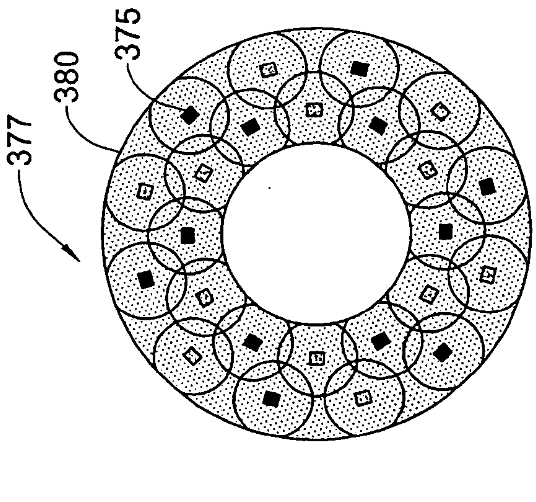

FIG. 9

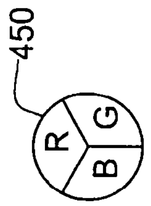

FIG. 10A

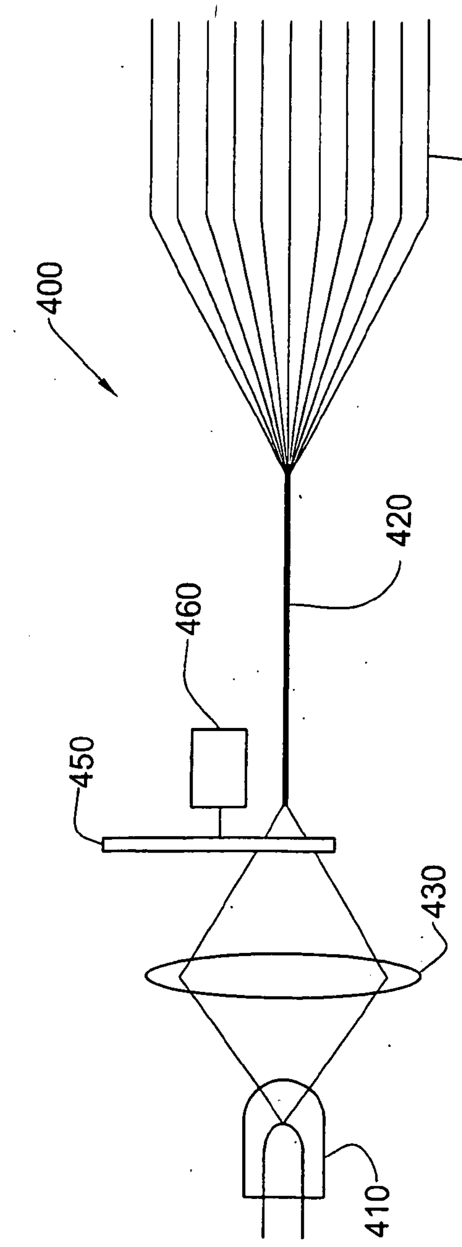

FIG. 10

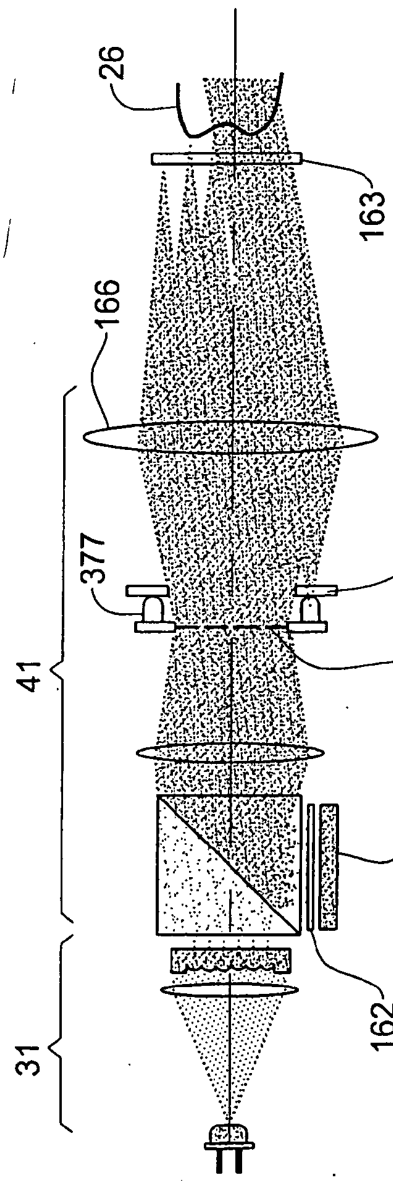

FIG. 11

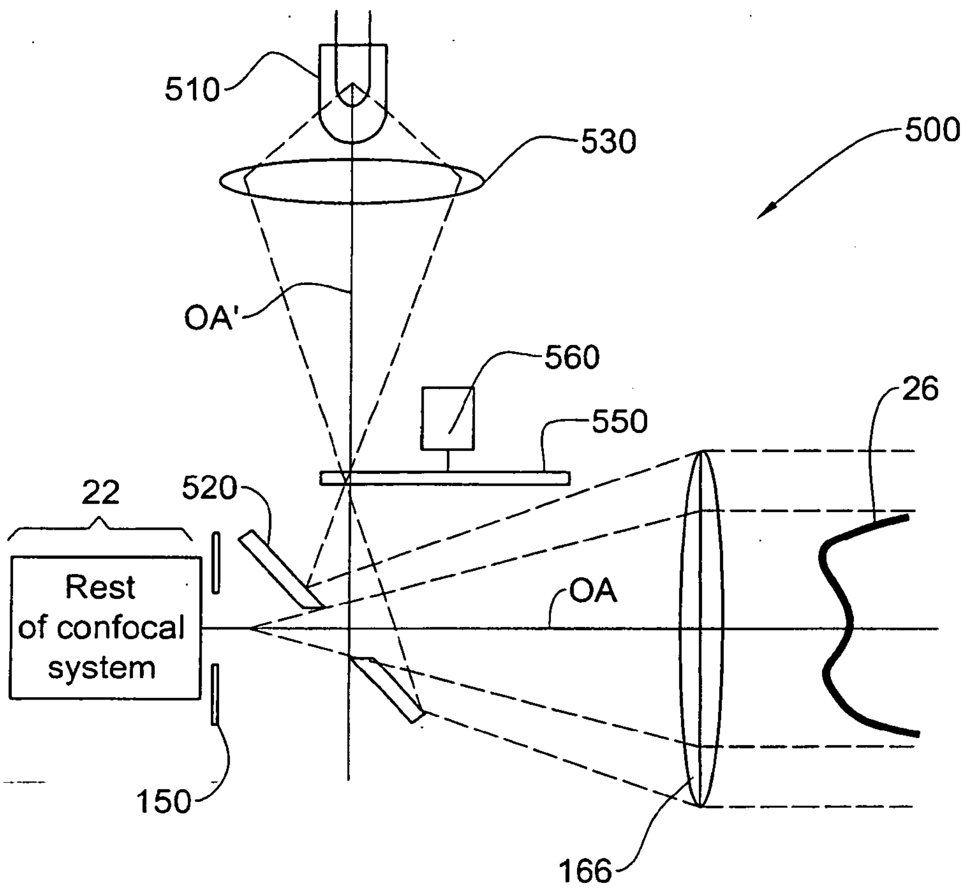
510
530
500
OA'
560
26
550
22
520
Rest
of confocal
system
OA
150
166

FIG. 12

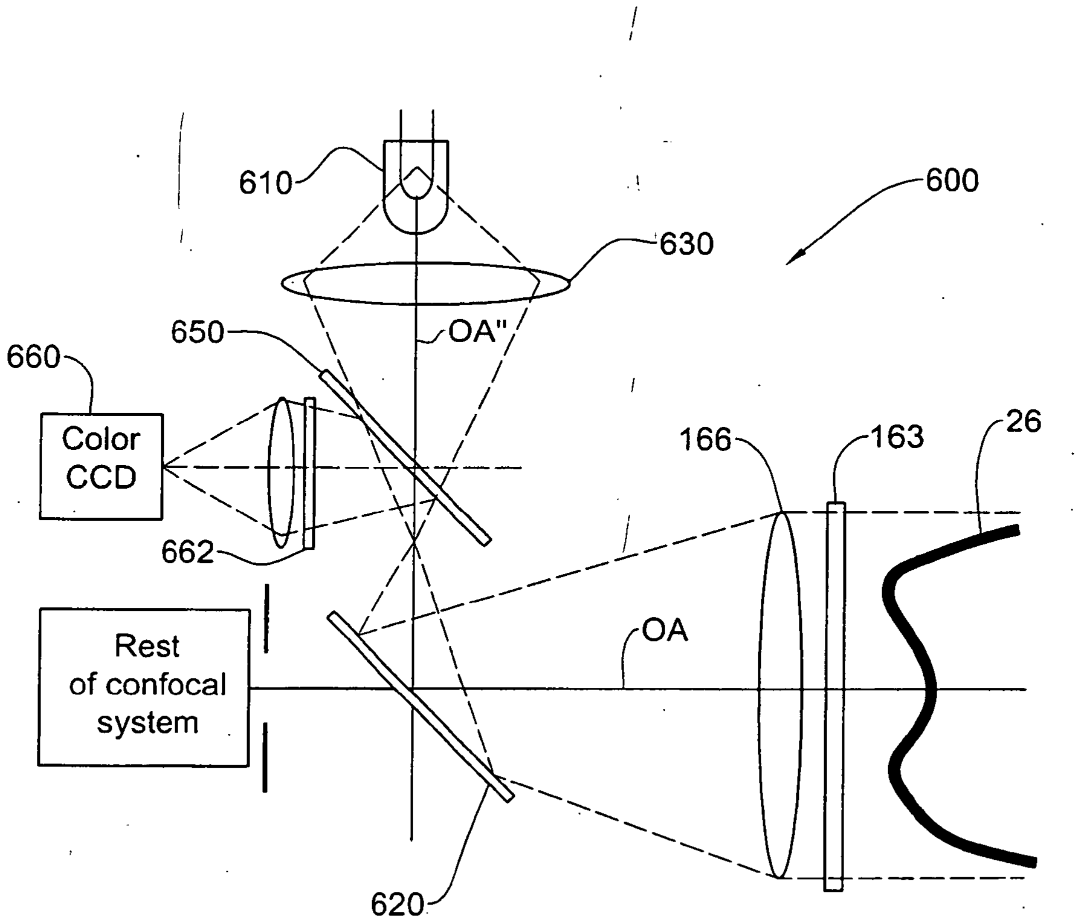
610
600
630
650
OA"
660
Color CCD
166
163
26
662
Rest of confocal system
OA
620

FIG. 13

REFERENCES CITED IN THE DESCRIPTION

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- US 6205243 B1 **[0008]**

专利名称(译)	用于对三维结构进行彩色成像的方法和设备		
公开(公告)号	EP1607064B1	公开(公告)日	2008-09-03
申请号	EP2005013108	申请日	2005-06-17
申请(专利权)人(译)	CADENT LTD.		
当前申请(专利权)人(译)	CADENT LTD.		
[标]发明人	BABAYOFF NOAM		
发明人	BABAYOFF, NOAM		
IPC分类号	A61C13/00 A61B5/00 A61B5/107 G01J3/50 A61B1/04 A61B1/24 A61B1/247 A61B5/05 A61C9/00 G01B11/24 G01J3/02		
CPC分类号	A61B1/00009 A61B1/00096 A61B1/0615 A61B1/0638 A61B1/0646 A61B1/0676 A61B1/0684 A61B1/24 A61B1/247 A61B5/0068 A61B5/0088 A61B5/1077 A61C9/0066 G01B11/24 G01J3/02 G01J3/0205 G01J3/0208 G01J3/0216 G01J3/0218 G01J3/0224 G01J3/0243 G01J3/0256 G01J3/10 G01J3/462 G01J3/50 G01J3/501 G01J3/508 G01J3/51 G06T7/12 G06T7/90 G06T2207/10024 G06T2207/10028 G06T2207/30036 H01L27/14868 H04N13/207 H04N13/257 H04N13/296 H04N13/15 H04N13/271 A61B5/1079 A61C9/0053 A61C19/04 G01B11/25 G01N21/255 G06T7/0012		
优先权	60/580108 2004-06-17 US 60/580109 2004-06-17 US		
其他公开文献	EP1607064A3 EP1607064A2		
外部链接	Espacenet		

摘要(译)

一种用于确定诸如牙齿段的结构的表面拓扑和相关联的颜色的设备包括：扫描器，用于提供沿着基本上正交于深度方向的二维阵列的点的深度数据;以及图像获取装置，用于阵列的每个点的数据，而器件相对于结构的空间布置基本上保持不变。处理器组合阵列中的每个点的颜色数据和深度数据，从而提供结构表面的三维彩色虚拟模型。还提供了一种用于确定结构的表面拓扑和相关联的颜色的相应方法。

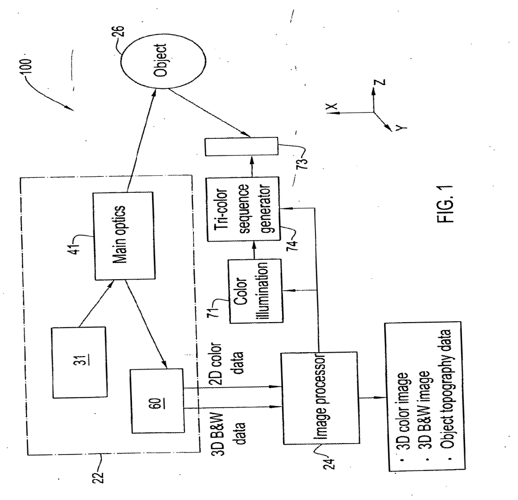

FIG. 1