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(54) **INTERACTIVE 3D CURSOR FOR USE IN MEDICAL IMAGING**

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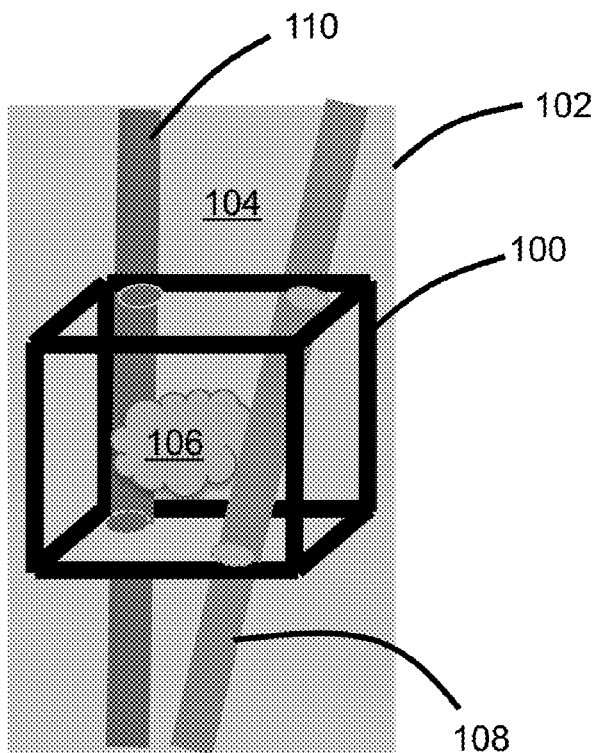See (63) and (60) Related U.S. Application Data.

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Related U.S. Application Data

(63) Continuation-in-part of application No. 14/877,442, filed on Oct. 7, 2015, now Pat. No. 9,980,691, which is a continuation-in-part of application No. 12/176, 569, filed on Jul. 21, 2008, now Pat. No. 9,349,183, which is a continuation-in-part of application No. 11/941,578, filed on Nov. 16, 2007, now Pat. No. 8,384,771.

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CPC *G06F 3/0346* (2013.01); *G06F 3/04812* (2013.01); *G06F 3/04842* (2013.01); *G06F 3/03543* (2013.01); *G06T 2207/30204* (2013.01); *G06T 19/006* (2013.01); *A61B 6/466* (2013.01); *G06T 2207/10081* (2013.01); *G06T 2207/10104* (2013.01); *G06T 7/62* (2017.01)

(57) **ABSTRACT**

An interactive 3D cursor facilitates selection and manipulation of a three-dimensional volume from a three-dimensional image. The selected volume image may be transparency-adjusted and filtered to remove selected tissues from view. Qualitative and quantitative analysis of tissues in a selected volume may be performed. Location indicators, annotations, and registration markers may be overlaid on selected volume images.
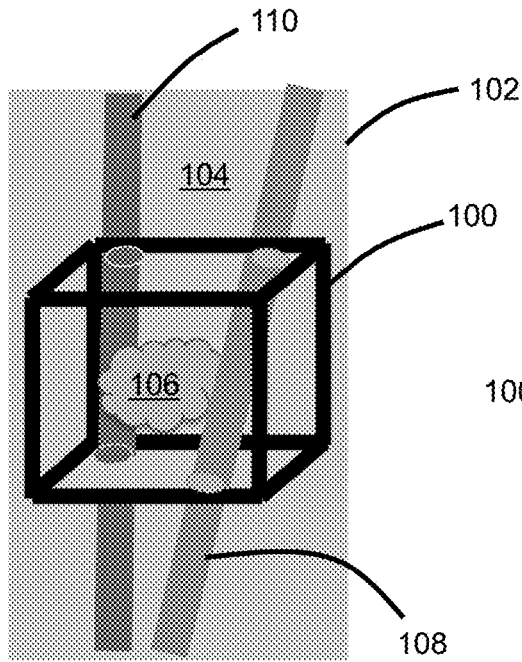
110

102

104

100

106

108

Figure 1A

112

110

100

106

108

Figure 1B

112

110

100

106

108

Figure 1C

100

112

100

106
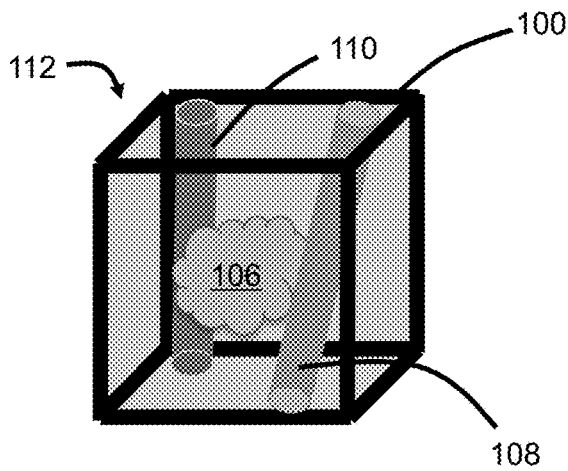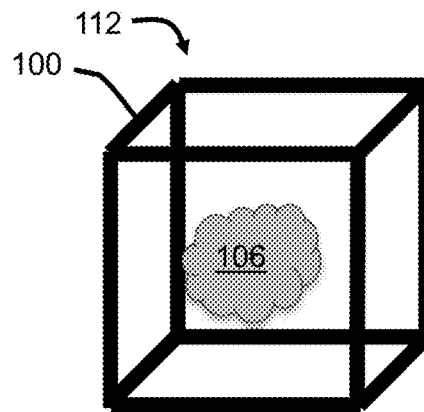
Figure 1D

Figure 2

Figure 3

400

404

412

Figure 4A

402

406

Figure 4B

408

410
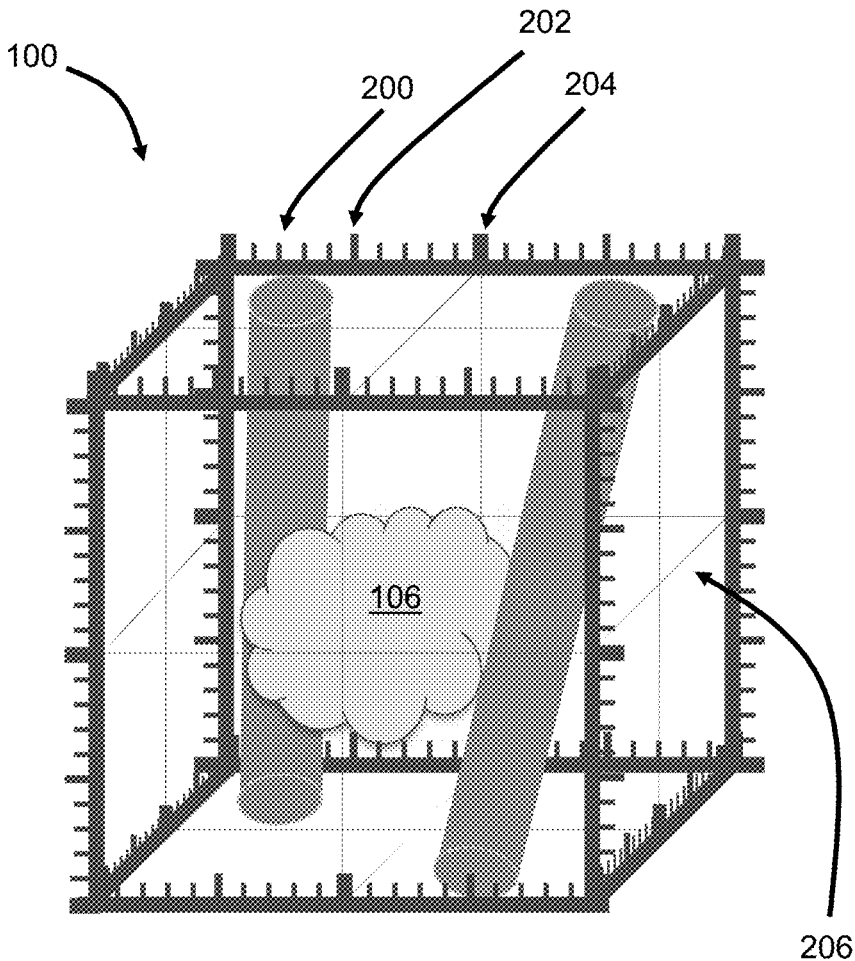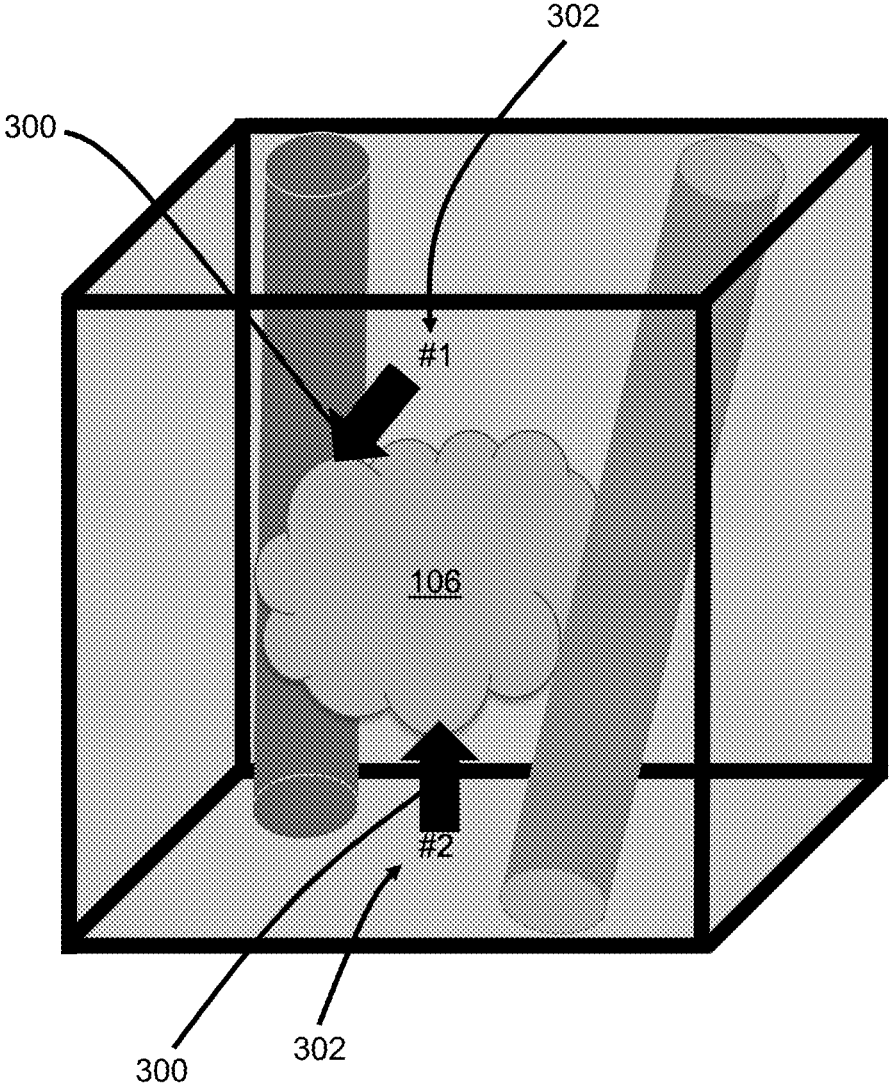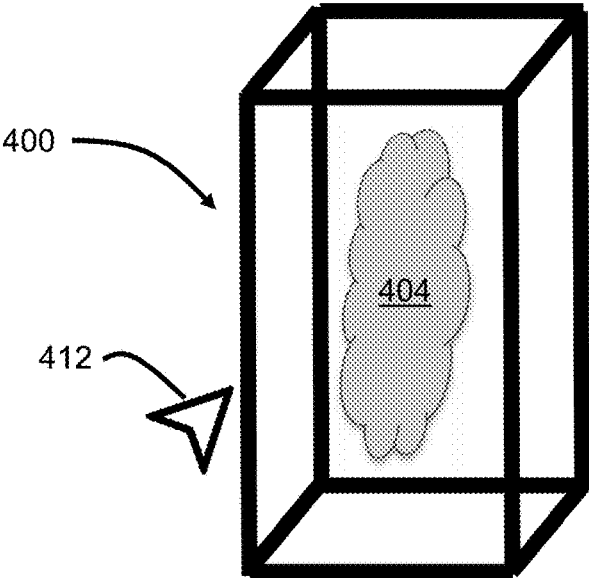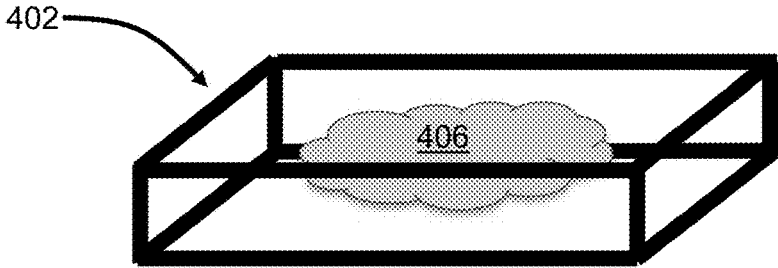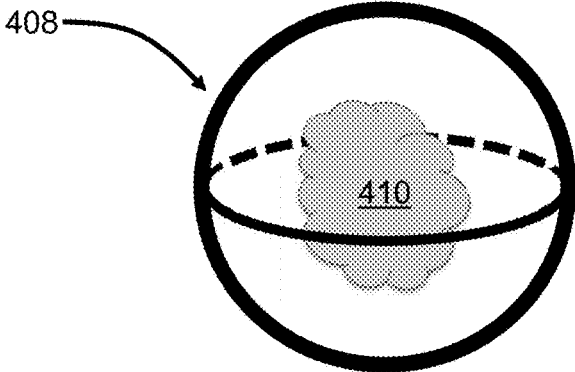
Figure 4C

500

Quantitative analysis of all tissues inside of 3D cursor

Volume
(# of
voxels)
in mL

504

Fat   Tumor   Vein   Artery

502

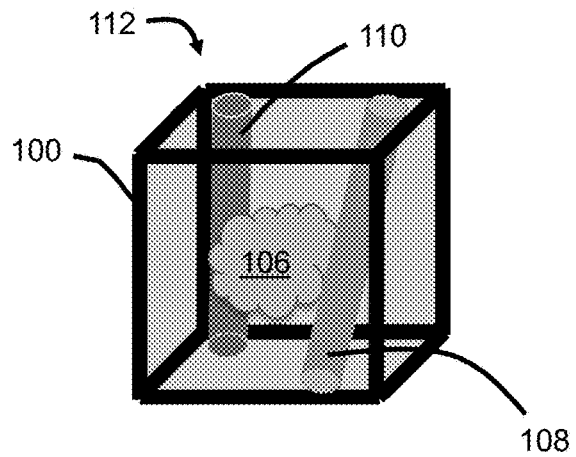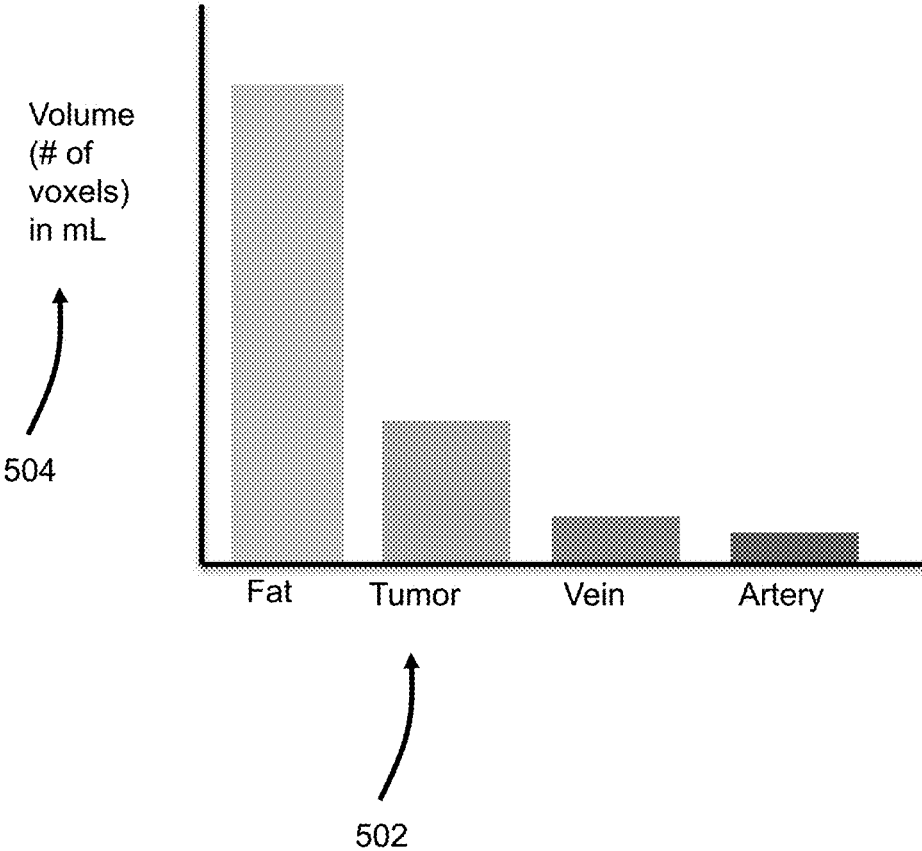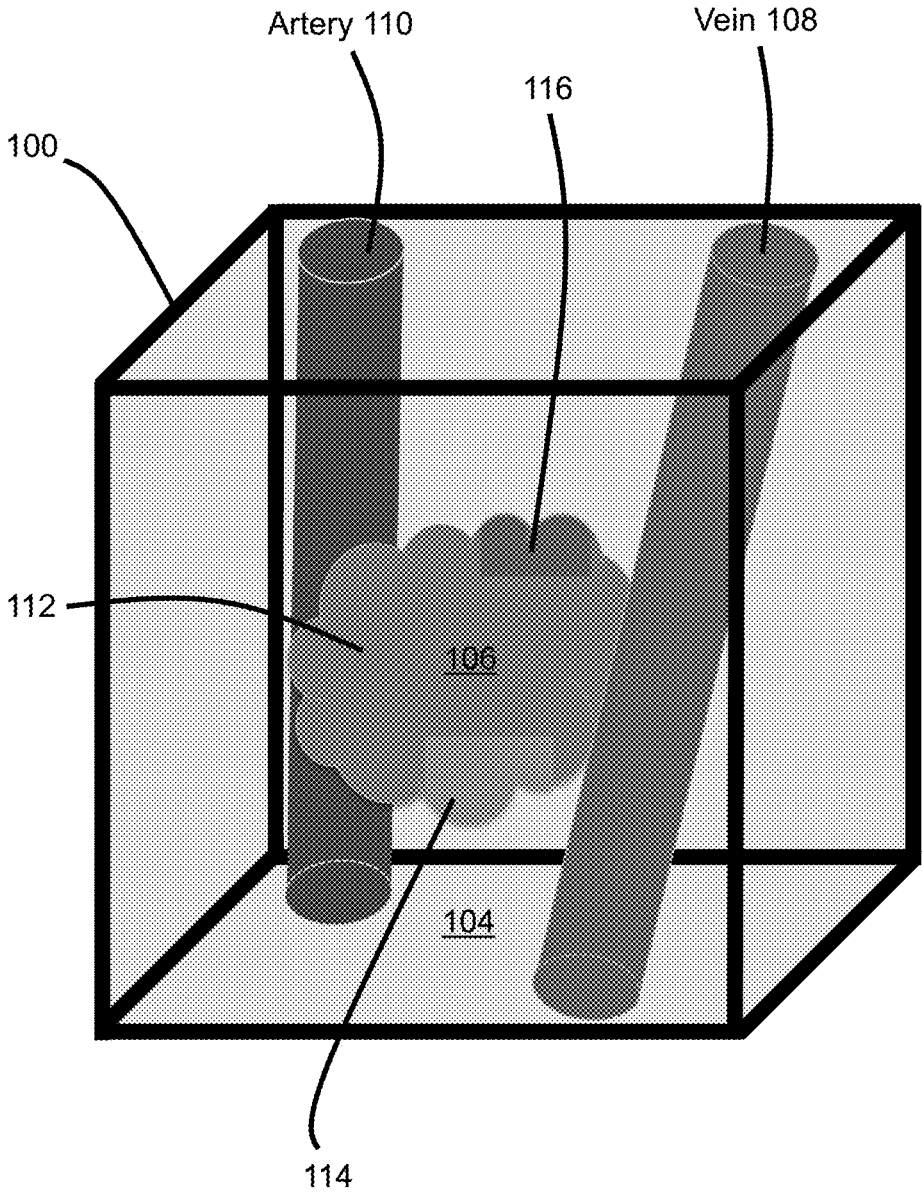Figure 5

Figure 6

Figure 7

Figure 8

100a

100b

900

Figure 9

1000

Radiology Report

1006 → Patient Identifying Information

1008 → Clinical History

1010 → Comparisons

1002 → Qualitative findings

1004 → Quantitative findings

1016 →

1012 → Conclusions

1014 → Recommendations

1018
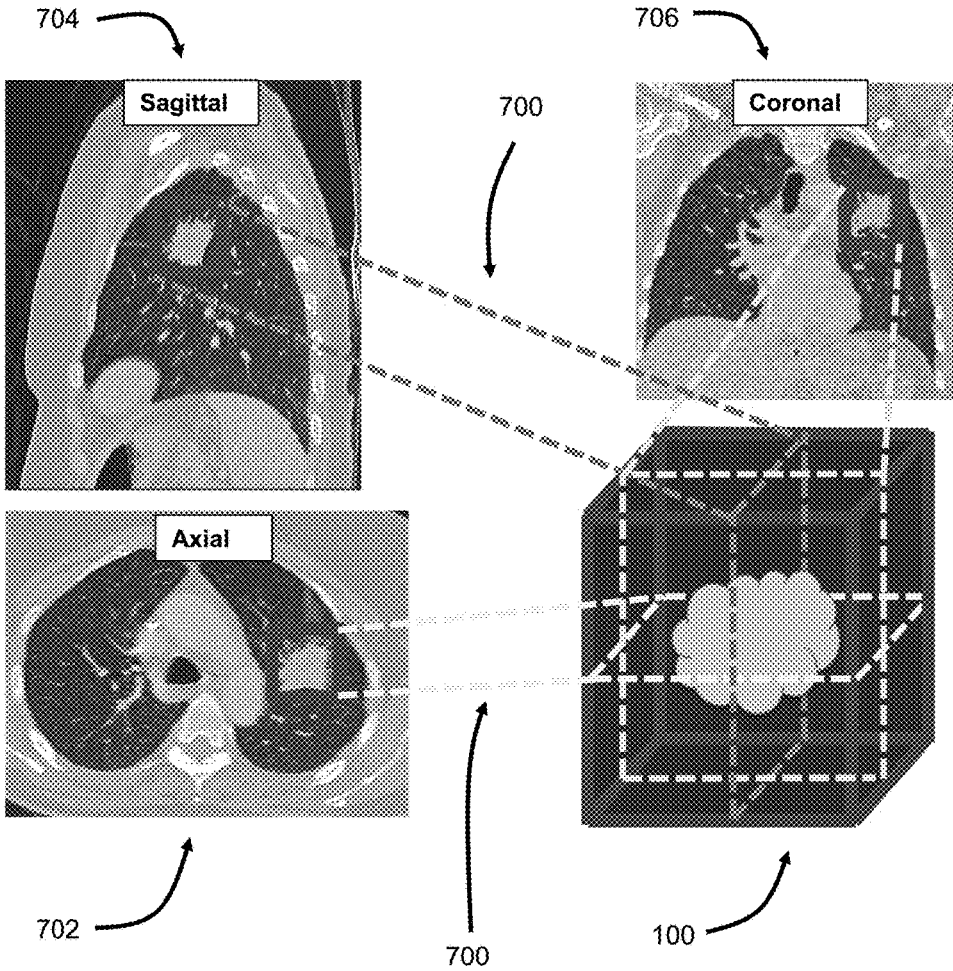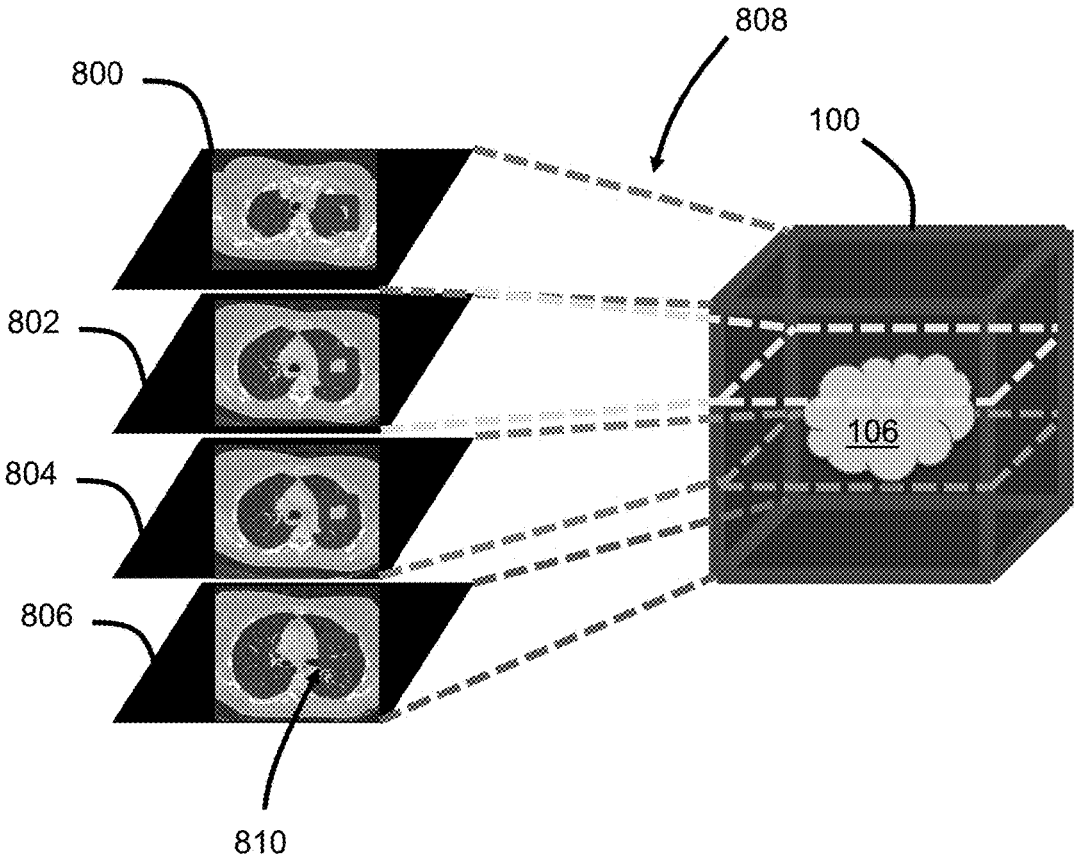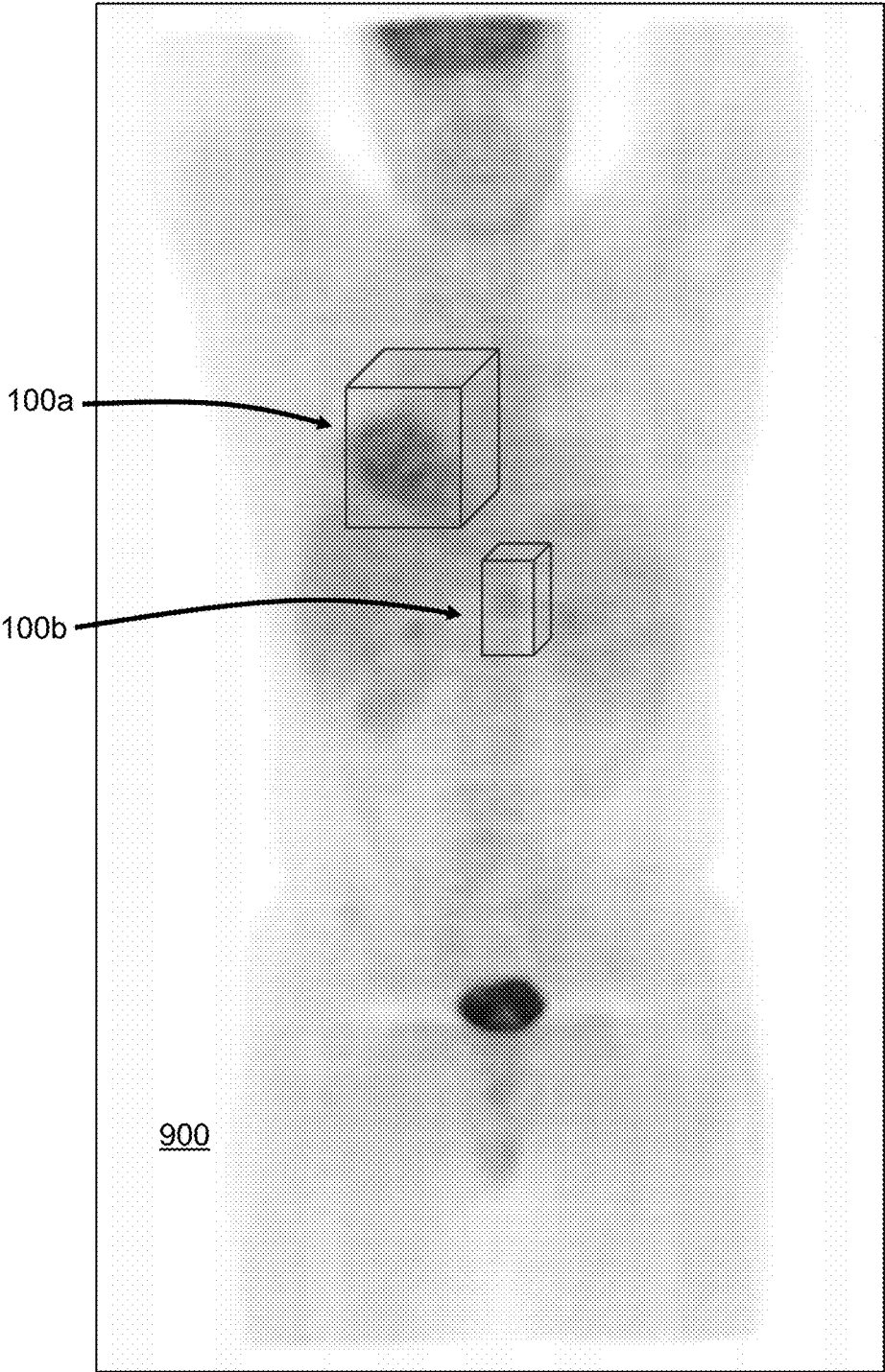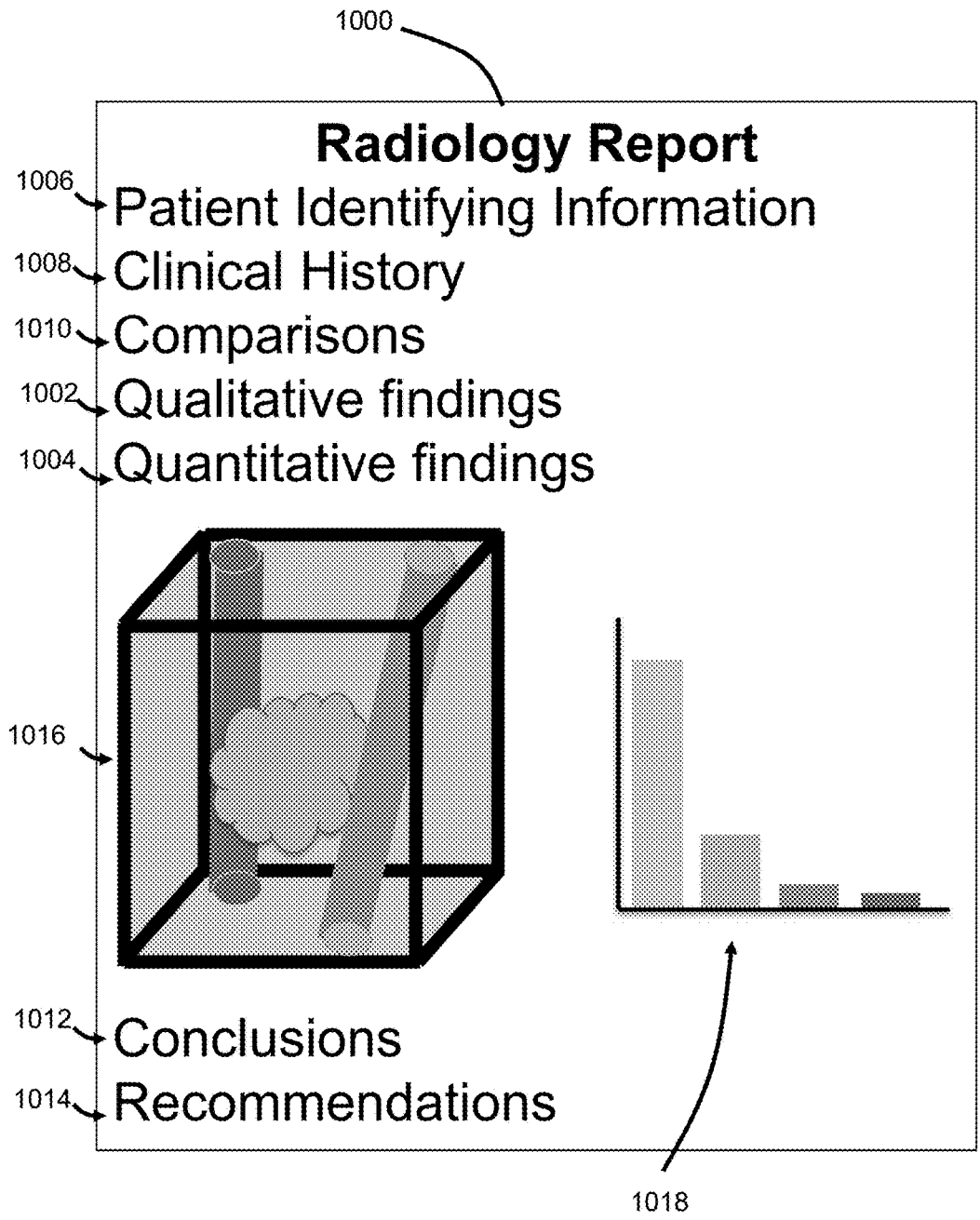
Figure 10

Figure 11

Figure 12A

Initial scan

Follow up scan

Figure 12B

Initial scan

Follow up scan

Figure 12C

Initial scan

Follow up scan

Figure 13

1406

1402

Instructor
1404

Students
1400

Figure 14

1 — Create a 3D cursor volume and shape that is approximate size and shape of patient organ/ tissue corresponding to the item currently being inspected on the checklist

2 — Position the 3D cursor over the organ/ tissue to be inspected. Display the 3D cursor as it is located within the total 3D volume

3 — Subtract tissue external to the 3D cursor. Rotate the 3D cursor to permit viewing from multiple angles

4 — Generate a statistical representation e.g., a histogram of tissue densities – color code the types of tissue that are suspicious

5 — Subtract additional tissue within the 3D cursor as deemed appropriate by the medical professional

6 — Inspect the volume within the cursor and identify region(s) of interest. Place arrows pointing to region(s) of interest

7 — Extract statistical representation and captures of imagery showing arrows and residual tissue within the 3D cursor to be inserted into the medical professional's report

8 — Use cross referencing as described above to confirm findings

9 — Iterate on the other items on checklist until finished

10 — Prepare the report of the medical professional's findings

Figure 15

1610

1602

1604

1600

1606

1608

Figure 16

INTERACTIVE 3D CURSOR FOR USE IN MEDICAL IMAGING

TECHNICAL FIELD

[0001] Aspects of this disclosure are generally related to human-machine interfaces, and more particularly to cursors.

BACKGROUND

[0002] The typical arrow-shaped cursor presented by a computer operating system is zero-dimensional. A zero-dimensional cursor designates the location of a single point in a space such as a two-dimensional window presented on a monitor. Mouse buttons can be used in combination with movement of the cursor to select objects in the two-dimensional space, but at any given instant of time a zero-dimensional cursor position designates only a single point in space.

[0003] The current standard for diagnostic radiologists reviewing computed tomography (CT) or magnetic resonance imaging (MRI) studies is a slice-by-slice method. A conventional keyboard, monitor, and mouse with a zero-dimensional cursor are used for manipulating the images. The use of mouse buttons and cursor movement for manipulating the images can become burdensome. For example, many images are included in radiology studies that are performed for the follow up of cancer to determine the response to treatment. The ability to recognize and analyze differences between images can be important. As an example, the recent Investigation of Serial Studies to Predict Your Therapeutic Response with Imaging and Molecular Analysis (I-SPY) trial tracked the changes in the tumor over multiple magnetic resonance imaging (MM) scans during the administration of neoadjuvant chemotherapy (NACT). It has been noted that the phenotypic a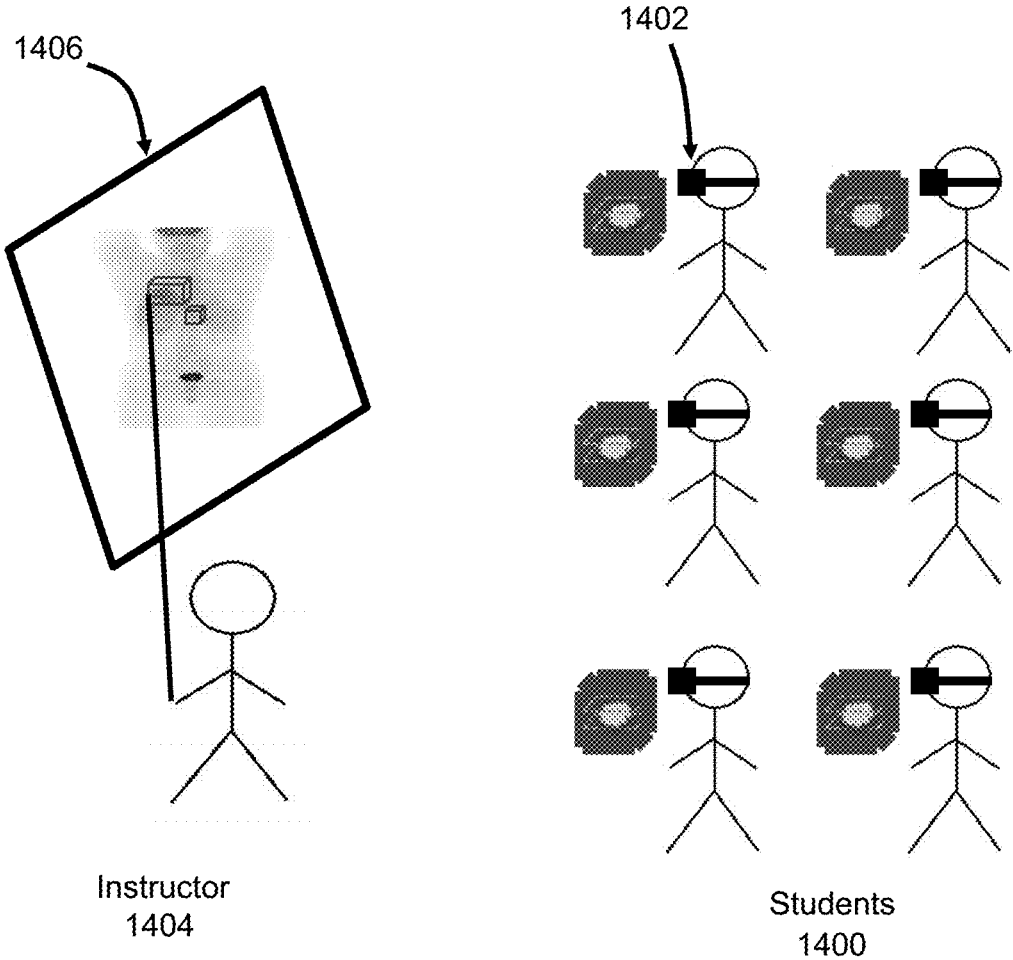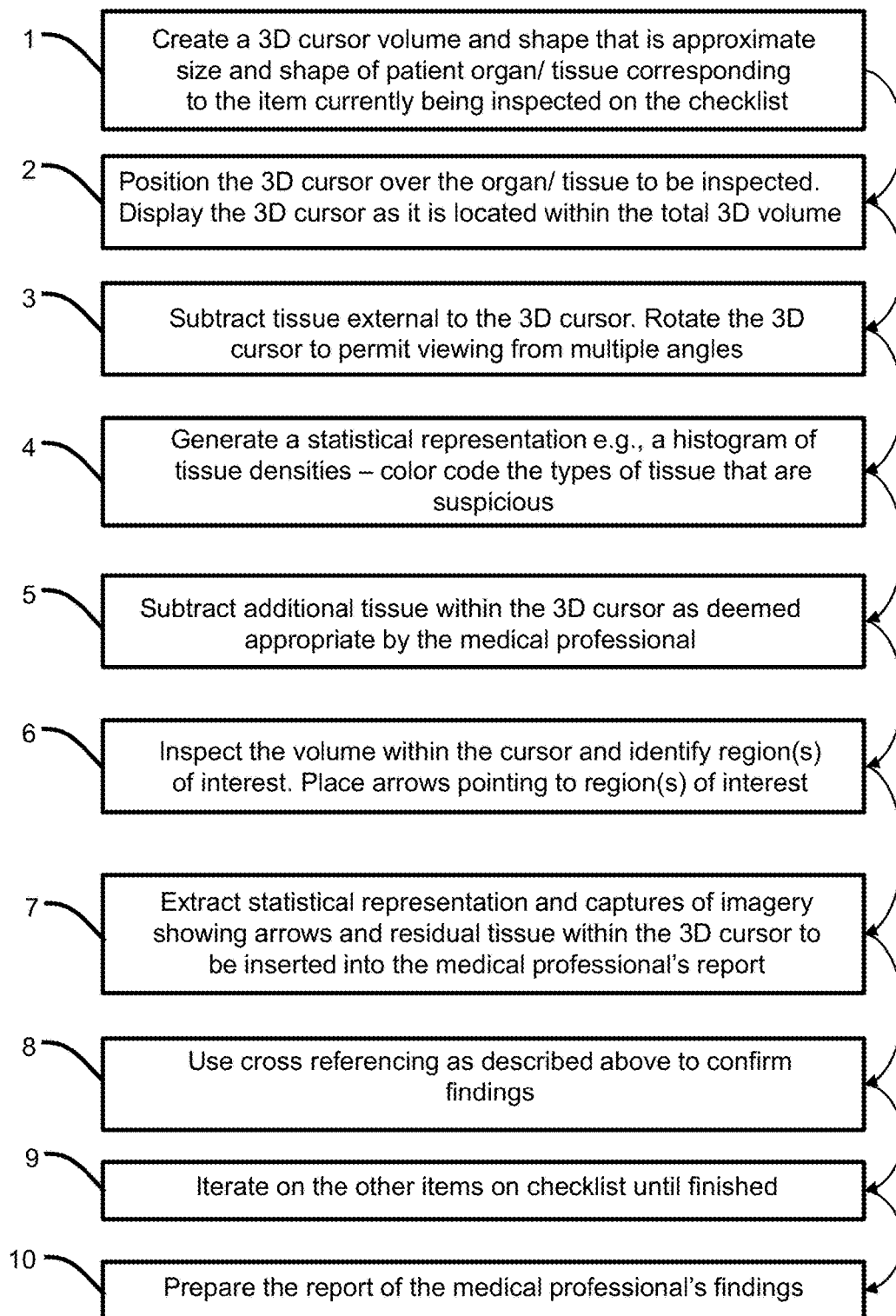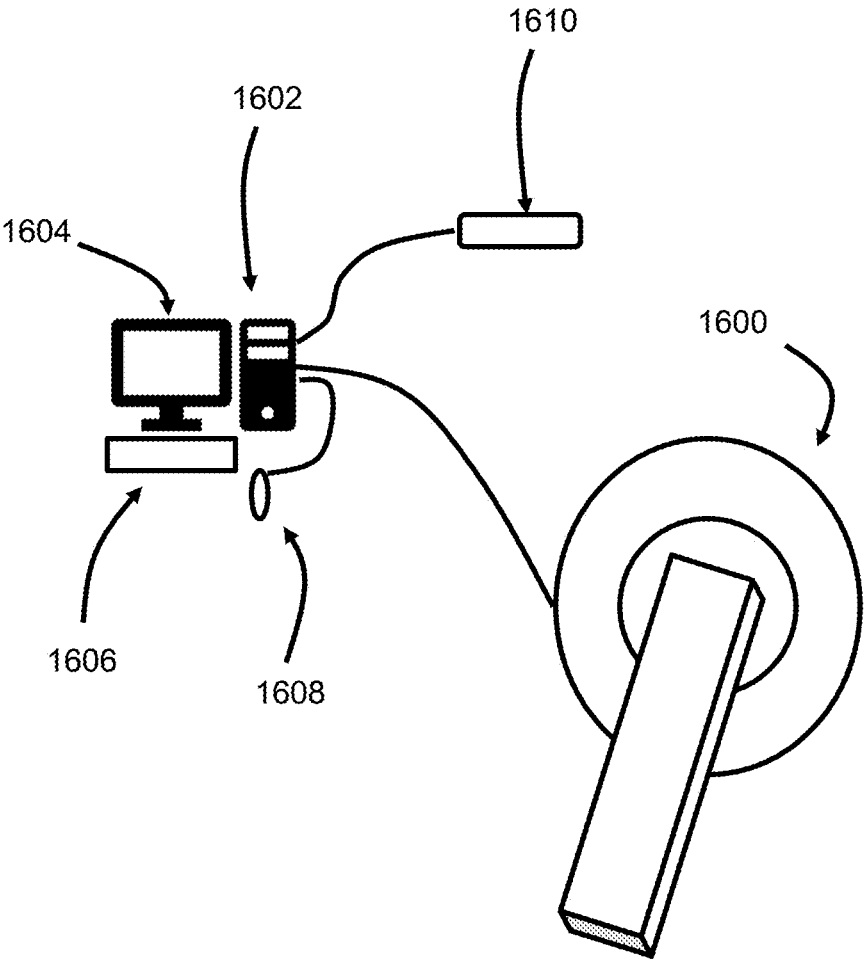ppearance (e.g., shape, margins) of a tumor correlated with the pathologic response to NACT. A more efficient and accurate interface for manipulating and presenting medical images would therefore have utility.

[0004] Known techniques for 3D viewing of medical images are described in U.S. Pat. No. 9,349,183, Method and Apparatus for Three Dimensional Viewing of Images, issued to Douglas, U.S. Pat. No. 8,384,771, Method and Apparatus for Three Dimensional Viewing of Images, issued to Douglas, Douglas, D. B., Petricoin, E. F., Liotta L., Wilson, E. D3D augmented reality imaging system: proof of concept in mammography. *Med Devices* (Auckl), 2016;9: 277-83, Douglas, D. B., Boone, J. M., Petricoin, E., Liotta, L., Wilson, E. Augmented Reality Imaging System: 3D Viewing of a Breast Cancer. *J Nat Sci.* 2016;2(9), and Douglas, D. B., Wilke, C. A., Gibson, J. D., Boone, J. M., Wintermark, M. Augmented Reality: Advances in Diagnostic Imaging. *Multimodal Technologies and Interaction,* 2017;1(4):29. In D3D imaging, the radiologist wears an augmented reality (AR), mixed reality (MR) or virtual reality (VR) headset and uses a joystick or gaming controller. Advantages include improved depth perception and human machine interface. Still, there are several challenges faced with this approach. First, an area of interest (e.g. tumor) may be in close proximity to structures that are similar in composition/density. Isolating the area of interest for better examination may be difficult. Second, many soft tissues in the body are mobile and deformable, so it can be difficult to achieve the best orientation to properly compare the tumor at multiple time points. Efficiently aligning the orientation to do so may be difficult. Third, certain portions of a tumor can respond to treatment and decrease in size while other portions of a tumor demonstrate increases in size. The pattern of tumor shrinkage has important prognostic implications. Furthermore, composition and complex morphologic features including spiculations (spikes extending from the surface), irregular margins and enhancement also have important implications. Consequently, there is a need for a system that facilitates recognition of the subtle, yet important changes in size, shape and margins. Fourth, a patient with metastatic cancer has several areas of interest in different areas of the body. It is difficult and time consuming to find each of the areas of interest at every time point to determine interval change. Consequently, there is a need for a system that enables the observer to do this efficiently.

SUMMARY

[0005] All examples, aspects and features mentioned in this document can be combined in any technically possible way.

[0006] In accordance with an aspect of the invention a method comprises: generating a three-dimensional cursor that has a non-zero volume; responsive to a first input, moving the three-dimensional cursor within a three-dimensional image; responsive to a second input, selecting a volume of the three-dimensional image designated by the three-dimensional cursor; and responsive to a third input, presenting a modified version of the selected volume of the three-dimensional image. In some implementations presenting the modified version of the selected volume of the three-dimensional image comprises removing an un-selected volume of the three-dimensional image from view. In some implementations presenting the modified version of the selected volume of the three-dimensional image comprises changing transparency of presented tissues within the selected volume. In some implementations presenting the modified version of the selected volume of the three-dimensional image comprises filtering a selected tissue to remove the selected tissue from view. In some implementations presenting the three-dimensional cursor with measurement markings on at least one edge, surface or side. In some implementations presenting the modified version of the selected volume of the three-dimensional image comprises presenting inputted location indicators. In some implementations presenting the modified version of the selected volume of the three-dimensional image comprises presenting inputted annotations. Some implementations comprise changing a size dimension of the three-dimensional cursor responsive to a fourth input. Some implementations comprise changing a geometric shape of the three-dimensional cursor responsive to a fifth input. Some implementations comprise automatically generating a statistical representation of the selected volume of the three-dimensional image. In some implementations presenting the modified version of the selected volume of the three-dimensional image comprises presenting at least one tissue type with false color. In some implementations presenting the modified version of the selected volume of the three-dimensional image comprises presenting volumetric changes over time with false color. Some implementations comprise presenting multiple computed tomography images associated with the selected volume using reference lines. Some implementations comprise presenting multiple axial computed tomography

images associated with the selected volume using reference lines. Some implementations comprise presenting a maximum intensity projection (MIP) image of a positron emission tomography (PET) scan with the three-dimensional cursor overlaid thereon to indicate orientation and location of the selected volume. Some implementations comprise presenting a radiology report enhanced with information obtained using the three-dimensional cursor. Some implementations comprise automatically calculating and presenting a quantitative analysis and a qualitative analysis associated with multiple time points. Some implementations comprise presenting the modified version of the selected volume of the three-dimensional image comprises presenting inputted registration markers. Some implementations comprise automatically calculating volumetric change based on the registration markers. Some implementations comprise automatically re-orienting the selected volume of the three-dimensional image based on the registration markers. Some implementations comprise using multiple volumes selected with the three-dimensional cursor to designate a pre-operative planning pathway for guiding surgical intervention. Some implementations comprise presenting the selected volume with an augmented reality, virtual reality or mixed reality headset.

[0007] In accordance with an aspect of the invention an apparatus comprises: a computing device; and a human-machine interface comprising a three-dimensional cursor that has a non-zero volume; the human-machine interface moving the three-dimensional cursor within a three-dimensional image responsive to a first input; the human-machine interface selecting a volume of the three-dimensional image designated by the three-dimensional cursor responsive to a second input; and the human-machine interface presenting a modified version of the selected volume of the three-dimensional image responsive to a third input. In some implementations, the human-machine interface removes an un-selected volume of the three-dimensional image from view. In some implementations, the human-machine interface changes transparency of presented tissues within the selected volume. In some implementations, the human-machine interface filters a selected tissue to remove the selected tissue from view. In some implementations, the human-machine interface presents the three-dimensional cursor with measurement markings on at least one edge, surface or side. In some implementations, the human-machine interface receives and implements inputted location indicators. In some implementations, the human-machine interface receives and implements inputted annotations. In some implementations, the human-machine interface changes a size dimension of the three-dimensional cursor responsive to a fourth input. In some implementations, the human-machine interface changes a geometric shape of the three-dimensional cursor responsive to a fifth input. In some implementations, the human-machine interface automatically generates and presents a statistical representation of the selected volume of the three-dimensional image. In some implementations, the human-machine interface presents at least one tissue type with false color. In some implementations, the human-machine interface presents volumetric changes over time with false color. In some implementations, the human-machine interface presents multiple computed tomography images associated with the selected volume using reference lines. In some implementations, the human-machine interface presents multiple axial computed

tomography images associated with the selected volume using reference lines. In some implementations, the human-machine interface presents a maximum intensity projection (MIP) image of a positron emission tomography (PET) scan with the three-dimensional cursor overlaid thereon to indicate orientation and location of the selected volume. In some implementations, the human-machine interface presents a radiology report enhanced with information obtained using the three-dimensional cursor. In some implementations, the human-machine interface automatically calculates and presents a quantitative analysis and a qualitative analysis associated with multiple time points. In some implementations, the human-machine interface presents inputted registration markers. In some implementations, the human-machine interface automatically calculates volumetric change after appropriate registration using the registration markers. In some implementations, the human-machine interface automatically re-orients the selected volume of the three-dimensional image based on the registration markers. In some implementations, the human-machine interface presents multiple volumes selected with the three-dimensional cursor to designate a pre-operative planning pathway for guiding surgical intervention. In some implementations, the human-machine interface presents the selected volume with an augmented reality, virtual reality or mixed reality headset.

BRIEF DESCRIPTION OF THE FIGURES

[0008] The patent or application file contains at least one drawing executed in color. Copies of this patent or patent application publication with color drawing(s) will be provided by the Office upon request and payment of the necessary fee.

[0009] FIG. 1A illustrates a 3D cursor selecting a volume of interest from a three-dimensional medical image.

[0010] FIG. 1B illustrates the volume of interest selected with the 3D cursor;

[0011] unselected portions have been removed from view.

[0012] FIG. 1C illustrates modification of the transparency of the selected volume of interest.

[0013] FIG. 1D illustrates filtering of selected areas of the selected volume of interest.

[0014] FIG. 2 illustrates a variant of the 3D cursor of FIG. 1A with measurement markings on edges and sides.

[0015] FIG. 3 illustrates location indicators and annotations positioned relative to the portion of the image within the selected volume of interest.

[0016] FIGS. 4A, 4B, and 4C illustrate three different examples of geometric shapes of the 3D cursor of FIG. 1A.

[0017] FIG. 5 illustrates presentation of a quantitative analysis of tissues inside of the volume of interest selected with the 3D cursor of FIG. 1A.

[0018] FIG. 6 illustrates use of false color and transparency changes to enhance viewing of the selected volume of interest.

[0019] FIG. 7 illustrates association of multiple computed tomography (CT) images of the chest in lung windows with the interactive 3D cursor using reference lines.

[0020] FIG. 8 illustrates association of multiple axial computed tomography (CT) slices of the chest in lung windows with the interactive 3D cursor using reference lines.

[0021] FIG. 9 illustrates a maximum intensity projection (MIP) image of a fludeoxyglucose (18F) positron emission tomography (PET) scan in which two varying sized inter-

active 3D cursors are overlaid to indicate 3D cursor shape, size, orientation, and location when respective volumes of interest were selected.

[0022] FIG. 10 illustrates a radiology report enhanced with information obtained using the interactive 3D cursor and including quantitative and qualitative analysis.

[0023] FIG. 11 illustrates a radiology report enhanced with information obtained using the interactive 3D cursor, and including added quantitative and qualitative analysis at multiple time points.

[0024] FIGS. 12A, 12B and 12C illustrate a technique for correction for mis-registration at multiple time points using three or more markers.

[0025] FIG. 13 illustrates use of multiple interactive 3D cursors to select volumes of interest to designate a safe pre-operative planning pathway for guiding surgical intervention.

[0026] FIG. 14 illustrates use of the interactive 3D cursor in an educational setting.

[0027] FIG. 15 illustrates process steps on a radiologist's review of a patient's image with integration of the interactive 3D cursor.

[0028] FIG. 16 illustrates a system for use of the interactive 3D cursor.

DETAILED DESCRIPTION

[0029] Some aspects, features and implementations described herein may include machines such as computers, electronic components, radiological components, optical components, and processes such as computer-implemented steps. It will be apparent to those of ordinary skill in the art that the computer-implemented steps may be stored as computer-executable instructions on a non-transitory computer-readable medium. Furthermore, it will be understood by those of ordinary skill in the art that the computer-executable instructions may be executed on a variety of tangible processor devices. For ease of exposition, not every step, device or component that may be part of a computer or data storage system is described herein. Those of ordinary skill in the art will recognize such steps, devices and components in view of the teachings of the present disclosure and the knowledge generally available to those of ordinary skill in the art. The corresponding machines and processes are therefore enabled and within the scope of the disclosure.

[0030] FIG. 1A illustrates a 3D (three-dimensional) cursor 100 overlaid on a three-dimensional medical image 102. In the illustrated example, the 3D cursor 100 defines a cubic volume of interest. The medical image 102 could include any portion of a body, or an entire body, for example and without limitation. For purposes of explanation the medical image 102 includes different types of tissue. More specifically, the image includes a background material 104, such as fat, a lobulated mass 106, a tubular-shaped vein 108, and an artery 110. The 3D cursor 100 can be moved relative to the image, e.g. in three dimensions, such as by manipulating an IO device such as a 3D mouse, for example and without limitation. A button click or other input designates (selects) the portion of the image that is located inside the three-dimensional volume of the 3D cursor 100. Distinguishing between a 3D image portion selected by a 3D cursor and other unselected image portions is described in US 2016/0026266 and U.S. Pat. No. 8,384,771, both of which are incorporated by reference.

[0031] FIG. 1B illustrates the selected image portion of FIG. 1A. More particularly, unselected portions of the image located outside of an image portion 112 selected with the 3D cursor 100 have been filtered-out or otherwise completely removed from view. Consequently, the removed portions of the image do not obstruct or hinder the view of the selected image portion. Moreover, the selected image portion 112 can be manipulated and viewed as a separate and distinct image from the larger medical image 102 from which it was selected.

[0032] FIG. 1C illustrates modification of the transparency of the selected image portion 112. More specifically, transparency may be decreased and/or increased such that tissues and other features can be better observed, e.g. such that overlapping tissues and features are visible. For example, tissues and features located proximate to the back of the selected image portion such as lobulated mass 106 can be seen through overlapping tissues and features located proximate to the front of the selected image portion such as vein 108, when transparency is sufficiently increased. The transparency may be manipulated with the IO device to achieve various levels of transparency. Further, different levels of transparency may be applied to different portions of the selected image portion.

[0033] FIG. 1D illustrates filtering of selected areas or tissues of the selected image portion 112 to remove those areas or tissues from view. In the illustrated example the background material 104, vein 108, and an artery 110 have been removed from view, leaving only the lobulated mass 106. The tissues to be filtered (removed from view) may be selected based on geometric shape, color, brightness, density, and any other of a variety of available image data, either alone or in combination. Moreover, a designated volume defined by a geometric shape may be removed, e.g. a geometric shape that traverses tissue boundaries.

[0034] Transparency modification and tissue filtering facilitate presentation of certain tissue types of concern, both within the cursor and outside of the cursor. Currently, the medical professional must see through any tissue within the cursor but external to the tissue type of concern from the viewing point of the medical professional, thus degrading the visibility of the tissue of concern. The illustrated improvements enable the medical professional to change the transparency of any tissue within the cursor-defined volume but external to the tissue type of concern. Alternatively, tissue types not of concern are subtracted from the volume contained within the interactive 3D cursor, leaving only the tissue of concern in the presented image. Multiple interactive 3D cursors in combination can be used to obtain varying patterns of tissue subtraction. This helps to overcome the limitations of degraded visibility due to tissue within the cursor but external to the tissue type of concern from the viewing point of the medical professional.

[0035] FIG. 2 illustrates an implementation of the 3D cursor 100 with dimensional measurement markings. Dimensional measurement markings may be available as a feature that can be turned ON and OFF. In the illustrated example, the 3D cursor is a 2 cm by 2 cm by 2 cm cube. The dimensional measurement markings include tick marks 200, 202, and 204 that respectively designate 1 mm, 5 mm, and 1 cm increments along the edges of the cube (and thus representing three dimensions). Tick marks that represent different magnitudes may be uniquely represented to facilitate visual size determination of the lobulated mass 106 that

represents the lesion of interest. 1 cm markings **206** are presented in each of two dimensions on each side of the cube.

[0036] The dimensional measurement markings can help serve as a reference for radiologist's activities to include visual assessment, orientation, comparisons with prior scans or measurements. Advantages may include mitigating the current lack of metrics are available to the medical professional to understand the size of the cursor and/or of the tissue elements contained within the cursor. This implementation places measurement metrics on each edge and side of the cursor to help enable the medical professional to rapidly understand the size of the subtended volume within the cursor. In the case where the cursor encapsulates a volume of concern such as a tumor, the three-dimensional size could be recorded in the medical professional report. This can help the visual assessment of each portion of the tumor to aid in the assessment of small changes in size of findings including lobulations of a mass's margin and spiculations.

[0037] Referring to FIG. **3**, location indicators **300** and annotations **302** may be placed by the radiologist or by automated techniques to highlight locations or regions of concern within the interactive 3D cursor. The location indicators may specify a point or region within the volume of the 3D cursor. Annotations can be added manually by the radiologist or by automated techniques to describe areas that are of concern, e.g., growing, spiculation, irregular margin, indistinct margin, etc. If spiculations are on the surface of a tumor, this could be an indicator of potential malignancy. The location indicators, such as, but not limited to, arrow(s) pointing to key regions of interest within/outside the 3D cursor helps to overcome the limitation of the inability to mark key points within the cursor. This feature will be useful in discussions between medical professions regarding a patient's condition. It will also be useful in communicating imaging findings between a medical professional and a patient.

[0038] Referring to FIGS. **4A**, **4B**, and **4C**, the 3D cursor may be may be implemented in a wide variety of different shapes. Examples include but are not limited to cube, cuboid, cylinder, sphere, ellipsoid, cone and tetrahedron. The shapes are not necessarily regular, and the lengths of edges may be resized, e.g. overall geometric shape scaling or changing individual edges, sides, or surfaces. For example, FIGS. **4A** and **4B** illustrate cuboid 3D cursors **400**, **402** for which edge length has been set or selected based on the dimensions and orientation of the respective feature of interest **404**, **406**. FIG. **4C** illustrates a spherical 3D cursor **408** for which the diameter may be set or selected based on the dimensions of the feature of interest **410**. In addition to dimensional changes, cursor geometric shape may be changed.

[0039] The ability to change the size, shape, and individual dimensions of the 3D cursor enables the cursor to be customized based on the particular volume of interest to the medical professional. A fixed-shape, fixed-size cursor might be too large or too small, e.g. so as to include a significant amount of tissue not of interest. For example, in examining the lungs, placement of a cube-shaped cursor could cause ribs to be included in the image. Changing the shape of the 3D cursor would help to overcome this limitation. Customization could be accomplished by wide variety of techniques, possibly including but not limited to selecting an edge, side or vertex of the original 3D cursor with a second type of

cursor **412**, and then "clicking and dragging" the selected edge, side, or vertex in the desired direction to expand or reduce the volume of the original 3D cursor. The interface may also enable selection and change between multiple 3D geometric shapes, e.g. changing from cuboid to spherical. Scrolling on the conventional slices while simultaneously drawing shapes can also be performed to generate the prescribed 3D cursor volume. The interactive 3D cursor thus provides an efficient interface for tissue subtraction to provide enhanced visualization of the tumor.

[0040] FIG. **5** illustrates presentation of a quantitative analysis **500** of all tissues inside a volume selected with the 3D cursor. The illustrated example includes a bar graph but it is to be understood that any of a wide variety of charts, graphs, and other techniques for presentation of data might be implemented. Quantitative analysis can help the radiologist understand how a feature of interest such as tumor **502** (e.g., the lobulated mass **106**, FIG. **1B**) is changing in volume **504** over multiple time points. The interface may include a statistical representation of the tissue types, possibly including but not limited to a histogram bar chart to depict the volume (e.g., number of voxels per unit volume) of the different types of tissue within the cursor, distinct markings for different types of tissue such as, but not limited to, color coding the bars of the histogram bar chart.

[0041] FIG. **6** illustrates an implementation of the interactive 3D cursor **100** with false color and transparency to enhance viewing. False color and transparency may be dynamically adjusted and turned ON and OFF. Different false colors may be applied to different tissue types within the volume of the 3D cursor. The colors could be selected to correspond to the colors used in the statistical representation (FIG. **5**). Alternatively, a respective unique false color could be selected for each different tissue type, or tissue types of particular interest or concern, and/or additional features of concern, e.g., irregular margin, indistinct margin, spiculation, etc. In the illustrated example, the background material **104** (fat) is depicted in light gray, the artery **110** is depicted in red, the vein **108** is depicted in blue, and the lobulated mass **106** is multicolored. Different colors may be selected or used to indicate stability of the lobulated mass **106** over time. For example, green may be used to indicate a stable volume **112** while orange is used to denote a slow growth volume **114**, thereby providing a visual warning indicator. Red may be used to indicate high rate of growth or concerning margin volume **116**. The extent of the volume of the lobulated mass can be determined automatically, e.g. based on density. Moreover, changes in volume of sub-regions of the lobulated mass may also be automatically determined, and color coding may be automatically implemented. This can help the radiologist understand how the mass is changing in volume over multiple time points.

[0042] FIG. **7** illustrates association of multiple computed tomography (CT) images of the chest in lung windows with the interactive 3D cursor **100** using reference lines **700**. The illustrated example includes an axial image **702**, a sagittal image **704**, and a coronal image **706** of the chest in lung windows. An advantage is enhanced ability to cross reference the 3D cursor to the original 2D slices **702**, **704**, **706** from which total 3D volume was obtained. Medical professionals have experience and familiarity with 2D slices and may feel more confident in their findings given the capability to switch back and forth between the 2D and 3D volumetric approaches. A small display adjacent to the

interactive 3D cursor could indicate which 2D slices contain tissue within in the interactive 3D cursor. Then the medical professional could direct the system to automatically select those slices which have tissue within the cursor and display them on a nearby 2D display unit. A corresponding visible boundary of the 3D cursor (e.g., red) projected on each of the slices may be presented.

[0043] FIG. **8** illustrates association of multiple axial computed tomography (CT) slices **800**, **802**, **804**, **806** of the chest in lung windows with the interactive 3D cursor **100** using reference lines **808**. The multiple axial computed tomography (CT) slices of the chest in lung windows show the location of the 3D cursor, i.e. the slice area that includes a cross-section of the 3D cursor, which in the illustrated example has selected a left upper lobe mass. Boundaries **810** of the 3D cursor in the slices are depicted in a color, e.g. red. Within the 3D cursor the lung cancer mass **106** is depicted in gray, surrounded by black that indicates non-cancerous lung tissue. This implementation helps the medical professional to rapidly visualize where the interactive 3D cursor is located relative to the slice images and the body. It also enables the medical professional to visualize the entire volumetric data with the interactive 3D cursor accurately positioned within the volume. Transparency of tissue within the 3D volume could be changed so that the interactive 3D cursor would stand out. This would help avoid left—right orientation mistakes that might occur during treatment. Multiple interactive 3D cursors which could be of differing sizes and/or shapes could be created and displayed.

[0044] FIG. **9** illustrates overlay of 3D cursors **100***a*, **100***b* on a maximum intensity projection (MIP) image **900** of a fludeoxyglucose (18F) positron emission tomography (PET) scan. Two different-sized interactive 3D cursors are used to highlight two separate areas of concern, including 3D cursor **100***a* for a right lung mass and cursor **100***b* for a vertebral body metastasis. This helps to automatically transfer data (e.g., picture of tissue within the cursor and statistical representations) from the viewing modality to the report of findings. Selection of key data through human machine interface such as, but limited to, a screen capture can be automatically transferred to the report of findings. This would provide quantitative results within the report together with qualitative impressions of the medical professional.

[0045] FIG. **10** illustrates a radiology report **1000** enhanced with information obtained from the interactive 3D cursor. Qualitative findings **1002** and quantitative findings **1004** may be included along with patient identifying information **1006**, clinical history **1008**, comparisons **1010**, conclusions **1012**, and recommendations **1014**. Also included are a selected volume image **1016** and statistical graphic **1018**. This helps to quantitatively track changes in volumes of concern (e.g., tumors) over time.

[0046] FIG. **11** illustrates a radiology report **1100** enhanced with information obtained from the interactive 3D cursor at multiple time points. Qualitative findings **1002** and quantitative findings **1004** may be included along with patient identifying information **1006**, clinical history **1008**, comparisons **1010**, conclusions **1012**, and recommendations **1014**. Also included are selected volume images **1102**, **1104** from different time points and respective statistical graphics **1106**, **1108** from those time points. Follow up reports can include current and prior exams **1110**, **1112** with quantitative analysis and qualitative analysis on how the lesion has changed over time. This may facilitate selection of a lesion

(e.g., tumor) at multiple time points using an interactive 3D cursor; qualitative assessment of the lesion at multiple time points; and, quantitative assessment of the lesion at multiple time points. This would enable the medical professional to better assess how a particular lesion is changing over time. A report of current findings as outlined in the previous implementation could be placed in a report together with the data obtained from an earlier examination. This would enable tracking over time the progress of treatment or that of changes in tissues of interest/concern.

[0047] FIGS. **12**A, **12**B, and **12**C illustrate a registration technique by which mis-registration can be corrected at multiple time points through the use of three or more markers **12**, **14**, **16**. Initially, the mass **106** within each 3D cursor **100** image is noted using different locations within the interactive 3D cursor and different orientations. Next, the user marks similar locations on each image of the mass with registration markers. In the illustrated example, a yellow marker **12**, a red marker **14**, and a blue marker **16** correspond to the same respective parts of the mass on each scan. Finally, tissues within the interactive 3D cursor are aligned in accordance with markers. Many soft tissues within the body can change in orientation from one scan to the next due to patient movement. Corresponding mis-registration can limit the ability to properly track how a lesion changes over time. This technique provides a method to correct for such mis-registration. Three or more recognizable spots of the lesion (e.g., tumor) can be marked with a false color, arrow, or other registration mark. Then, these locations can be automatically aligned with one another. Shadows can be added to help bring out depth perception. Proper alignment will accurately align the shadows. This enhances visual assessment for how a lesion is changing over time to include changes in tumor composition, size and morphology.

[0048] FIG. **13** illustrates use of multiple image volumes selected with the 3D cursor to designate a safe pre-operative planning pathway to guide surgical intervention. In the illustrated example, multiple green interactive 3D cursors **1300** mark a surgeon-selected dissection pathway that is deemed safe in the pre-operative setting. The interactive 3D cursor **100** containing the cancerous lesion **106** is shown at a distal end of the planned surgical path represented by abutting or overlapping volumes selected with the 3D cursors **1300**. The selected path that the surgeon will excise avoids the artery **110** with a minimum clearance of 10 mm. This provides the advantage of 3D depiction of possible surgical cuts. The path could include, but is not limited to, one or more of the following properties: a serpentine shape; measurements could subsequently be made to measure absolute distance between a point on the planned path to some region of concern (e.g., artery); the path could also be projected on a head mounted display at different intervals during the course of the operation. This feature would facilitate surgical planning as well as a potential to improve accuracy of the surgery.

[0049] FIG. **14** illustrates use of the interactive 3D cursor in an educational setting. Students **1400** are depicted wearing AR (augmented reality) headsets **1402** and an instructor **1404** is pointing to an abnormality on the board **1406**. This facilitates presentation of medical information (e.g., anatomy) in a classroom environment. The interactive 3D cursor could be placed around the organ of interest and other parts of the body could be eliminated. Items from implementations discussed above such as metrics and arrows

could be used. The students would be provided 3D head displays and joined into a display system so that they could see the tissue within the interactive 3D cursor. This would eliminate any confusion on the part of the students as to what specific detail in the imagery was being discussed.

[0050] FIG. 15 illustrates process steps on a radiologist's review of a patient's image with integration of the interactive 3D cursor into his/her practice. Step 1 is to create an interactive 3D cursor volume and shape that approximates the size and shape of patient organ/tissue corresponding to the item currently being inspected on the checklist. Step 2 is to position the interactive 3D cursor over the organ/tissue to be inspected. The interactive 3D cursor as it is located within the total 3D image volume may be presented on a display. Step 3 is to subtract from view all tissue external to the interactive 3D cursor. The interactive 3D cursor may be rotated to permit viewing from multiple angles. If interactive cursors are used at multiple time points to track how a particular lesion (e.g., tumor) changes over time, the 3D cursors can be rotated in synchrony with on another. Step 4 is to generate a statistical representation e.g., a histogram of tissue densities—color coded with the types of tissue that are suspicious. Step 5 is to subtract from view additional tissue within the interactive 3D cursor as deemed appropriate by the medical professional. Step 6 is to inspect the volume within the cursor and identify region(s) of interest and place indicators, annotations, and registration markers relative to region(s) of interest. Step 7 is to extract a statistical representation and capture imagery showing indicators, annotations, and registration markers and residual tissue within the interactive 3D cursor to be inserted into the medical professional's report. Step 8 is to use cross-referencing as described the above to confirm findings. Step 9 is to iterate on the other items on the checklist until finished. Step 10 is to prepare the report of the medical professional's findings. This procedure provides an opportunity to enhance medical image review process by medical professionals.

[0051] FIG. 16 illustrates a system for use of the interactive 3D cursor. A medical imaging device 1600 is connected to a computer workstation 1602. A wide variety of medical imaging devices and computer workstations could be used. Images are captured by the medical imaging device and sent to the computer workstation. The computer workstation includes non-volatile storage, computer-readable memory, processors, and a variety of other resources including but not limited to IO devices that provide a human-machine interface. In the illustrated example, the IO devices include a monitor 1604, keyboard 1606, 3D mouse 1608, and VR headset 1610. The IO devices are used to prompt a software program that runs on the computer workstation to perform the various process steps and implement the various features that have already been described above.

[0052] There are multiple potential advantages of the interactive 3D cursor. For example, there is reduction in time spent for classification of multiple lesions. The radiologist doesn't have to sort through many prior imaging studies to find the lesion and the interactive 3D cursor will save time. There is reduction in error when tracking multiple lesions, i.e. reducing the likelihood of mistakes when identifying different specific lesions that are nearby one another when comparing multiple scans. One possibility is to analyze the images obtained using the 3D cursor and using multiple

uniquely tagged (e.g. numbered) cursors for any suspicious regions. The medical profession could then switch to slices for confirmation.

[0053] Several features, aspects, embodiments and implementations have been described. Nevertheless, it will be understood that a wide variety of modifications and combinations may be made without departing from the scope of the inventive concepts described herein. Accordingly, those modifications and combinations are within the scope of the following claims.

What is claimed is:

1. A method comprising
   generating a three-dimensional cursor that has a non-zero volume;
   responsive to a first input, moving the three-dimensional cursor within a three-dimensional image;
   responsive to a second input, selecting a volume of the three-dimensional image designated by the three-dimensional cursor; and
   responsive to a third input, presenting a modified version of the selected volume of the three-dimensional image.

2. The method of claim 1 wherein presenting the modified version of the selected volume of the three-dimensional image comprises removing an un-selected volume of the three-dimensional image from view.

3. The method of claim 1 wherein presenting the modified version of the selected volume of the three-dimensional image comprises changing transparency of presented tissues within or external to the selected volume.

4. The method of claim 1 wherein presenting the modified version of the selected volume of the three-dimensional image comprises filtering a selected tissue to remove the selected tissue from view.

5. The method of claim 1 comprising presenting the three-dimensional cursor with measurement markings on at least one edge, surface or side.

6. The method of claim 1 wherein presenting the modified version of the selected volume of the three-dimensional image comprises presenting inputted location indicators.

7. The method of claim 1 wherein presenting the modified version of the selected volume of the three-dimensional image comprises presenting inputted annotations.

8. The method of claim 1 comprising changing a size dimension of the three-dimensional cursor responsive to a fourth input.

9. The method of claim 8 comprising changing a geometric shape of the three-dimensional cursor responsive to a fifth input.

10. The method of claim 1 comprising automatically generating a statistical representation of the selected volume of the three-dimensional image.

11. The method of claim 1 wherein presenting the modified version of the selected volume of the three-dimensional image comprises presenting at least one tissue type with false color.

12. The method of claim 1 wherein presenting the modified version of the selected volume of the three-dimensional image comprises presenting volumetric changes over time with false color.

13. The method of claim 1 comprising presenting multiple computed tomography images associated with the selected volume using reference lines.

14. The method of claim 1 comprising presenting multiple axial computed tomography images associated with the selected volume using reference lines.

15. The method of claim 1 comprising presenting a maximum intensity projection (MIP) image of a positron emission tomography (PET) scan with the three-dimensional cursor overlaid thereon to indicate orientation and location of the selected volume.

16. The method of claim 1 comprising presenting a radiology report enhanced with information obtained using the three-dimensional cursor.

17. The method of claim 16 comprising automatically calculating and presenting a quantitative analysis and a qualitative analysis associated with multiple time points.

18. The method of claim 1 wherein presenting the modified version of the selected volume of the three-dimensional image comprises presenting inputted registration markers.

19. The method of claim 18 comprising automatically calculating volumetric change based on the registration markers.

20. The method of claim 18 comprising automatically re-orienting the selected volume of the three-dimensional image based on the registration markers.

21. The method of claim 1 comprising using multiple volumes selected with the three-dimensional cursor to designate a pre-operative planning pathway for guiding surgical intervention.

22. The method of claim 1 comprising presenting the selected volume with an augmented reality, virtual reality or mixed reality headset.

23. An apparatus comprising

a computing device; and

a human-machine interface comprising a three-dimensional cursor that has a non-zero volume;

the human-machine interface moving the three-dimensional cursor within a three-dimensional image responsive to a first input;

the human-machine interface selecting a volume of the three-dimensional image designated by the three-dimensional cursor responsive to a second input; and

the human-machine interface presenting a modified version of the selected volume of the three-dimensional image responsive to a third input.

24. The apparatus of claim 23 wherein the human-machine interface removes an un-selected volume of the three-dimensional image from view.

25. The apparatus of claim 23 wherein the human-machine interface changes transparency of presented tissues within the selected volume.

26. The apparatus of claim 23 wherein the human-machine interface filters a selected tissue to remove the selected tissue from view.

27. The apparatus of claim 23 wherein the human-machine interface presents the three-dimensional cursor with measurement markings on at least one edge, surface or side.

28. The apparatus of claim 23 wherein the human-machine interface receives and implements inputted location indicators.

29. The apparatus of claim 23 wherein the human-machine interface receives and implements inputted annotations.

30. The apparatus of claim 23 wherein the human-machine interface changes a size dimension of the three-dimensional cursor responsive to a fourth input.

31. The apparatus of claim 30 wherein the human-machine interface changes a geometric shape of the three-dimensional cursor responsive to a fifth input.

32. The apparatus of claim 23 wherein the human-machine interface automatically generates and presents a statistical representation of the selected volume of the three-dimensional image.

33. The apparatus of claim 23 wherein the human-machine interface presents at least one tissue type with false color.

34. The apparatus of claim 23 wherein the human-machine interface presents volumetric changes over time with false color.

35. The apparatus of claim 23 wherein the human-machine interface presents multiple computed tomography images associated with the selected volume using reference lines.

36. The apparatus of claim 23 wherein the human-machine interface presents multiple axial computed tomography images associated with the selected volume using reference lines.

37. The apparatus of claim 23 wherein the human-machine interface presents a maximum intensity projection (MIP) image of a positron emission tomography (PET) scan with the three-dimensional cursor overlaid thereon to indicate orientation and location of the selected volume.

38. The apparatus of claim 23 wherein the human-machine interface presents a radiology report enhanced with information obtained using the three-dimensional cursor.

39. The apparatus of claim 23 wherein the human-machine interface automatically calculates and presents a quantitative analysis and a qualitative analysis associated with multiple time points.

40. The apparatus of claim 23 wherein the human-machine interface presents inputted registration markers.

41. The apparatus of claim 40 wherein the human-machine interface automatically calculates volumetric change based on the registration markers.

42. The apparatus of claim 40 wherein the human-machine interface automatically re-orients the selected volume of the three-dimensional image based on the registration markers.

43. The apparatus of claim 23 wherein the human-machine interface presents multiple volumes selected with the three-dimensional cursor to designate a pre-operative planning pathway for guiding surgical intervention.

44. The apparatus of claim 23 wherein the human-machine interface presents the selected volume with an augmented reality, virtual reality or mixed reality headset.

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