

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
14 February 2008 (14.02.2008)

PCT

(10) International Publication Number
WO 2008/019241 A2

(51) International Patent Classification:
G06F 19/00 (2006.01)

(21) International Application Number:

PCT/US2007/074689

(22) International Filing Date: 30 July 2007 (30.07.2007)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/835,852 4 August 2006 (04.08.2006) US

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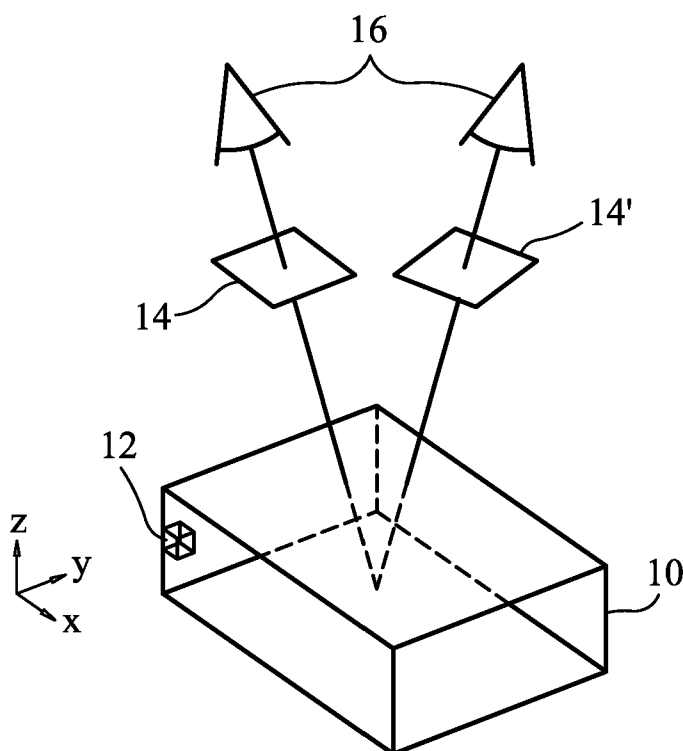
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(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

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(54) Title: METHOD FOR VIEWING THREE-DIMENSIONAL DATA SETS



(57) Abstract: The present invention provides a method for viewing three-dimensional data sets. As applied to a three-dimension data set obtained by OCT techniques, a plane at a particular angle is established within the data set, and voxels on either side of the plane may be emphasized relative to other voxels, for example, by increasing the transparency or decreasing the intensity of surrounding voxels. The emphasized voxels may then form a flat slice or slab within the data set that, by analogy with the slit-lamp, may be considered a "virtual slit" that highlights a section of the data set. The dimmer, non-emphasized surrounding voxels allow the section to be viewed in context. As in the slit-lamp, the method of the present invention may place the slit position, width and angle under the observer's control, which can be varied to highlight particular features of interest.



Published:

- *without international search report and to be republished
upon receipt of that report*

METHOD FOR VIEWING THREE-DIMENSIONAL DATA SETS

FIELD OF THE INVENTION

The present invention relates to a method for visualizing a three-dimensional data set, and in particular, a method for viewing images obtained through optical
5 coherence tomography.

BACKGROUND OF THE INVENTION

Numerous imaging methods are available for providing desired information in a particular clinical situation or setting. One such method employs tomography, which generally is a technique for creating a full three-dimensional image of a non-
10 planar object through correlating or combining a series of two-dimensional image slices through the particular object. One of the more popular examples of this particular technique includes X-Ray Computed Axial Tomography (CAT) scanning. In addition, another technique, Optical Coherence Tomography (OCT), has become a versatile and useful tool that can perform micron-resolution, cross-sectional imaging
15 of biological tissue, such as in the field of ophthalmology. In particular, OCT is a form of range-finding that makes use of the second-order coherence of a classical optical source to effectively section or "slice" a partially reflective sample with a resolution governed by the coherence length of the source. Sources of short coherence length (and consequently broad spectrum), such as ultrashort laser pulses,
20 are typically used in an OCT apparatus.

During operation of an OCT apparatus, for example, a target object of interest may be placed in one arm of an interferometer and illuminated through a beamsplitter with short coherence length light. Light is reflected from all depths within the target object in proportion to the localized reflectivity, and subsequently returned towards
25 the beamsplitter. At the same time, a mirror in the second arm of the interferometer also returns a portion of the original beam to the beamsplitter. Upon returning to the beamsplitter, the two beams are directed towards one or more detectors, where they are combined with each other. The combined beams coherently interfere only when the optical path lengths to the sample and to the mirror are equal. As a result, the
30 presence and strength of interfering light in a detector is indicative of the reflectance of the target object at a depth into the object corresponding to the reference mirror position and at the spatial location corresponding to the location of the detector. If an

array of detectors is placed in the sensing plane, an entire level-slice can be recorded simultaneously. The full three-dimensional image may be constructed by scanning the mirror and recording the obtained level slices.

Recent advances in OCT have enabled high-resolution data sets to be obtained
5 representing the reflectance of a large volume of tissue. In a particular ophthalmic application, OCT may be used to image a 6mm x 6mm retinal area to a depth of 2mm. Such imaging may create a three-dimensional data set of 200 megabytes (MB) or more. While such detail and resolution provides obvious benefits in identifying and quantifying physiological features of the imaged tissue, clinical presentation of the
10 large quantity of information contained in the three-dimensional data set presents a significant obstacle, i.e., the data set and corresponding images may be difficult for a physician to both qualitatively and quantitatively analyze. Present viewing of images obtained by high-speed OCT systems, while representing three-dimensional data, usually consists of looking at two-dimensional cross-sections. When viewed in
15 sequence, the physician constructs a mental three-dimensional image of the information, which may include the retinal anatomy and its pathological disturbance. Given the large amount of data for a voluminous tissue sample, such mental earmarking presents a potentially difficult task in navigating a particular three-dimensional data set obtained through OCT methods, and further acts as a significant
20 impediment to the wide-spread deployment of high-speed OCT technologies.

In light of the limitations described above, it would be desirable to provide methods for the efficient review and analysis of OCT data, and further, to allow an eye care professional to navigate and view the OCT images similarly to more traditional techniques, such as a slit-lamp examination of the eye.

SUMMARY OF THE INVENTION

The present invention provides a method for viewing three-dimensional data sets. As applied to a three-dimension data set obtained by OCT techniques, a plane at a particular angle is established within the data set, and voxels on either side of the
5 plane may be emphasized relative to other voxels, for example, by increasing the transparency or decreasing the intensity of surrounding voxels. The data set may be rendered with appropriate transparency and intensity to enable viewing throughout its depth (i.e., superficial voxels with higher values might not obscure deeper voxels). The data set may then be viewed stereoscopically to allow the observer to appreciate
10 the arrangement of objects in depth.

In addition, the emphasized voxels may then form a flat slice or slab within the data set that, by analogy with the slit-lamp, may be considered a “virtual slit” that highlights a section of the data set. The dimmer, non-emphasized surrounding voxels allow the section to be viewed in context, as opposed to other techniques which
15 render portions of the data set completely transparent, thereby reducing the ability to view the desired images in context with the surrounding structure and depth. As in the slit-lamp, the method of the present invention may place the slit position, width and angle under the observer’s control, which can be varied to highlight particular features of interest.

20 The method for viewing three-dimensional data described herein, including use of a “virtual slit-lamp,” presents a view that is more familiar to an eye care professional and removes the requirement of holding a memory of surrounding regions while viewing a particular cross-section. Thus the method may be instantly and intuitively obvious to ophthalmologists and optometrists who use “slit-lamp”
25 visualization of structures clinically. Moreover, the method may be equally applicable in studying or illustrating quantified features within any three-dimensional object, or more abstractly, any mathematical relationships of four or more variables (three independent variables and one or more dependent variables).

In particular, the present invention may provide a method for viewing three-
30 dimensional data, the method including the steps of obtaining a three-dimensional data set including a first plurality of voxels, with each voxel including a defined value for at least one of color, intensity, and transparency. The three dimensional data set

may be obtained by OCT techniques, radiography techniques, ultrasound techniques, and/or any other imaging procedure or technique providing a three-dimensional data set. The method may further include projecting the three-dimensional data set onto first and second stereoscopic planes for binocular viewing. A second plurality of
5 voxels may be selected or otherwise identified from the first plurality of voxels, and the method may include modifying the defined values for the second plurality of voxels, or alternatively, modifying the defined values for the voxels not included in the second plurality of voxels. The step of modifying the defined values may include an adjustment of any and/or all of the color, intensity and transparency of the
10 particular voxels being modified, or any other visible characteristics thereof. The second plurality of selected voxels may define a substantially continuous two-dimensional segment of the data set, whether planar, contoured, or having planar and contoured segments.

BRIEF DESCRIPTION OF THE DRAWINGS

15 A more complete understanding of the present invention, and the attendant advantages and features thereof, will be more readily understood by reference to the following detailed description when considered in conjunction with the accompanying drawings, wherein like designations refer to like elements, and wherein:

FIG. 1 illustrates an embodiment of a method of stereoscopic viewing of
20 suitably rendered data values of a three-dimensional data sets in accordance with the present invention; and

FIG. 2 depicts an embodiment of a method of stereoscopic viewing of suitably rendered data values of a three-dimensional data set with a superimposed highlighted slit in accordance with the present invention.

25 DETAILED DESCRIPTION OF THE INVENTION

The operation and/or application of the method of the present invention, namely a method for viewing three-dimensional data sets, and the corresponding value for ophthalmic OCT can be understood by first considering the principles underlying a routine slit-lamp examination of the eye. A slit-lamp consists of a
30 stereoscopic microscope and a moveable light source that produces a narrow, slit-shaped beam of light. The microscope provides separate views for each of the observer's eyes, thus preserving binocular information and, for an observer with

normal stereoscopic vision, the perception of three dimensions. The slit beam illuminates a tissue plane that lies at an angle to the line of sight and highlights the tissue intercepted by the beam against a darker background. Surrounding structures are dimly lit with scattered light, which allows the highlighted tissue to be seen in context. As a result, the operator sees the highlighted tissue as a cross-section. The observer may vary the position, angle and width of the beam as desired to emphasize particular features of interest. Accordingly, the principles involved in slit-lamp examination are, therefore, 1) stereoscopic viewing to provide a three-dimensional percept to the observer and 2) a slit-shaped illumination beam under observer control.

Now referring to FIG. 1, an apparatus and method for viewing a three-dimensional data set 10 analogous to viewing with a stereoscopic microscope is shown. The data set 10 is arranged as a three-dimensional array of a plurality of volume elements (voxels) 12 in an image space (x, y, z axes). Each voxel 12 may include defined values for color, intensity and/or transparency according to pre-determined parameters that encode the intensity, polarization, and/or other properties of light as measured by an OCT instrument. The three-dimensional array of voxels 12 may then be projected onto two stereoscopic projection planes 14, 14' to form a pair of images that, when viewed binocularly by an observer 16 with an appropriate apparatus, will produce the perception of depth. Both the strength of the perception of depth and the magnification of image features can be controlled by varying the parameters of the projection. In addition, the data set, manipulation of the data set, and the projection of the data set for viewing may be computer implemented processes performed by a capable computational and/or processing device.

Methods for generating stereoscopic projections are well known. Stereoscopic viewing of OCT data may be achieved through several available methods, including use of a stereo viewer that permits rapid alternate viewing of the two images by the two eyes, or spectral separation of the images to be viewed through filters of two different colors, to name but two examples.

Now referring to FIG. 2, an apparatus and method for viewing the three-dimensional data set 10 analogous to slit illumination is shown. Primarily, a plurality of voxels within the data set are selected and/or otherwise identified for viewing. The selected plurality of voxels may define a substantially continuous two-dimensional

segment, which may include planar characteristics, contoured characteristics, and/or a combination of both. Upon identification and/or selection of the desired plurality of voxels, the relative visible characteristics (i.e., color, intensity, transparency and the like) of either the selected plurality of voxels, or those voxels not included in the
5 selected plurality, may be modified to provide a visual distinction between the selected voxels and the remaining voxels of the data set 10.

For example, in a particular application, a plane 18 at a particular angle may be established within the data set, and voxels on either side of the plane are emphasized relative to other voxels. Voxels can be emphasized, for example, by
10 increasing the transparency or decreasing the intensity of surrounding voxels. The emphasized voxels may then form a flat slice or slab within the data set that, by analogy with the slit-lamp, may be considered a “virtual slit” that highlights a section of the data set. The dimmer, non-emphasized surrounding voxels allow the highlighted section to be viewed in context. As in the slit-lamp, the method of the
15 present invention may place the slit position, width and/or angle under the observer’s control, which can be varied to highlight particular features of interest. Of course, the data set and any manipulation thereof, including the adjustment of the “virtual slit” or highlighted segment of the data set may be performed on a computer or similar processing machine able to provide the desired computational and visual output. The
20 ability of the observer to manipulate the “virtual slit” provides for dynamic control of the particular portion of the image data that is emphasized and further enables simplified navigation and viewing of the data set. The modified data set may be viewed stereoscopically, so that the observer will see a three-dimensional translucent image within which a cross-sectional plane has been highlighted. This provides a
25 view of a two-dimensional subset of the data at a selected cross-section within the three dimensions.

Exemplary applications of the method of the present invention to visualizing three-dimensional OCT images of structures in the eye include, for example, revealing the cystic spaces of macular edema over a much larger area than can be
30 appreciated in single b-scans, examining the topography of the optic nerve head for detecting the damage due to glaucoma and, for anterior segment OCT, producing images that are directly analogous to the conventional slit-lamp view.

The capabilities of the method of the present invention extend beyond the slit-lamp analogy, however, because the relation between the observer 16, the selected voxels and the three-dimensional data set 10 is not constrained by the pupil of the eye. For example, the three-dimensional array can be rotated to allow viewing of the
5 imaged tissue from any direction. Similarly, the slit can intersect the data set at any angle to emphasize and/or otherwise highlight particular voxels and/or regions of interest. As an explicit example of these capabilities, consider in FIG. 2 a three-dimensional data set representing a retina imaged by OCT and oriented such that the usual fundus view extends in the x,y directions and retinal depth extends in z. A slit
10 parallel to the yz plane viewed along the x axis will provide the same view as a conventional B-scan and a horizontal slit would produce an en face section of the retina that could be varied in depth, producing an image similar to a C-scan.

An additional capability of the method of the present invention is that the two-dimensional surface cutting through the three-dimensional data set does not need to be
15 planar, as it is a mathematical construct of data obtained through the imaging process. As such, the particular "slice" or portion of interest could be, for example, a curved sheet that follows the curvature of the retinal image to allow layer-by-layer examination of the retina, or may conform to the appropriate contour and/or curvature of the particular tissue specimen being examined.

20 The method of the present invention may be incorporated and/or integrated with an OCT apparatus as a software or user interface module. A module including the "virtual slit" method of the present invention has the advantage of minimal computation time, as the only processing required is a conversion of voxel intensity values to transparency and/or other intensity values according to the pre-determined
25 parameters that encode the voxel intensity. Through the integrated interface, a physician or operator may manipulate the particular characteristics of the "virtual slit" to navigate and view desired portions of the tissue sample in context. Moreover, the physician or operator is not necessarily constrained to viewing the specimen along a particular axis or restricted to a particular imaging layer. Rather, the "virtual slit"
30 may provide for complete freedom to highlight and/or navigate the tissue specimen from practically any angle, to any depth, along any desired line or curve.

The "virtual slit" view may also be augmented to reveal previously determined tissue surfaces. For example, image segmentation algorithms may be applied to the data set to divide the tissue along interfaces that separate layers or structures having different properties or characteristics. The result of segmentation may provide one or
5 more surfaces which can be mathematically represented as thin sheets in a three-dimensional space. In addition, segmented surfaces may be added to the three-dimensional data set to highlight interfaces between respective portions of the array. While these sheets may usually be displayed by themselves, they may also be rendered within the three-dimensional data set with suitable transparency and color so
10 that they can be viewed stereoscopically in relation to other structures. Further, the intersection of these sheets with the "virtual slit" can be highlighted to emphasize the position of the sheet on the surface revealed by the slit.

The methods of the present invention may further provide for the viewing and/or manipulation of a projection view of a particular portion of the three-
15 dimensional data set. For example, rather than viewing the data and corresponding images stereoscopically, a projection may be viewed of a given depth and or region of the data set, resulting in a monocular view. This would allow the desired images and/or information to be projected onto a printed page or other two-dimensional surface when stereo methods are not available or are not desired. The resulting
20 projection would retain much of the information of the image, losing only the percept of depth.

The method for viewing three-dimensional data as described herein is particularly advantageous for ophthalmic data because it allows direct comparison with stereoscopic views of the ocular structures obtained by the clinician directly with
25 images or views obtained by slit-lamp and ophthalmoscope techniques. Of course, while the method disclosed herein has been described in relation to ophthalmic applications, the features and advantages of the method of the present invention is contemplated to be equally applicable in any field and/or application where navigating, viewing, and/or manipulating a three-dimensional data set is desired.
30 Moreover, the techniques described may be used with additional imaging applications, including but not limited to radiography, ultrasound, and the like. For example, even with stereoscopic viewing of a segmented or non-segmented rendering

of a 3-D radiologic image, some layers may be sufficiently dense that deeper structures are obscured. For example, by usual methods, the surface of an organ, such as the heart, may be viewed easily, but the internal structures (chambers and valves) might be obscured. Soft tissue structures within or near bone may pose a particular
5 problem. By adjusting the voxel characteristics and appearance, i.e., by making the voxels semitransparent, the inner structures might be seen and studied with a virtual slit that can be moved. Segmentation methods might identify layers that should specifically be reduced in intensity such that subtle voxels and the contrast between them remain above the noise level of the image signal and hence are visible as the
10 entire image is made less opaque for viewing by the described method. Alternatively, as the image is made semitransparent, the reduced voxel intensity might be reduced logarithmically rather than linearly so as not to lose the information in the less intense portions of the image.

It will be appreciated by persons skilled in the art that the present invention is
15 not limited to what has been particularly shown and described herein above. In addition, unless mention was made above to the contrary, it should be noted that all of the accompanying drawings are not to scale. A variety of modifications and variations are possible in light of the above teachings without departing from the scope and spirit of the invention, which is limited only by the following claims.

What is claimed is:

1. A method for viewing three-dimensional data, comprising the steps of:
obtaining a three-dimensional data set including a first plurality of voxels,
with each voxel including a defined value for at least one of color, intensity, and
5 transparency; and
projecting the three-dimensional data set onto first and second stereoscopic
planes for binocular viewing.
2. The method of Claim 1, further comprising the steps of selecting a second
plurality of voxels from the first plurality; and modifying the defined values for
10 the second plurality of voxels.
3. The method of Claim 2, wherein the step of modifying the defined values includes
increasing at least one of the color, intensity and transparency of the second
plurality of voxels.
4. The method of Claim 2, wherein the second plurality of voxels is substantially
15 coplanar within the three-dimensional data set.
5. The method of Claim 2, wherein the second plurality of voxels comprises a
substantially continuous two-dimensional segment of the data set.
6. The method of Claim 1, further comprising the steps of selecting a second
plurality of voxels from the first plurality and modifying the defined values for the
20 voxels not included in the second plurality of voxels.
7. The method of Claim 6, wherein the step of modifying the defined values includes
decreasing at least one of the color, intensity and transparency of the voxels not
included in the second plurality of voxels.
8. The method of Claim 6, wherein the second plurality of voxels is substantially
25 coplanar within the three-dimensional data set.
9. The method of Claim 6, wherein the second plurality of voxels comprises a
substantially continuous two-dimensional segment of the data set.
10. The method of Claim 1, further comprising the steps of selecting a plane within
the data set, and modifying the defined values of voxels lying on either side of the
30 plane.
11. The method of Claim 10, further comprising the step of adjusting an angle of the
selected plane with respect to the data set.

12. The method of Claim 1, further comprising the step of modifying a magnification of the three-dimensional data set projected onto the first and second stereoscopic planes.
- 5 13. The method of Claim 1, further comprising the step of rotating the three-dimensional data set.
14. The method of Claim 1, wherein the data set is obtained from an optical coherence tomography technique.
15. The method of Claim 1, wherein the data set is obtained from a radiography
10 technique.
16. The method of Claim 1, wherein the data set is obtained from an ultrasound technique.

