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Warnings:					
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2	Specification	Provisional_Application.pdf	1331498 00f1b2c65d9ba43270c47a26de244a37aceb652	no	27
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4	Application Data Sheet	Application_Data_Sheet.pdf	281970 f4f6dd511d38382c782877db4933a842f842e280	no	10
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PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 C.F.R. § 1.53(c).

Attorney Docket Number **0079124-000065****Inventor(s)**

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Title of Invention

FOCUS SCANNING APPARATUS RECORDING COLOR

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This invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.

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☒ Application Data Sheet. See 37 CFR 1.76**Method of Payment of Filing Fees****FILING FEE AMOUNT**

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Focus scanning apparatus recording color

Field of the invention

- 5 The invention relates to three dimensional (3D) scanning of the surface geometry and surface color of objects. A particular application is within dentistry, particularly for intraoral scanning.

Background of the invention

10

3D scanners are widely known from the art, and so are intraoral dental 3D scanners (e.g., Sirona Cerec, Cadent Itero, 3Shape TRIOS).

15

The ability to record surface color is useful in many applications. For example in dentistry, the user can differentiate types of tissue or detect existing restorations. For example in materials inspection, the user can detect surface abnormalities such as crystallization defects or discoloring. None of the above is generally possible from 3D surface information alone.

20

WO2010145669 mentions the possibility of recording color. In particular, several sequential images, each taken for an illumination in a different color - typically blue, green, and red - are combined to form a synthetic color image. This approach hence requires means to change light source color, such as color filters. Furthermore, in handheld use, the scanner will move relative to the scanned object during the illumination sequence, reducing the quality of the synthetic color image.

25

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Also US7698068 and US8102538 (Cadent Inc.) describe an intraoral scanner that records both 3D geometry data and 3D texture data with one or more image sensor(s). However, there is a slight delay between the color and the 3D geometry recording, respectively. US7698068 requires sequential illumination in different colors to form a synthetic image, while US8102538 mentions white light as a possibility, however from a second illumination source or recorded by a second image sensor, the first set being used for recording the 3D geometry.

WO2012083967 discloses a scanner for recording 3D geometry data and 3D texture data with two separate cameras. While the first camera has a relatively shallow depth of field as to provide focus scanning based on multiple images, the second camera has a relatively large depth of field as to provide color texture information from a single image.

Color-recording scanning confocal microscopes are also known from the prior art (e.g., Keyence VK9700; see also JP2004029373). A white light illumination system along with a color image sensor is used for recording 2D texture, while a laser beam forms a dot that is scanned, i.e., moved over the surface and recorded by a photomultiplier, providing the 3D geometry data from many depth measurements, one for each position of the dot. The principle of a moving dot requires the measured object not to move relative to the microscope during measurement, and hence is not suitable for handheld use.

Summary of the invention

It is an object of the present invention to provide a scanner for obtaining the 3D surface geometry and surface color of the surface of an object, which does not require that some 2D images are recorded for determining the 3D surface geometry while other images are recorded for determining the surface color.

It is an object of the present invention to provide a scanner for obtaining the 3D surface geometry and surface color of the surface of an object, which obtains surface color and the 3D surface geometry simultaneously such that an alignment of data relating to 3D surface geometry and data relating to surface color is not required.

Disclosed is a scanner for obtaining 3D surface geometry and surface color of an object, the scanner comprising:

- a multichromatic light source configured for providing a probe light, and

- a color image sensor comprising an array of image sensor pixels for recording one or more 2D images of light received from said object,

where at least for a block of said image sensor pixels, both surface color and 3D surface geometry of a part of the object are derived at least partly from one 2D

5 image recorded by said color image sensor

Disclosed is a scanner for obtaining 3D surface geometry and surface color of an object, the scanner comprising:

- a multichromatic light source configured for providing a probe light,
- 10 - a color image sensor comprising an array of image sensor pixels, and
- an optical system configured for guiding light received from the object to the color image sensor such that 2D images of said object can be recorded by said color image sensor;

15 wherein the scanner is configured for acquiring a number of said 2D images of a part of the object and for deriving both surface color and 3D surface geometry of the part of the object from at least one of said recorded 2D images at least for a block of said image sensor pixels, such that the surface color and 3D surface geometry are obtained concurrently by the scanner.

20 Disclosed is a scanner for obtaining 3D surface geometry and surface color of an object, the scanner comprising:

- a multichromatic light source configured for providing a probe light;
- a color image sensor comprising an array of image sensor pixels, where the image sensor is arranged to record 2D images of light received from
- 25 the object; and

- an image processor configured for deriving both surface color and 3D surface geometry of at least a part of the object from at least one of said 2D images recorded by the color image sensor.

5 Disclosed is a scanner system for obtaining 3D surface geometry and surface color of an object, said scanner system comprising

- a scanner according to any of the embodiments, where the scanner is configured for deriving surface color and 3D surface geometry of the object, and optionally for obtaining a partial or full 3D surface geometry of the part of the object; and
- a data processing unit configured for post-processing 3D surface geometry and/or surface color readings from the color image sensor, or for post-processing the obtained partial or full 3D surface geometry.

15 In some embodiments, the data processing unit comprises a computer readable medium on which is stored computer implemented algorithms for performing said post-processing.

In some embodiments, the data processing unit is integrated in a cart or a personal computer.

20 Disclosed is a method of obtaining 3D surface geometry and surface color of an object, the method comprising:

- providing a scanner or scanner system according to any of the embodiments;
- illuminating the surface of said object with probe light from said multichromatic light source;
- recording one or more 2D images of said object using said color image sensor; and

- deriving both surface color and 3D surface geometry of a part of the object from at least some of said recorded 2D images at least for a block of said image sensor pixels, such that the surface color and 3D surface geometry are obtained concurrently by the scanner.

5

The present invention is a significant improvement over the state of the art in that only a single image sensor and a single multichromatic light source is required, and that surface color and 3D surface geometry for at least a part of the object can be derived from the same image or images, which also means that alignment of
10 color and 3D surface geometry is inherently perfect. In the scanner according to the present invention, there is no need for taking into account or compensating for relative motion of the object and scanner between obtaining 3D surface geometry and surface color. Since the 3D surface geometry and the surface color are obtained at precisely the same time, the scanner automatically maintains its
15 spatial disposition with respect to the object surface while obtaining the 3D surface geometry and the surface color. This makes the scanner of the present invention suitable for handheld use, for example as an intraoral scanner, or for scanning moving objects.

In the context of the present invention, the phrase "surface color" may refer to the
20 apparent color of an object surface and thus in some cases, such as for semi-transparent or semi-translucent objects such as teeth, be caused by light from the object surface and/or the material below the object surface, such as material immediately below the object surface.

In some embodiments, the 3D surface geometry and the surface color are both
25 determined from light recorded by the color image sensor.

In some embodiments, the light received from the object originates from the multichromatic light source, i.e. it is probe light reflected or scattered from the surface of the object.

In some embodiments, the light received from the object is fluorescence excited by the probe light from the multichromatic light source, i.e. fluorescence emitted by fluorescent materials in the object surface.

5 In some embodiments, a second light source is used for the excitation of fluorescence while the multichromatic light source provides the light for obtaining the geometry and color of the object.

10 In some embodiments, the scanner comprises a first optical system, such as an arrangement of lenses, for transmitting the probe light from the multichromatic light source towards an object and a second optical system for imaging light received from the object at the color image sensor.

15 In some embodiments, only one optical system images the probe light onto the object and images the object, or at least a part of the object, onto the color image sensor, preferably along the same optical axis, however along opposite optical paths. The scanner may comprise at least one beam splitter located in the optical path, where the beam splitter is arranged such that it directs the probe light from the multichromatic light source towards the object while it directs light received from the object towards the color image sensor.

20 In some embodiments, the surface color and 3D surface geometry of the part of the object are derived from a plurality of recorded 2D images. In that case, both surface color and 3D surface geometry of the part of the object can be derived from a number of the plurality of recorded 2D images.

Several scanning principles are suitable for this invention, such as triangulation and focus scanning.

25 In some embodiments, the scanner is a focus scanner configured for obtaining a stack of 2D images of the object from a number of different focus plane positions. In some focus scanning embodiments, the focus plane is adjusted in such a way that the image of e.g. a spatial pattern projected by the light source on the probed object is shifted along the optical axis while recording 2D images at a number of focus plane positions such that said stack of recorded 2D images can be obtained

for a given position of the scanner relative to the object. The focus plane position may be varied by means of at least one focus element, e.g., a moving focus lens.

In some focus scanner embodiments, the scanner comprises means for incorporating a spatial pattern in said probe light and means for evaluating a correlation measure at each focus plane position between at least one image pixel and a weight function, where the weight function is determined based on information of the configuration of the spatial pattern. Determining in-focus information may then relate to calculating a correlation measure of the spatially structured light signal provided by the pattern with the variation of the pattern itself (which we term reference) for every location of the focus plane and finding the location of an extremum of this series. In some embodiments, the pattern is static. Such a static pattern can for example be realized as a chrome-on-glass pattern.

One way to define the correlation measure mathematically with a discrete set of measurements is as a dot product computed from a signal vector, $I = (I_1, \dots, I_n)$, with $n > 1$ elements representing sensor signals and a reference vector, $f = (f_1, \dots, f_n)$, of reference weights. The correlation measure A is then given by

$$A = f \cdot I = \sum_{i=1}^n f_i I_i$$

The indices on the elements in the signal vector represent sensor signals that are recorded at different pixels, typically in a block of pixels. The reference vector f can be obtained in a calibration step.

By using knowledge of the optical system used in the scanner, it is possible to transform the location of an extremum of the correlation measure, i.e., the focus plane into depth data information, on a pixel block basis. All pixel blocks combined thus provide an array of depth data. In other words, depth is along an optical path that is known from the optical design and/or found from calibration, and each block of pixels on the image sensor represents the end point of an optical path.

Therefore, depth along an optical path, for a bundle of paths, yields a 3D surface geometry within the field of view of the scanner.

It can be advantageous to smooth and interpolate the series of correlation measure values, such as to obtain a more robust and accurate determination of the location of the maximum. For example, a polynomial can be fitted to the values of A for a pixel block over several images on both sides of the recorded maximum, and a location of a deduced maximum can be found from the maximum of the fitted polynomial, which can be in between two images.

Color for a block of pixels is at least partially derived from the same image from which 3D geometry is derived. In case the location of the maximum of A is represented by an image, then also color is derived from that same image. In case the location of the maximum of A is found by interpolation to be between two images, then at least one of those two images should be used to derive color, or both images using interpolation for color also. It is also possible to average color data from more than two images used in the determination of the location of the maximum of the correlation measure, or to average color from a subset or superset of multiple images used to derive 3D surface geometry. In any case, some image sensor pixels readings are used to derive both surface color and 3D surface geometry for at least a part of the scanned object.

Typically, there are three color filters, so the overall color is composed of three contributions, such as red, green, and blue, or cyan, magenta, and yellow. Note that color filters typically allow a range of wavelengths to pass, and there is typically cross-talk between filters, such that, for example, some green light will contribute to the intensity measured in pixels with red filters.

For an image sensor with a color filter array, a color component c_j within a pixel block can be obtained as

$$c_j = \sum_{i=1}^n g_{j,i} I_i$$

where $g_{j,i} = 1$ if pixel i has a filter for color c_j , 0 otherwise. For an RGB filter array like in a Bayer pattern, j is one of red, green, or blue. Further weighting of the individual color components, i.e., color calibration, may be required to obtain natural color data, typically as compensation for varying filter efficiency,

illumination source efficiency, and different fraction of color components in the filter pattern. The calibration may also depend on focus plane location and/or position within the field of view, as the mixing of the light source component colors may vary with those factors.

5 In some embodiments, color is obtained for every pixel in a pixel block. In sensors with a color filter array or with other means to separate colors such as diffractive means, depending on the color measured with a particular pixel, an intensity value for that color is obtained. In other words, in this case a particular pixel has a color value only for one color. Recently developed color image sensors allow
10 measurement of several colors in the same pixel, at different depths in the substrate, so in that case, a particular pixel can yield intensity values for several colors. In summary, it is possible to obtain a resolution of the surface color data that is inherently higher than that of the 3D geometry data.

In the embodiments where color resolution is higher than 3D geometry resolution,
15 a pattern will be visible when at least approximately in focus, which preferably is the case when color is derived. The image can be filtered such as to visually remove the pattern, however at a loss of resolution. In fact, it can be advantageous to be able to see the pattern for the user. For example in intraoral scanning, it may be important to detect the position of a margin line, the rim or
20 edge of a preparation. The image of the pattern overlaid on the 3D geometry of this edge is sharper on a side that is seen approximately perpendicular, and more blurred on the side that is seen at an acute angle. Thus, a user, who in this example typically is a dentist or dental technician, can use the difference in sharpness to more precisely locate the position of the margin line than may be
25 possible from examining the 3D surface geometry alone.

High spatial contrast of the in-focus pattern image on the object is desirable to obtain a good signal to noise ratio of the correlation measure on the color image sensor. Improved spatial contrast can be achieved by preferential imaging of the specular surface reflection from the object on the color image sensor. Thus, some
30 embodiments of the invention comprise means for preferential/selective imaging of specularly reflected light. This may be provided if the scanner further comprises

means for polarizing the probe light, for example by means of at least one polarizing beam splitter.

In some embodiments, the polarizing optics is coated such as to optimize preservation of the circular polarization of a part of the spectrum of the multichromatic light source that is used for obtaining the 3D surface geometry.

The scanner according to the invention may further comprise means for changing the polarization state of the probe light and/or the light received from the object. This can be provided by means of a retardation plate, preferably located in the optical path. In some embodiments of the invention the retardation plate is a quarter wave retardation plate.

Especially for intraoral applications, the scanner can have an elongated tip, with means for directing the probe light and/or imaging an object. This may be provided by means of at least one folding element. The folding element could be a light reflecting element such as a mirror or a prism.

For a more in-depth description of the above aspects of this invention, see WO2010145669.

The invention disclosed here comprises a multichromatic light source, for example a white light source, for example a multi-die LED.

Light received from the scanned object, such as probe light returned from the object surface or fluorescence generated by the probe light by exciting fluorescent parts of the object, is recorded by a color image sensor. In some embodiments, the color image sensor comprises a color filter array such that every pixel in the color image sensor is a color-specific filter. The color filters are preferably arranged in a regular pattern, for example where the color filters are arranged according to a Bayer color filter pattern. The image data thus obtained are used to derive both 3D surface geometry and surface color for each block of pixels. For a focus scanner utilizing a correlation measure, the 3D surface geometry may be found from an extremum of the correlation measure as described above.

In some embodiments, the 3D surface geometry is derived from light in a first part of the spectrum of the probe light provided by the multichromatic light source.

Preferably, the color filters are aligned with the image pixels, preferably such that each pixel has a color filter for a particular color only.

In some embodiments, the color filter array is such that its proportion of pixels with color filters that match the first part of the spectrum is larger than 50%.

- 5 In some embodiments, the scanner is configured to derive the surface color with a higher resolution than the 3D surface geometry.

In some embodiments, the higher surface color resolution is achieved by demosaicing, where color values for pixel blocks may be demosaiced to achieve an apparently higher resolution of the color image than is present in the 3D
10 surface geometry. The demosaicing may operate on pixel blocks or individual pixels.

In case a multi-die LED or another illumination source comprising physically or optically separated light emitters is used, it is preferable to aim at a Köhler type illumination in the scanner, i.e. the illumination source is defocused at the object
15 plane in order to achieve uniform illumination and good color mixing for the entire field of view. In case color mixing is not perfect and varies with focal plane location, color calibration of the scanner will be advantageous.

It can be preferable to compute the 3D surface geometry only from pixels with one or two kinds of color filters. A single color requires no achromatic optics and is thus
20 provides for a scanner that is easier and cheaper to build. Furthermore, folding elements can generally not preserve the polarization state for all colors equally well. When only some color(s) is/are used to compute 3D surface geometry, the reference vector f will contain zeros for the pixels with filters for the other color(s). Accordingly, the total signal strength is generally reduced, but for large enough
25 blocks of pixels, it is generally still sufficient. Preferentially, the pixel color filters are adapted for little cross-talk from one color to the other(s). Note that even in the embodiments computing geometry from only a subset of pixels, color is preferably still computed from all pixels.

To obtain a full 3D surface geometry and color representation of an object, i.e. a
30 colored full 3D surface geometry of said part of the object surface, typically several

partial representations of the object have to be combined, where each partial representation is a view from substantially the same relative position of scanner and object. In the present invention, a view from a given relative position preferably obtains the 3D geometry and color of the object surface as seen from that relative position.

For a focus scanner, a view corresponds to one pass of the focusing element(s), i.e. for a focus scanner each partial representation is the 3D surface geometry and color derived from the stack of 2D images recorded during the pass of the focus plane position between its extremum positions.

The 3D surface geometry found for various views can be combined by algorithms for stitching and registration as widely known in the literature, or from known view positions and orientations, for example when the scanner is mounted on axes with encoders. Color can be interpolated and averaged by methods such as texture weaving, or by simply averaging corresponding color components in multiple views of the same location on the 3D surface. Here, it can be advantageous to account for differences in apparent color due to different angles of incidence and reflection, which is possible because the 3D surface geometry is also known. Texture weaving is described by e.g. Callieri M, Cignoni P, Scopigno R. "Reconstructing textured meshes from multiple range rgb maps". VMV 2002, Erlangen, Nov 20-22, 2002.

In some embodiments, the scanner and/or the scanner system is configured for generating a partial representation of the object surface based on the obtained surface color and 3D surface geometry.

In some embodiments, the scanner and/or the scanner system is configured for combining partial representations of the object surface obtained from different relative positions to obtain a full 3D surface geometry and color representation of the part of the object.

In some embodiments, the combination of partial representations of the object to obtain the full 3D surface geometry and color representation comprises computing the color in each surface point as a weighted average of corresponding points in all overlapping partial 3D surface geometries at that surface point. The weight of

each partial presentation in the sum may be determined by several factors, such as the presence of saturated pixel values or the orientation of the object surface with respect to the scanner.

Such a weighted average is advantageous in cases where some scanner positions and orientations relative to the object will give a better estimate of the actual color than other positions and orientations. If the illumination of the object surface is uneven this can to some degree also be compensated for by weighting the best illuminated parts higher.

In some embodiments, the scanner comprises an image processor configured for performing a post-processing of the 3D surface geometry, the surface color readings, or the derived partial or full 3D surface geometries of the object. The scanner may be configured for performing the combination of the partial representations using e.g. computer implemented algorithms executed by an image processor of the scanner.

The scanner system may be configured for performing the combination of the partial representations using e.g. computer implemented algorithms executed by the data processing unit as part of the post-processing of the 3D surface geometry, surface color, partial 3D geometry and/or full 3D geometry, i.e. the post-processing comprises computing the color in each surface point as a weighted average of corresponding points in all overlapping partial 3D surface geometries at that surface point.

Saturated pixel values should preferably have a low weight to reduce the effect of highlights on the recording of the surface color. The color for a given part of the surface should preferably be determined primarily from 2D images where the color can be determined precisely which is not the case when the pixel values are saturated.

In some embodiments, the scanner and/or scanner system is configured for detecting saturated pixels in the recorded 2D images and for mitigating or removing the error in the obtained color caused by the pixel saturation. The error caused by the saturated pixel may be mitigated or removed by assigning a low weight to the saturated pixel in the weighted average.

Specularly reflected light has the color of the light source rather than the color of the object surface. If the object surface is not a pure white reflector then specular reflections can hence be identified as the areas where the pixel color closely matches the light source color. When obtaining the surface color it is therefore
5 advantageous to assign a low weight to pixels or pixel groups whose color values closely match the color of the multichromatic light source in order to compensate for such specular reflections.

Specular reflections may also be a problem when intra orally scanning a patient's set of teeth since teeth rarely are completely white. It may hence be advantageous
10 to assume that for pixels where the readings from the color images sensor indicate that the surface of the object is a pure white reflector, the light recorded by this pixel group is caused by a specular reflection from the teeth or the soft tissue in the oral cavity and accordingly assign a low weight to these pixels to compensate for the specular reflections.

15 In some embodiments, the compensation for specular reflections from the object surface is based on information derived from a calibration of the scanner in which a calibration object e.g. in the form of a pure white reflector is scanned. The color image sensor readings then depend on the spectrum of the multichromatic light source and on the wavelength dependence of the scanner's optical system caused
20 by e.g. a wavelength dependent reflectance of mirrors in the optical system. If the optical system guides light equally well for all wavelengths of the multichromatic light source, the color image sensor will record the color (also referred to as the spectrum) of the multichromatic light source when the pure white reflector is scanned.

25 In some embodiments, compensating for the specular reflections from the surface is based on information derived from a calculation based on the wavelength dependence of the scanner's optical system, the spectrum of the multichromatic light source and a wavelength dependent sensitivity of the color image sensor. In some embodiments, the scanner comprises means for optically suppressing
30 specularly reflected light to achieve better color measurement. This may be provided if the scanner further comprises means for polarizing the probe light, for example by means of at least one polarizing beam splitter.

When scanning inside an oral cavity there may be red ambient light caused by probe light illumination of surrounding tissue, such as the gingiva, palette, tongue or buccal tissue. In some embodiments, the scanner and/or scanner system is hence configured for suppressing the red component in the recorded 2D images.

5 In some embodiments, the scanner and/or scanner system is configured for comparing the color of sections of the recorded 2D images and/or of the partial presentations of the object with predetermined color ranges for teeth and for oral tissue, respectively, and for suppressing the red component of the recorded color for sections where the color is not in either one of the two predetermined color
10 ranges. The teeth may e.g. be assumed to be primarily white with one ratio between the intensity of the different components of the recorded image, e.g. with one ratio between the intensity of the red component and the intensity of the blue and/or green components in a RGB configuration, while oral tissue is primarily reddish with another ratio between the intensity of the components. When a color
15 recorded for a region of the oral cavity shows a ratio which differs from both the predetermined ratio for teeth and the predetermined ratio for tissue, this region is identified as a tooth region illuminated by red ambient light and the red component of the recorded image is suppressed relative to the other components, either by reducing the recorded intensity of the red signal or by increasing the recorded
20 intensities of the other components in the image.

In some embodiments, the color of points with a surface normal directly towards the scanner are weighted higher than the color of points where the surface normal is not directed towards the scanner. This has the advantage that points with a surface normal directly towards the scanner will to a higher degree be illuminated
25 by the white light from the scanner and not by the ambient light.

In some embodiments, the color of points with a surface normal directly towards the scanner are weighted lower if associated with specular reflections.

In some embodiments the scanner is configured for simultaneously compensating for different effects, such as compensating for saturated pixels and/or for specular
30 reflections and/or for orientation of the surface normal. This may be done by generally raising the weight for a selection of pixels or pixel groups of a 2D image

and by reducing the weight for a fraction of the pixels or pixel groups of said selection.

In some embodiments, the method comprises a processing of recorded 2D images, partial or full 3D representations of the part of the object, where said
5 processing comprises

- compensating for pixel saturation by omitting or reducing the weight of saturated pixels when deriving the surface color, and/or
- compensating for specular reflections when deriving the surface color by omitting or reducing the weight of pixels whose color values closely
10 matches the light source color, and/or
- compensating for red ambient light by comparing color of the 2D images with predetermined color ranges, and suppressing the red component of the recorded color if this is not within a predetermined color range.

15 Disclosed is a method of using a scanner of this invention to display color texture on 3D surface geometry. It is advantageous to display the 2D color data as a texture on the 3D surface geometry, for example on a computer screen. The combination of color and geometry is a more powerful conveyor of information than either type of data alone. For example, dentists can more easily differentiate
20 between different types of tissue. In the rendering of the 3D surface geometry, appropriate shading can help convey the 3D surface geometry on the texture, for example with artificial shadows revealing sharp edges better than texture alone could do.

When the multichromatic light source is a multi-die LED or similar, the scanner of
25 this invention can also be used to detect fluorescence. Disclosed is a method of using the scanner of the invention to display fluorescence on 3D surface geometry.

In some embodiments, the scanner is configured for exciting fluorescence on said object by illuminating it with only a subset of the LED dies in the multi-die LED,

and where said fluorescence is recorded by only or preferentially reading out only those pixels in the color image sensor that have color filters at least approximately matching the color of the fluoresced light, i.e. measuring intensity only in pixels of the image sensors that have filters for longer-wavelength light. In other words, the scanner is capable of selectively activating only a subset of the LED dies in the multi-die LED and of only recording or preferentially reading out only those pixels in the color image sensor that have color filters at a higher wavelength than that of the subset of the LED dies, such that light emitted from the subset of LED dies can excite fluorescent materials in the object and the scanner can record the fluorescence emitted from these fluorescent materials. The subset of the dies preferably comprises one or more LED dies which emits light within the excitation spectrum of the fluorescent materials in the object, such as an ultraviolet, a blue, a green, a yellow or a red LED die. Such fluorescence measurement yields a 2D data array much like the 2D color image, however unlike the 2D image it cannot be taken concurrently with the 3D surface geometry. For a slow-moving scanner, and/or with appropriate interpolation, the fluorescence image can still be overlaid the 3D surface geometry. It is advantageous to display fluorescence on teeth because it can help detect caries and plaque.

In some embodiments, the processing means comprises a microprocessor unit configured for extracting the 3D surface geometry from 2D images obtained by the color image sensor and for determining the surface color from the same images.

Disclosed is a method of using a scanner of this invention to average color and/or 3D surface geometry from several views, where each view represents a substantially fixed relative orientation of scanner and object.

Disclosed is a method using a scanner of this invention to combine color and/or 3D surface geometry from several views, where each view represents a substantially fixed relative orientation of scanner and object, such as to achieve a more complete coverage of the object than would be possible in a single view.

Brief description of drawings

Fig. 1 shows a handheld embodiment of the scanner according to the invention.

Fig. 2 shows prior art pattern generating means and associated reference weights.

Fig. 3 shows a pattern generating means and associated reference weights according to the present invention.

5 Fig. 4 shows a color filter array according to the present invention

The scanner embodiment illustrated in fig. 1 is a hand-held scanner with components inside the housing 100. The scanner comprises a tip which can be entered into a cavity, a multichromatic light source in the form of a multi-die LED
10 101, pattern generation means 130 for incorporating a spatial pattern in the probe light, a beam splitter 140, an image acquisition means 180 including an image sensor 181, electronics and potentially other elements, an optical system typically comprising at least one lens, the object being scanned 200, and the image sensor. The light from the light source 101 travels back and forth through the optical
15 system 150. During this passage the optical system images the pattern 130 onto the object being scanned 200 and further images the object being scanned onto the image sensor 181.

The image sensor 181 has a color filter array 1000. Although drawn as a separate entity because of its importance in the invention, the color filter array is typically
20 integrated with the image sensor, with a single-color filter for every pixel.

The lens system includes a focusing element 151 which can be adjusted to shift the focal imaging plane of the pattern on the probed object 200. In the example embodiment, a single lens element is shifted physically back and forth along the optical axis.

25 As a whole, the optical system provides an imaging of the pattern onto the object being probed and from the object being probed to the camera.

The device may include polarization optics 160. Polarization optics can be used to selectively image specular reflections and block out undesired diffuse signal from sub-surface scattering inside the scanned object. The beam splitter 140 may also

have polarization filtering properties. It can be advantageous for optical elements to be anti-reflection coated.

5 The device may include folding optics, a mirror 170, which directs the light out of the device in a direction different to the optical axis of the lens system, e.g. in a direction perpendicular to the optical axis of the lens system.

There may be additional optical elements in the scanner, for example one or more condenser lens in front of the light source 101.

10 In the example embodiment, the LED 101 is a multi-die LED with two green, one red, and one blue die. Only the green portion of the light is used for obtaining the 3D surface geometry. Accordingly, the mirror 170 is coated such as to optimize preservation of the circular polarization of the green light, and not that of the other colors. Note that during scanning all dies within the LED are active, i.e., emitting light, so the scanner emits apparently white light onto the scanned object 200. The LED may emit light at the different colors with different intensities such that e.g.
15 one color is more intense than the other colors. This may be desired in order to reduce cross-talk between the readings of the different color signals in the color image sensor. In case that the intensity of e.g. the red and blue diodes in a RGB system is reduced, the apparently white light emitted by the light source will appear greenish-white.

20 Figure 2 shows an example of prior art pattern generation means 130 that is applied as a static pattern in a spatial correlation embodiment of WO20101455669, as imaged on a monochromatic image sensor 180. The pattern can be a chrome-on-glass pattern. Only a portion of the pattern is shown, namely one period. This period is represented by a pixel block of 6 by 6 image pixels, and
25 2 by 2 pattern fields. The fields drawn in gray in Fig. 2 (a) are in actuality black because the pattern mask is opaque for these fields; gray was only chosen for visibility and thus clarity of the Figure. Figure 2(b) illustrates the reference weights f for computing the spatial correlation measure A for the pixel block, where $n = 6 \times 6 = 36$, such that

$$A = \sum_{i=1}^n f_i I_i$$

where I are the intensity values measured in the 36 pixels in the pixel block for a given image. Note that perfect alignment between image sensor pixels and pattern fields is not required, but gives the best signal for the 3D surface geometry measurement.

- 5 Figure 3 shows the extension of the principle in Figure 2 for the present invention. The pattern is the same as in Figure 2 and so is the image sensor geometry. However, the image sensor is a color image sensor with a Bayer color filter array. In Figure 2 (a), pixels marked "B" have a blue color filter, while "G" indicates green and "R" red pixel filters, respectively. Figure 2 (b) shows the corresponding
10 reference weights f . Note that only green pixels have a non-zero value. This is so because only the green fraction of the spectrum is used for obtaining the 3D surface geometry.

For the pattern / color filter combination of Figure 3, a color component c_j within a pixel block can be obtained as

$$c_j = \sum_{i=1}^n g_{j,i} I_i$$

- 15 where $g_{j,i} = 1$ if pixel i has a filter for color c_j , 0 otherwise. For an RGB color filter array like in the Bayer pattern, j is one of red, green, or blue. Further weighting of the individual color components, i.e., color calibration, may be required to obtain natural color data, typically as compensation for varying filter efficiency, illumination source efficiency, and different fraction of color components in the filter
20 pattern. The calibration may also depend on focus plane location and/or position within the field of view, as the mixing of the LED's component colors may vary with those factors.

- Figure 4 shows an alternative color filter array with a higher fraction of green pixels than in the Bayer pattern. Assuming that only the green portion of the illumination
25 is used to obtain the 3D surface geometry, the filter of Figure 4 will potentially provide a better quality of the obtained 3D surface geometry than a Bayer pattern

filter, at the expense of poorer color representation. The poorer color representation will however in many cases still be sufficient while the improved quality of the obtained 3D surface geometry often is very advantageous.

Claims

1. A scanner for obtaining 3D surface geometry and surface color of an object, the scanner comprising:
 - a multichromatic light source configured for providing a probe light, and
 - a color image sensor comprising an array of image sensor pixels for recording one or more 2D images of light received from said object, where at least for a block of said image sensor pixels, both surface color and 3D surface geometry of a part of the object are derived at least partly from one 2D image recorded by said color image sensor.
2. A scanner according to claim 1, wherein the surface color and 3D surface geometry of the part of the object are derived from a plurality of recorded 2D images, and where for a number of the plurality of recorded 2D images both surface color and 3D surface geometry of the part of the object are derived.
3. A scanner according to any of the preceding claims where the scanner is a focus scanner configured for obtaining a stack of 2D images of the object from a number of different focus plane positions.
4. A scanner according to the preceding claim where the scanner comprises means for incorporating a spatial pattern in said probe light and means for evaluating a correlation measure at each focus plane position between at least one image pixel and a weight function, where the weight function is determined based on information of the configuration of the spatial pattern.
5. A scanner according to the preceding claim and where the spatial pattern is static.
6. A scanner according to any of the preceding claims where the color image sensor comprises a color filter array.

7. A scanner according to any of the preceding claims where the color filters of the array are arranged according to a Bayer color filter pattern.
- 5 8. A scanner according to any of the preceding claims where the 3D surface geometry is derived from light in a first part of the spectrum provided by the multichromatic light source
- 10 9. A scanner according to the preceding claim where the color filter array is such that its proportion of pixels with color filters that match the first part of the spectrum is larger than 50%.
10. A scanner according to any of the preceding claims where the multichromatic light source is a multi-die LED
- 15 11. A scanner according to any of the preceding claims where the scanner is configured to derive the surface color with a higher resolution than the 3D surface geometry
- 20 12. A scanner according to the preceding claim where the higher surface color resolution is achieved by demosaicing.
- 25 13. A scanner according to any of the preceding claims where the scanner is configured for exciting fluorescence on said object by illuminating it with only a subset of the LED dies in the multi-die LED, and where said fluorescence is recorded by only or preferentially reading out only those pixels in the color image sensor that have color filters at least approximately matching the color of the fluoresced light.
- 30 14. The scanner according to any of the preceding claims, wherein the scanner is configured for generating a partial representation of the part of the object surface based on the obtained surface color and 3D surface geometry, and for combining partial representations obtained from different relative

positions to obtain a full 3D surface geometry and color representation of the part of the object.

5 15. A scanner for obtaining 3D surface geometry and surface color of an object, the scanner comprising:

- a multichromatic light source configured for providing a probe light,
- a color image sensor comprising an array of image sensor pixels, and
- an optical system configured for guiding light received from the object to the color image sensor such that 2D images of said object can be recorded by said color image sensor;

10 wherein the scanner is configured for acquiring a number of said 2D images of a part of the object and for deriving both surface color and 3D surface geometry of the part of the object from at least one of said recorded 2D images at least for a block of said image sensor pixels, such that surface color and 3D surface geometry are obtained concurrently by the scanner.

15 16. A scanner for obtaining 3D surface geometry and surface color of an object, the scanner comprising:

- a multichromatic light source configured for providing a probe light;
- 20 - a color image sensor comprising an array of image sensor pixels, where the image sensor is arranged to record 2D images of light received from the object; and
- an image processor configured for deriving both surface color and 3D surface geometry of at least a part of the object from at least one of said 2D images recorded by the color image sensor.

25 17. A scanner system for obtaining 3D surface geometry and surface color of an object, said scanner system comprising

- a scanner according to any of the preceding claims, where the scanner is configured for deriving surface color and 3D surface geometry of the object, and optionally for obtaining a partial or full 3D surface geometry of the part of the object; and

- 5
- a data processing unit configured for post-processing 3D surface geometry and/or surface color readings from the color image sensor, or for post-processing the obtained partial or full 3D surface geometry.

10

18. The scanner system according to the preceding claim, wherein the post-processing comprises computing the color in each surface point as a weighted average of corresponding points in all overlapping partial 3D surface geometries at that surface point.

15

19. The scanner system according to claim 17 or 18, wherein the scanner system is configured for detecting saturated pixels in the recorded 2D images and for mitigating or removing the error in the obtained color caused by the pixel saturation.

20. The scanner system according to the preceding claim wherein the error caused by the saturated pixel is mitigated or removed by assigning a low weight to the saturated pixel in the weighted average.

20

21. The scanner system according to any of claims 17 to 20, wherein the scanner system is configured for comparing the color of sections of the recorded 2D images and/or of the partial presentations of the object with predetermined color ranges for teeth and for oral tissue, and for suppressing the red component of the recorded color for sections where the color is not in one of the two predetermined color ranges.

25

22. A method of obtaining 3D surface geometry and surface color of an object, the method comprising:

- providing a scanner or scanner system according to any of the previous claims;

- illuminating the surface of said object with probe light from said multichromatic light source;
- recording one or more 2D images of said object using said color image sensor; and
- 5 - deriving both surface color and 3D surface geometry of a part of the object from at least some of said recorded 2D images at least for a block of said image sensor pixels, such that the surface color and 3D surface geometry are obtained concurrently by the scanner.

23. The method according to claim 22, wherein the method comprises a
 10 processing of recorded 2D images, partial or full 3D representations of the part of the object, where said processing comprises

- compensating for pixel saturation by omitting or reducing the weight of saturated pixels when deriving the surface color, and/or
- 15 - compensating for red ambient light by comparing color of the 2D images with predetermined color ranges, and suppressing the red component of the recorded color if this is not within a predetermined color range.

Abstract

Disclosed is a scanner, a scanner system, a user interface and a method for obtaining 3D surface geometry and surface color of an object, the scanner comprising:

- 5 - a multichromatic light source configured for providing a probe light, and
- a color image sensor comprising an array of image sensor pixels for recording one or more 2D images of light received from said object, where at least for a block of said image sensor pixels, both surface color and 3D surface geometry of a part of the object are derived at least
- 10 partly from one 2D image recorded by said color image sensor.

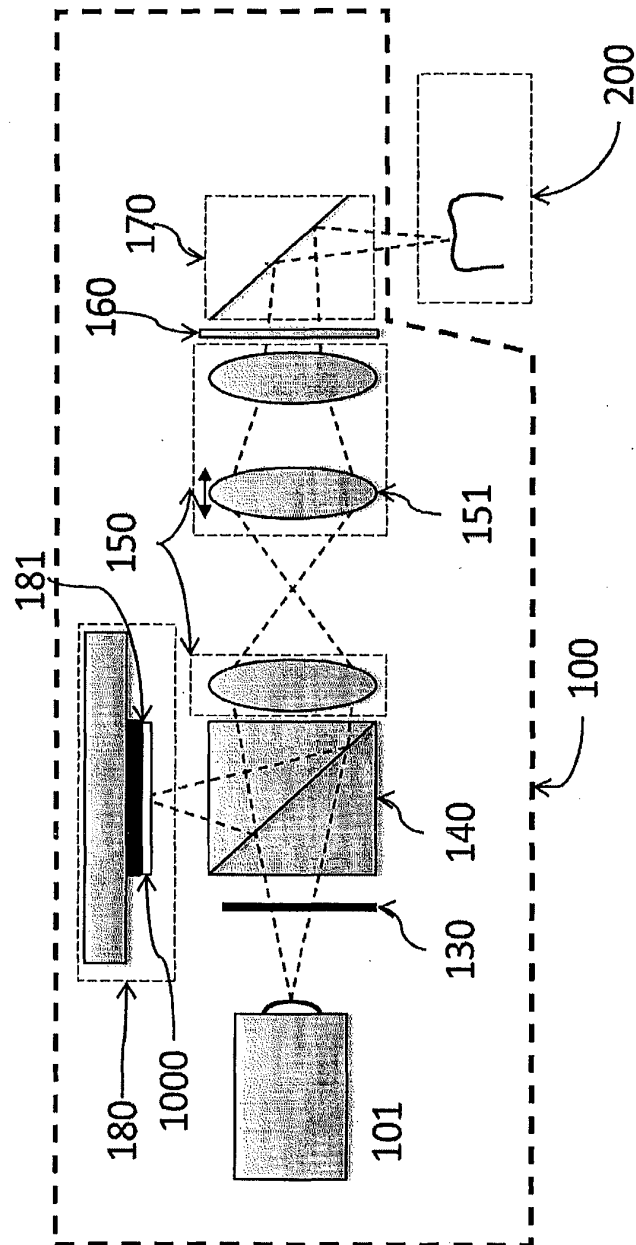
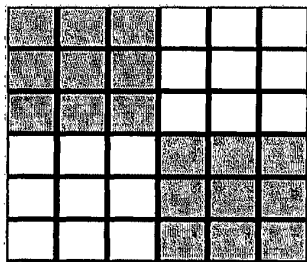
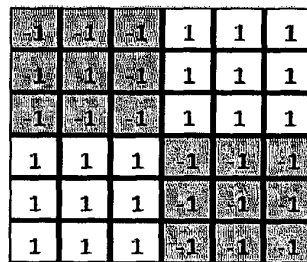


Fig. 1

2/3

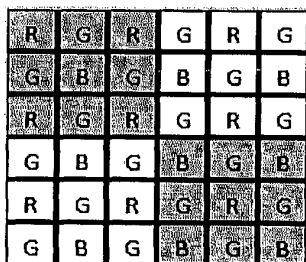


(a)

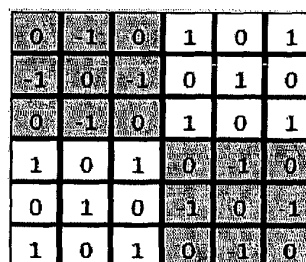


(b)

Fig. 2



(a)



(b)

Fig. 3

3/3

G	G	G	G	G	G
G	R	G	G	R	G
G	G	G	G	G	G
G	G	G	G	G	G
G	B	G	G	B	G
G	G	G	G	G	G

Fig. 4

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		Application Number	Unassigned
Title of Invention	FOCUS SCANNING APPARATUS RECORDING COLOR		

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Secrecy Order in Parent Appl.?:: No

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Application Data Sheet 37 CFR 1.76		Attorney Docket Number	0079124-000065
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Application Data Sheet 37 CFR 1.76		Attorney Docket Number	0079124-000065
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Application Data Sheet 37 CFR 1.76		Attorney Docket Number	0079124-000065
		Application Number	Unassigned
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Application Data Sheet 37 CFR 1.76		Attorney Docket Number	0079124-000065
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Title of Invention	FOCUS SCANNING APPARATUS RECORDING COLOR		

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Application Data Sheet 37 CFR 1.76		Attorney Docket Number	0079124-000065
		Application Number	Unassigned
Title of Invention	FOCUS SCANNING APPARATUS RECORDING COLOR		

Correspondence Information:

Correspondence Customer Number:: 21839

Application Information:

Title:: FOCUS SCANNING APPARATUS RECORDING COLOR

Attorney Docket Number:: 0079124-000065

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Application Data Sheet 37 CFR 1.76		Attorney Docket Number	0079124-000065
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Title of Invention	FOCUS SCANNING APPARATUS RECORDING COLOR		

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Filing Date (YYYY-MM-DD)::

Priority Claimed::

Authorization to Permit Access:

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In accordance with 37 CFR 1.14(c), access may be provided to information concerning the date of filing this Authorization.

Application Data Sheet 37 CFR 1.76		Attorney Docket Number	0079124-000065
		Application Number	Unassigned
Title of Invention	FOCUS SCANNING APPARATUS RECORDING COLOR		

Applicant Information:

Providing assignment information in this section does not substitute for compliance with any requirement of part 3 of Title 37 of CFR to have an assignment recorded by the Office.

Applicant 1

If the applicant is the inventor (or the remaining joint inventor or inventors under 37 CFR 1.45), this section should not be completed. The information to be provided in this section is the name and address of the legal representative who is the applicant under 37 CFR 1.43; or the name and address of the assignee, person to whom the inventor is under an obligation to assign the invention, or person who otherwise shows sufficient proprietary interest in the matter who is the applicant under 37 CFR 1.46. If the applicant is an applicant under 37 CFR 1.46 (assignee, person to whom the inventor is obligated to assign, or person who otherwise shows sufficient proprietary interest) together with one or more joint inventors, then the joint inventor or inventors who are also the applicant should be identified in this section.

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- ☐ Person to whom the inventor is obligated to assign
- ☐ Person who shows sufficient proprietary interest

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Non-Applicant Assignee Information:

Providing assignment information in this section does not substitute for compliance with any requirement of part 3 of Title 37 of CFR to have an assignment recorded by the Office.

Application Data Sheet 37 CFR 1.76		Attorney Docket Number	0079124-000065
		Application Number	Unassigned
Title of Invention	FOCUS SCANNING APPARATUS RECORDING COLOR		

Assignee 1

Complete this section only if non-applicant assignee information is desired to be included on the patent application publication in accordance with 37 CFR 1.215(b). Do not include in this section an applicant under 37 CFR 1.46 (assignee, person to whom the inventor is obligated to assign, or person who otherwise shows sufficient proprietary interest), as the patent application publication will include the name of the applicant(s).

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Signature 	Date	2013-02-13
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