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(54) **METHOD APPARATUS AND SYSTEM FOR ANALYZING IMAGES**

VERFAHREN, VORRICHTUNG UND SYSTEM ZUR ANALYSE VON BILDERN

PROCÉDÉ, APPAREIL ET SYSTÈME D'ANALYSE D'IMAGES

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(56) References cited:
US-A1- 2004 236 225 US-A1- 2007 051 889
US-A1- 2007 213 617

- **KACZMAREK M ET AL: "Optical excitation methods in active dynamic thermography in medical diagnostics" PROCEEDINGS OF THE SPIE - THE INTERNATIONAL SOCIETY FOR OPTICAL ENGINEERING SPIE-INT. SOC. OPT. ENG USA, vol. 5566, no. 1, 2004, pages 120-126, XP002519609 ISSN: 0277-786X**
- **DENG Z-S ET AL: "Enhancement of thermal diagnostics on tumors underneath the skin by induced evaporation" PROCEEDINGS OF THE 2005 27TH ANNUAL INTERNATIONAL CONFERENCE OF THE ENGINEERING IN MEDICINE AND BIOLOGY SOCIETY, IEEE-EMBS 2005, INSTITUTE OF ELECTRIC, vol. 7, 2005, pages 7525-7528, XP002519610**
- **VALENTINA AGOSTINI ET AL: "Evaluation of feature-based registration in dynamic infrared imaging for breast cancer diagnosis" ENGINEERING IN MEDICINE AND BIOLOGY SOCIETY, 2006. EMBS '06. 28TH ANNUAL INTERNATIONAL CONFERENCE OF THE IEEE, IEEE, PISCATAWAY, NJ, USA, 30 August 2006 (2006-08-30), pages 953-956, XP031235634 ISBN: 978-1-4244-0032-4**

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DescriptionFIELD AND BACKGROUND OF THE INVENTION

[0001] The present invention, in some embodiments thereof, relates to thermal images and, more particularly, but not exclusively, to the analysis of thermal images.

[0002] The use of imaging in diagnostic medicine dates back to the early 1900s. Presently there are numerous different imaging modalities at the disposal of a physician allowing imaging of hard and soft tissues and characterization of both normal and pathological tissues.

[0003] Infra red imaging is utilized for characterizing a thermally distinguishable site in a human body for the purposes of identifying inflammation. Infrared cameras produce two-dimensional images known as thermographic images. A thermographic image is typically obtained by receiving from the body of the subject radiation at any one of several infrared wavelength ranges and analyzing the radiation to provide a two-dimensional temperature map of the surface. The thermographic image can be in the form of either or both of a visual image and corresponding temperature data. The output from infrared cameras used for infrared thermography typically provides an image comprising a plurality of pixel data points, each pixel providing temperature information which is visually displayed, using a color code or gray-scale code. The temperature information can be further processed by computer software to generate for example, mean temperature for the image, or a discrete area of the image, by averaging temperature data associated with all the pixels or a sub-collection thereof.

[0004] Based on the thermographic image, a physician diagnoses the site, and determines, for example, whether or not the site includes an inflammation while relying heavily on experience and intuition.

[0005] U.S. Patent No. 7,072,504 discloses an approach which utilizes two infrared cameras (left and right) in combination with two visible light cameras (left and right). The infrared cameras are used to provide a three-dimensional thermographic image and the visible light cameras are used to provide a three-dimensional visible light image. The three-dimensional thermographic and three-dimensional visible light images are displayed to the user in an overlapping manner.

[0006] International Patent Publication No. 2006/003658 discloses a system which includes non-thermographic image data acquisition functionality and thermographic image data acquisition functionality. The non-thermographic image data acquisition functionality acquires non-thermographic image data, and the thermographic image data acquisition functionality acquires thermographic image data.

[0007] U.S. Patent No. 7,292,719 discloses a system for determining presence or absence of one or more thermally distinguishable objects in a living body. A combined image generator configured combines non-thermographic three-dimensional data of a three-dimensional

tissue region in the living body with thermographic two-dimensional data of the tissue region so as to generate three-dimensional temperature data associated with the three-dimensional tissue region.

[0008] Also of interest is U.S. Patent No. 6,442,419 disclosing a scanning system including an infrared detecting mechanism which performs a 360° data extraction from an object, and a signal decoding mechanism, which receives electrical signal from the infrared detecting mechanism and integrates the signal into data of a three-dimensional profile curved surface and a corresponding temperature distribution of the object.

[0009] Additional background art includes U.S. Patent No. 6,850,862 which discloses the generation of three-dimensional maps of temperature distribution, and U.S. Patent No. 5,961,466 which discloses detection of breast cancer from a rapid time series of infrared images which is analyzed to detect changes in the distribution of thermoregulatory frequencies over different areas of the skin.

[0010] Further background art includes U.S. Published Application No. 20070213617 which discloses a combination of near-IR and mid-IR frequencies for detection of cancer. An IR transmissive or transparent window that can be IR-imaged through is utilized to distort the breast and/or manipulate an artificial heat-flow into or out of the breast.

SUMMARY OF THE INVENTION

[0011] According to an aspect of some embodiments of the present invention there is provided apparatus for locating a thermally distinguishable region within a living body. The apparatus comprises: an input unit for receiving a series of thermospatial representations describing a section of a living body, wherein each thermospatial representation is defined over a three-dimensional spatial representation of the body and has thermal data associated with a surface of the three-dimensional spatial representation, and wherein at least two thermospatial representations of the series describe said body section while having at least two different shapes; and a computing platform configured for calculating a deformation function which maps one shape of the at least two different shapes to another shape of the at least two different shapes, extracting transient thermal history of the body section based on thermal variations present in the series and estimating a location or presence of an internal thermally distinguishable region in the body section based on the transient thermal history.

[0012] According to a preferred embodiment of the present invention there is provided an imaging and processing system, comprising the apparatus described above and a thermospatial imaging system operable to provide the input unit with the series of thermospatial representations.

[0013] According to some preferred embodiments of the invention the apparatus further comprises a size estimator, configured for estimating a size of the internal

thermally distinguishable region, based on the transient thermal history.

[0014] According to some preferred embodiments of the invention the computing platform is configured for comparing the transient thermal history to a reference transient thermal history, so as to determine the likelihood for the presence of the thermally distinguishable region.

[0015] According to some preferred embodiments of the invention a change in an ambient temperature at a surface of the body section is imposed between at least two successive thermospatial representations of the series.

[0016] According to some preferred embodiments of the invention the location of the internal thermally distinguishable region is estimated by determining amount of temperature change for each point of a plurality of points over a surface of the body section.

[0017] According to some preferred embodiments of the invention the location of the internal thermally distinguishable region is estimated by determining a temperature change rate for the point.

[0018] According to some preferred embodiments of the invention the location of the internal thermally distinguishable region is estimated by comparing a temperature change rate of one point of the plurality of points to a temperature change rate of another point of the plurality of points.

[0019] According to some preferred embodiments of the invention the location of the internal thermally distinguishable region is estimated by determining onset of a steady thermal state for the point.

[0020] According to some preferred embodiments of the invention the location of the internal thermally distinguishable region is estimated by determining onset of temperature change for the point.

[0021] According to some preferred embodiments of the invention the extraction of the transient thermal history is done by selecting a set of points belonging to one thermospatial representation of the series, utilizing the deformation function for determining a corresponding set of points belonging to another thermospatial representation of the series, and determining an individual thermal variation for each point in the set.

[0022] According to some preferred embodiments of the invention the body section is a breast of a woman.

[0023] Unless otherwise defined, all technical and/or scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which the invention pertains. Although methods and materials similar or equivalent to those described herein can be used in the practice or testing of embodiments of the invention, exemplary methods and/or materials are described below. In case of conflict, the patent specification, including definitions, will control. In addition, the materials, methods and examples are illustrative only and are not intended to be necessarily limiting.

[0024] Implementation of the method and/or system of

embodiments of the disclosure can involve performing or completing selected tasks manually, automatically, or a combination thereof. Moreover, according to actual instrumentation and equipment of embodiments of the method and/or system of the disclosure, several selected tasks could be implemented by hardware, by software or by firmware or by a combination thereof using an operating system.

[0025] For example, hardware for performing selected tasks according to embodiments of the invention could be implemented as a chip or a circuit. As software, selected tasks according to embodiments of the invention could be implemented as a plurality of software instructions being executed by a computer using any suitable operating system. In an exemplary embodiment of the disclosure one or more tasks according to exemplary embodiments of method and/or system as described herein are performed by a data processor, such as a computing platform for executing a plurality of instructions. Optionally, the data processor includes a volatile memory for storing instructions and/or data and/or a non-volatile storage, for example, a magnetic hard-disk and/or removable media, for storing instructions and/or data. Optionally, a network connection is provided as well. A display and/or a user input device such as a keyboard or mouse are optionally provided as well.

BRIEF DESCRIPTION OF THE DRAWINGS

[0026] Some embodiments of the invention are herein described, by way of example only, with reference to the accompanying drawings and images. With specific reference now to the drawings in detail, it is stressed that the particulars shown are by way of example and for purposes of illustrative discussion of embodiments of the invention. In this regard, the description taken with the drawings makes apparent to those skilled in the art how embodiments of the invention may be practiced.

[0027] In the drawings:

FIGS. 1A-C are schematic illustrations of a thermospatial representation, according to some embodiments of the present invention;

FIG. 2 is a flowchart diagram of a method suitable for analyzing thermal data, according to various exemplary embodiments;

FIG. 3 is a schematic illustrations of a deformation function, according to various exemplary embodiments of the present invention;

FIG. 4 is a flowchart diagram of a calibration procedure, according to various exemplary embodiments;

FIGS. 5A-B are schematic illustrations showing two shapes of a body section and two corresponding profiles of heat signals, according to various exemplary embodiments of the present invention;

FIGS. 6A-C are schematic illustrations showing two shapes of a body section and two heat signals as a function of the time as measured at two points on

the surface of the body section;
 FIG. 7 is a schematic illustration of an apparatus for analyzing thermal data, according to various exemplary embodiments of the present invention;
 FIG. 8 is a schematic illustration of an imaging and processing system, according to some embodiments of the present invention;
 FIGs. 9A-F and 10A-E are schematic illustration of a thermospatial imaging system, according to various exemplary embodiments of the present invention;
 FIGs. 11A-D are thermal images of a right breast (Figures 11A and 11C) and a left breast (Figures 11B and 11D) of a female subject standing with her hands at the side of her body (Figures 11A-B) and with her hands overhead (Figures 11C-D).

DESCRIPTION OF SPECIFIC EMBODIMENTS OF THE INVENTION

[0028] The present invention, in some embodiments thereof, relates to thermal images and, more particularly, but not exclusively, to the analysis of thermal images.

[0029] Before explaining at least one embodiment of the invention in detail, it is to be understood that the invention is not necessarily limited in its application to the details of construction and the arrangement of the components and/or methods set forth in the following description and/or illustrated in the drawings and/or the Examples. The invention is capable of other embodiments or of being practiced or carried out in various ways.

[0030] The present inventors have devised an approach which enables the analysis of thermal data, e.g., for the purpose of determining presence location and/or size of a thermally distinguishable region. When the thermal data is acquired from a body section such as a breast of a woman, the analysis of the present embodiments can be used to extract properties of the underlying tissue.

[0031] For example, determination of the presence, location and/or size of a tumor which is a thermally distinguished from healthy tissue. An elevated temperature is generally associated with a tumor due to the metabolic abnormality of the tumor and proliferation of blood vessels (angiogenesis) at and/or near the tumor. In a cancerous tumor the cells double faster and thus are more active and generate more heat. This tends to enhance the temperature differential between the tumor itself and the surrounding temperature. The present embodiments can therefore be used for diagnosis of cancer, particularly, but not exclusively breast cancer.

[0032] The analysis according to some embodiments of the present invention is based on surface information, which is obtained or captured from the surface of the body section, and which includes spatial information as well as thermal information.

[0033] The spatial information comprises data pertaining to geometric properties of a non-planar surface which at least partially encloses a three-dimensional volume.

Generally, the non-planar surface is a two-dimensional object embedded in a three-dimensional space. Formally, a non-planar surface is a metric space induced by a smooth connected and compact Riemannian 2-manifold. Ideally, the geometric properties of the non-planar surface would be provided explicitly for example, the slope and curvature (or even other spatial derivatives or combinations thereof) for every point of the non-planar surface. Yet, such information is rarely attainable and the spatial information is provided for a sampled version of the non-planar surface, which is a set of points on the Riemannian 2-manifold and which is sufficient for describing the topology of the 2-manifold. Typically, the spatial information of the non-planar surface is a reduced version of a 3D spatial representation, which may be either a point-cloud or a 3D reconstruction (e.g., a polygonal mesh or a curvilinear mesh) based on the point cloud. The 3D spatial representation is expressed via a 3D coordinate system, such as, but not limited to, Cartesian, Spherical, Ellipsoidal, 3D Parabolic or Paraboloidal coordinate 3D system.

[0034] The term "surface" is used herein as an abbreviation of the term "non-planar surface".

[0035] The spatial data, in some embodiments of the present invention, can be in a form of an image. Since the spatial data represent the surface, such an image is typically a two-dimensional image which, in addition to indicating the lateral extent of body members, further indicates the relative or absolute distance of the body members, or portions thereof, from some reference point, such as the location of the imaging device. Thus, the image typically includes information residing on a non-planar surface of a three-dimensional body and not necessarily in the bulk. Yet, it is commonly acceptable to refer to such image as "a three-dimensional image" because the non-planar surface is conveniently defined over a three-dimensional system of coordinate. Thus, throughout this specification and in the claims section that follows, the terms "three-dimensional image" and "three-dimensional representation" primarily relate to surface entities.

[0036] The thermal information comprises data pertaining to heat evacuated from or absorbed by the surface. Since different parts of the surface generally evacuate or absorb different amount of heat, the thermal information comprises a set of tuples, each comprising the coordinates of a region or a point on the surface and a thermal numerical value (e.g., temperature, thermal energy) associated with the point or region. The thermal information can be transformed to visible signals, in which case the thermal information is in the form of a thermographic image. The terms "thermographic image" and thermal information are used interchangeably throughout the specification without limiting the scope of the present invention in any way. Specifically, unless otherwise defined, the use of the term "thermographic image" is not to be considered as limited to the transformation of the thermal information into visible signals. For example, a thermographic image can be stored in the

memory of a computer readable medium as a set of tuples as described above.

[0037] The surface information (thermal and spatial) of a body is typically in the form of a synthesized representation which includes both thermal data representing the thermal image and spatial data representing the surface, where the thermal data is associated with the spatial data (*i.e.*, a tuple of the spatial data is associated with a heat-related value of the thermal data). Such representation is referred to as a thermospatial representation. The thermospatial representation can be in the form of digital data (*e.g.*, a list of tuples associated with digital data describing thermal quantities) or in the form of an image (*e.g.*, a three-dimensional image color-coded or grey-level coded according to the thermal data). A thermospatial representation in the form of an image is referred to hereinafter as a thermospatial image.

[0038] The thermospatial image is defined over a 3D spatial representation of the body and has thermal data associated with a surface of the 3D spatial representation, and arranged gridwise over the surface in a plurality of picture-elements (*e.g.*, pixels, arrangements of pixels) each represented by an intensity value or a grey-level over the grid. It is appreciated that the number of different intensity values can be different from the number of grey-levels. For example, an 8-bit display can generate 256 different grey-levels. However, in principle, the number of different intensity values corresponding to thermal information can be much larger. As a representative example, suppose that the thermal information spans over a range of 37 °C and is digitized with a resolution of 0.1 °C. In this case, there are 370 different intensity values and the use of grey-levels is less accurate by a factor of approximately 1.4. In some embodiments of the present invention the processing of thermal data is performed using intensity values, and in some embodiments of the present invention the processing of thermal data is performed using grey-levels. Combinations of the two (such as double processing is also contemplated).

[0039] The term "pixel" is sometimes abbreviated herein to indicate a picture-element. However, this is not intended to limit the meaning of the term "picture-element" which refers to a unit of the composition of an image.

[0040] When the thermospatial representation is in the form of digital data, the digital data describing thermal properties can also be expressed either in terms of intensities or in terms of grey-levels as described above. Digital thermospatial representation can also correspond to thermospatial image whereby each tuple corresponds to a picture-element of the image.

[0041] Typically, one or more thermographic images are mapped onto the surface of the 3D spatial representation to form the thermospatial representation. The thermographic image to be mapped onto the surface of the 3D spatial representation preferably comprises thermal data which are expressed over the same coordinate system as the 3D spatial representation. Any type of thermal data can be used. In one embodiment the thermal data

comprises absolute temperature values, in another embodiment the thermal data comprises relative temperature values each corresponding, *e.g.*, to a temperature difference between a respective point of the surface and some reference point, in an additional embodiment, the thermal data comprises local temperature differences. Also contemplated, are combinations of the above types of temperature data, for example, the thermal data can comprise both absolute and relative temperature values, and the like.

[0042] Typically, but not obligatorily, the information in the thermographic image also includes the thermal conditions (*e.g.*, temperature) at one or more reference markers.

[0043] The mapping of the thermographic image onto the surface of the 3D spatial representation is by positioning the reference markers (*e.g.*, by comparing their coordinates in the thermographic image with their coordinates in the 3D spatial representation), to thereby match also other points hence to form the synthesized thermospatial representation.

[0044] Optionally and preferably, the mapping of thermographic images is accompanied by a correction procedure in which thermal emissivity considerations are employed.

[0045] The thermal emissivity of a body member is a dimensionless quantity defined as the ratio between the amount of thermal radiation emitted from the surface of the body member and the amount of thermal radiation emitted from a black body having the same temperature as the body member. Thus, the thermal emissivity of an idealized black body is 1 and the thermal emissivity of all other bodies is between 0 and 1. It is commonly assumed that the thermal emissivity of a body is generally equal to its thermal absorption factor.

[0046] The correction procedure can be performed using estimated thermal characteristics of the body of interest. Specifically, the thermographic image is mapped onto a non-planar surface describing the body taking into account differences in the emissivity of regions on the surface of the body. A region with a different emissivity value compared to its surrounding can be, for example, a scarred region, a pigmented region, a nipple region on the breast, a nevus. Additionally, the emissivity values of subjects with different skin colors may differ.

[0047] In some embodiments of the present invention, the thermographic image is weighted according to the different emissivity values of the surface. For example, when information acquired by a thermal imaging device includes temperature or energy values, at least a portion of the temperature or energy values can be divided by the emissivity values of the respective regions on the surface of the body. One of ordinary skill in the art will appreciate that such procedure results in effective temperature or energy values which are higher than the values acquired by the thermal imaging device. Since different regions may be characterized by different emissivity values, the weighted thermographic image pro-

vides better estimate regarding the heat emitted from the surface of the body.

[0048] A representative example of a synthesized thermospatial image for the case that the body comprise the breasts of a woman is illustrated in Figures 1a-c, showing a 3D spatial representation illustrated as a non-planar surface (Figure 1a), a thermographic image illustrated as planar isothermal contours (Figure 1b), and a synthesized thermospatial image formed by mapping the thermographic image on a surface of the 3D spatial representation (Figure 1c). As illustrated, the thermal data of the thermospatial image is represented as grey-level values over a grid generally shown at **102**. It is to be understood that the representation according to grey-level values is for illustrative purposes and is not to be considered as limiting. As explained above, the processing of thermal data can also be performed using intensity values. Also shown in Figures 1a-c, is a reference marker **101** which optionally, but not obligatorily, can be used for the mapping.

[0049] The 3D spatial representation, thermographic image and synthesized thermospatial image can be obtained in any technique known in the art, such as the technique disclosed in International Patent Publication No. WO 2006/003658, U.S. Published Application No. 20010046316, and U.S. Patent Nos. 6,442,419, 6,765,607, 6,965,690, 6,701,081, 6,801,257, 6,201,541, 6,167,151, 6,094,198 and 7,292,719.

[0050] Some embodiments of the invention can be embodied on a tangible medium such as a computer for performing the method steps. Some embodiments of the invention can be embodied on a computer readable medium, comprising computer readable instructions for carrying out the method steps. Some embodiments of the invention can also be embodied in electronic device having digital computer capabilities arranged to run the computer program on the tangible medium or execute the instruction on a computer readable medium. Computer programs implementing method steps of the present embodiments can commonly be distributed to users on a tangible distribution medium. From the distribution medium, the computer programs can be copied to a hard disk or a similar intermediate storage medium. The computer programs can be run by loading the computer instructions either from their distribution medium or their intermediate storage medium into the execution memory of the computer, configuring the computer to act in accordance with the method of this invention. All these operations are well-known to those skilled in the art of computer systems.

[0051] Figure 2 is a flowchart diagram of a method suitable for analyzing thermal data, according to various exemplary embodiments. It is to be understood that, unless otherwise defined, method steps described hereinbelow can be executed either contemporaneously or sequentially in many combinations or orders of execution. Specifically, the ordering of the flowchart diagrams is not to be considered as limiting. For example, two or more

method steps, appearing in the following description or in the flowchart diagrams in a particular order, can be executed in a different order (e.g., a reverse order) or substantially contemporaneously. Additionally, several method steps described below are optional and may not be executed.

[0052] The method begins at step **10** and continues to step **12** in which a series of thermospatial representation of a section of a living body is obtained. Each thermospatial representation of the series includes thermal data representing a thermal image of the body section and spatial data representing a non-planar surface of the body section, where the thermal data is associated with the spatial data.

[0053] Different thermospatial representations of the series include thermal data acquired from the body section at different time instants. Optionally, different thermospatial representations of the series include spatial data acquired from the body section at different time instants. Such series of thermospatial representations is used by the method of the present embodiments to determine thermal and optionally spatial changes occurred in the body section over time.

[0054] The series can include any number of thermospatial representations. It was found by the inventors of the present invention that two thermospatial representations are sufficient to perform the analysis, but more than two thermospatial representations (e.g., 3, 4, 5 or more) can also be used, for example, to increase accuracy of the results and/or to allow selection of best acquisitions.

[0055] The thermospatial representations of the series can be generated by the method or it can be generated by another method or system from which the thermospatial representations can be serially read by the method. Techniques for generating thermospatial representations are disclosed in International Patent Publication No. WO 2006/003658, U.S. Published Application No. 20010046316, and U.S. Patent Nos. 6,442,419, 6,765,607, 6,965,690, 6,701,081, 6,801,257, 6,201,541, 6,167,151, 6,094,198 and 7,292,719.

[0056] Generally, acquisitions of the thermal and spatial data can be performed while the body is in a transient or steady thermal condition.

[0057] The term "steady thermal condition" or "steady thermal state" as used herein refer to a thermal state of a body section in which there is no point over the entire surface of the body section for which temporal variations in the temperature are higher than 0.5 °C per minute.

[0058] The term "transient thermal condition" or "transient thermal state" as used herein refer to a thermal state of a body section other than a steady thermal state. More preferably, in a transient thermal condition or a transient thermal state there is at least one point over the surface of the body section for which temporal variations in the temperature are higher than 0.5 °C per minute.

[0059] Since the series includes more than one thermospatial representation, some acquisitions can be performed while the body is in a transient thermal condition

and other acquisitions can be performed while the body is in a steady thermal condition. Yet, in various exemplary embodiments of the present invention the body section is in a transient thermal condition between successive acquisitions of the thermal and spatial data.

[0060] In one embodiment, for example, one acquisition of thermal and spatial data can be performed while the body is in a first steady thermal state, and subsequent acquisition of thermal and spatial data can be performed while the body is in a second steady thermal state which differs from the first steady thermal state. In another embodiment, a first acquisition can be performed while the body is in a first steady thermal state, a second acquisition can be performed while the body is in a first transient thermal state, and a third acquisition can be performed while the body is in a second steady thermal state which differs from the first steady thermal state. Also contemplated are embodiments in which all acquisitions are performed while the body is in a transient thermal state, and embodiments in which all acquisitions are performed while the body is in a steady thermal state.

[0061] A transient thermal condition of the body section between and optionally during acquisitions of thermal and spatial data can be ensured in more than one way.

[0062] In some embodiments of the present invention, the ambient temperature at the surface of the body section is changed between two successive captures of surface information. A change in the ambient temperature corresponds to different boundary conditions for different thermospatial representations. Specifically, in these embodiments, two successive thermospatial representations describe the body section while the subject is exposed to two different ambient temperatures. A change in the ambient temperature can be imposed, for example, by establishing contact between a cold object and the body section or directing a flow of cold gas (*e.g.*, air) to the surface of the body section between successive data acquisitions. Also contemplated is a procedure in which the body section is immersed in cold liquid (*e.g.*, water) between successive data acquisitions. Also contemplated is a procedure in which another body section is exposed to a different (*e.g.*, lower) temperature so as to ensure transient thermal condition. For example, the subject can immerse his or her limb in a cold liquid (*e.g.*, water).

[0063] In some embodiments of the present invention, two or more of the thermospatial representations of the series describe the body section while having two or more different shapes. This is typically accomplished by changing the posture of the subject between successive data acquisitions. The change of subject's posture is preferably such that the shape of the body section of interest is deformed. For example, when the body section is a breast of a woman subject, in one posture the woman can stand with her hands at the side of her body and in another posture the woman can stand with her hands overhead, stand with her hands extended in front at shoulder height, bend forwards, lie in prone position and

the like. These exemplified postures correspond to different breast shapes.

[0064] Change of posture results in transient thermal condition due to a deformation in the thermal path between the thermally distinguished region and other tissue regions. Specifically, upon a posture change, some body tissues move closer to the thermally distinguished region and the thermal path between these tissues and the thermally distinguished region shortens. Conversely, other body tissues move farther from the thermally distinguished region and the thermal path between these tissues and the thermally distinguished region lengthens. Since the length of the thermal path affects the amount of heat transferred over this path, shortening or lengthening of the thermal path results change in heat transfer. When the body of the subject contains, for example, a tumor having elevated temperature, change of posture effects temperature increment for tissues which move closer to the tumor and temperature decrement for tissues which move farther from the tumor.

[0065] Figures 11a-d are thermal images of a right breast (Figures 11a and 11c) and a left breast (Figures 11b and 11d) of a female subject standing with her hands at the side of her body (Figures 11a-b) and with her hands overhead (Figures 11c-d). As shown, the change in posture results in a change in the shape of the breasts and a change in the thermal state of their surfaces. The surfaces of breasts were therefore in a transient thermal condition while and immediately after the change in posture.

[0066] When the body section is deformed between two acquisitions, the thermal and spatial data are optionally acquired such that the thermospatial representations are alignable with respect to a predetermined fixed reference point on the body. For example, the reference point can be a mark on the arm-pit.

[0067] In some embodiments of the present invention the method continues to step 14 in which a deformation function which maps one shape of the body section to another shape thereof is calculated. These embodiments are particularly useful when the body section is deformed between two successive acquisitions. The deformation function generally includes spatial information which describes how picture-elements (*e.g.*, pixels, group of pixels, spots) are transformed under shape deformation. The deformation function can include surface information or volume information as desired. When the deformation function includes surface information the mapping is between points on the surface of the body section before the deformation and points on the surface of the body section after the deformation. When the deformation function includes volume information, the mapping is between points in the body section and on its surface before the deformation and points in the body section on its surface of after the deformation.

[0068] Ideally, a deformation function provides mapping pixelwise between two thermospatial representations. In such ideal case applying the deformation func-

tion to the location of each pixel in the thermospatial representation before the deformation creates the spatial information of the thermospatial representation after the deformation. Yet, it was found by the present inventors that it is sufficient to calculate mapping for several picture-elements (e.g., pixels, group of pixels, spots) rather than for each and every pixel of the thermospatial representations. In any event, when step **14** of the method is executed, the deformation function maps between at least one picture-element in the body section before deformation and at least one picture-element in the body section after deformation.

[0069] The calculated deformation function is typically in the form of a mapping table in which each entry corresponds to the mapping between two corresponding picture-elements, one being part of the shape before deformation and the other being part of the deformed shape. The calculation of the deformation function can be using any technique known in the art. A representative example includes, without limitation, a finite element method in which the deformation function is approximated as piecewise smooth between discrete elements. The elements can be of arbitrary shape and they typically share nodes and faces with adjacent elements and form at least part of the shape of the body section.

[0070] An illustrative example of a deformation function is provided in Figure 3 showing a first shape (left) and a second shape (right) where the second shape is deformed with respect to the first shape. For clarity of presentation, the shapes are illustrated as planar shapes on a rectangular grid. It is to be understood, however, that it is not intended to exclude non-planar shapes and curved or other non-rectangular grids from the scope of the present invention. The deformation function is represented in Figure 3 as an arrow, mapping spots **28**, **26** in the first shape to their corresponding spots **28'**, **26'** in the second shape. Although Figure 3 illustrates the mapping of two spots, this need not necessarily be the case, since the mapping can be employed to any number of picture-elements (including a mapping of a single picture-element in the first shape to its corresponding picture-element in the deformed shape).

[0071] In some embodiments of the present invention the method continues to step **16** in which a characteristic heat conduction of the body section is estimated based on the series of thermospatial representations. Characteristic heat conduction can be estimated by performing a calibration procedure in which the depth of one or more identifiable tissue regions is known or calculated and the rate of heat transfer to or from the identifiable tissue regions is measured. In various exemplary embodiments of the invention the identifiable tissue regions are sections of blood vessels. It was found by the inventor of the present invention that blood vessel sections can be identified from thermal data with to a relatively high confidence level, and that these blood vessel sections can be used for estimating the thermal conductivity.

[0072] For example, in some embodiments of the

present invention step **16** is executed by performing the following calibration procedure (see Figure 4).

[0073] The procedure begins at **30** and continues to **31** at which a first data acquisition is performed while the body section is in a first shape referred to hereinafter as the "undeformed shape." The procedure continues to **32** at which a first thermospatial representation is constructed, and **33** at which the depth of an identifiable tissue region is calculated using the first thermospatial representation. The identifiable tissue region can be for example, a distinguishable blood vessel section. Calculation of depth from the thermospatial representation can be done, for example, by triangulation or any other technique known in the art.

[0074] The procedure subsequently proceeds to **34** in which a second data acquisition is performed while the body section is in a second shape which is deformed with respect to the undeformed shape. A second thermospatial representation is then constructed. While the shape is still deformed, data is repeatedly acquired until the identifiable tissue region is in a steady thermal state (decision **35**). The repetition of data acquisition (process **34**) can be done only for thermal data since there is no change in the shape of the body section between successive acquisitions.

[0075] The procedure continues to **36** at which the thermal stabilization period is determined. Generally, the thermal stabilization period can be defined as the elapsed time between the deformation of the body shape and the onset of steady state. The procedure can also calculate the difference in steady state temperatures before and after deformation. The procedure proceeds to **37** in which the second thermospatial representation is used for recalculating the depth of the same identifiable tissue region so as to determine the difference in the depths due to the deformation. The procedure then continues to **38** at which the thermal conductivity is calculated based on the knowledge of the thermal stabilization period and the differences in depths and steady state temperatures. To this end, the Stefan-Boltzmann law can be used to approximate heat flux.

[0076] The procedure ends at **39**.

[0077] Referring again to the flowchart diagram of Figure 2, the method continues to step **18** in which transient thermal history of the body section is extracted, based on thermal variations among the series of thermospatial representations. The transient thermal history includes temporal variation of local thermal quantities over at least part of the surface of the body section. The local thermal quantities can be for example temperatures, intensity values or grey-levels as individually measured at one or more surface locations. The temperatures, intensity values or grey-levels can be absolute or they can be relative to other surface locations.

[0078] The variations in local thermal quantities can be extracted for any number of picture-elements of the thermospatial representations. Typically the method selects a set of picture-elements and extracts temporal variations

in the thermal quantities for each picture-element in the set.

[0079] The term "set of picture-elements" encompass a plurality of picture-elements as well as a single picture-element. In some embodiments of the present invention the set of picture-elements includes all the picture-elements of the thermospatial representation.

[0080] In embodiments in which a deformation function is calculated, the deformation function is utilized for determining a correspondence between sets of picture-element belonging to different thermospatial representations of the series to allow determination of individual thermal variation for each picture-element in the set.

[0081] For each picture-element of the set, the temporal variations can be defined in a binary manner (e.g., whether the picture-element exhibits an increment or a decrement in temperature due to the transient thermal condition), or by value (e.g., the change or rate of change in temperature exhibited by the picture-element due to the transient thermal condition). For one or more picture-elements, the transient thermal history can optionally be expressed in terms of thermal stabilization period (onset of a steady thermal state at the picture-element) or thermal response delay (onset of temperature change at the picture-element). Also contemplated are embodiments in which more than one type of temporal variation is extracted for each picture-element of the set. It was found by the present inventor that the use of two or more types of temporal variation for each picture-element is advantageous from the standpoint of accuracy and specificity. Yet, the use of one type of temporal variation is not excluded from the scope of the present invention.

[0082] In various exemplary embodiments of the invention the method proceeds to step 20 in which the transient thermal history is compared to a reference transient thermal history. Typically, but not obligatorily, the reference thermal history represents a situation in which no thermally distinguishable region is present.

[0083] The reference thermal history generally corresponds to a thermal history as extracted from a series of reference thermospatial representations, which can be obtained from a library or can be constructed by the method of the present embodiments. The reference thermospatial representation can describe a reference body section other than the body section being analyzed. Typically, the reference body section is a body section which is similar in shape to the body section being analyzed. For example, when the body section is a breast of a woman, the reference body section can be the other breast of the same woman. Preferably, but not obligatorily, the reference body section is devoid of thermally distinguishable region.

[0084] The comparison between thermal histories can be used for determining the likelihood for the presence of a thermally distinguishable region in the body section. Generally, when the distribution of the transient thermal variations over the surface of the reference body section, is considerably different from the distribution of the tran-

sient thermal variations over the surface of the body section being analyzed, the method can determine that it is likely that a thermally distinguishable region is present. For example, when the transient thermal variations are distributed generally uniformly over the surface of the reference body section, but exhibit a considerable local nature over the surface of the body section being analyzed, the method can determine that it is likely that a thermally distinguishable region is present.

[0085] This can be better understood from the following non-limiting example. Suppose that the reference body section has a similar shape to the body section of interest such that there is a geometrical correspondence between a set S of points on the surface of the body section of interest and a set S_R of points on the surface of the reference body section. Suppose further that $P_1 \in S$ and $P_2 \in S$ correspond to $Q_1 \in S_R$ and $Q_2 \in S_R$, respectively, and that the method determines the temporal derivative (transient temperature change) $\partial T / \partial t$ at each of points P_1, P_2, Q_1 and Q_2 . In some embodiments of the present invention if the ratio $(\partial T(P_1) / \partial t) / (\partial T(P_2) / \partial t)$ is substantially different (say, by more than 10 %) from the ratio $(\partial T(Q_1) / \partial t) / (\partial T(Q_2) / \partial t)$, the method determines that it is likely that a thermally distinguishable region is present. If, on the other hand the above ratios are similar (say, within 10 %) the method determines that it is not likely that a thermally distinguishable region is present. The likelihood can also be quantified (e.g., expressed as percentage) based on the difference or ratio between the above ratios.

[0086] The method continues to step 22 in which the transient thermal history information is used to estimate a location of an internal thermally distinguishable region in body section.

[0087] Generally, the location of the internal thermally distinguishable region is estimated by analyzing the differences between the thermospatial representations in the series. Figure 5a is a schematic illustration of an undeformed shape 52 and a deformed shape 50. Also shown in Figure 5a is a thermally distinguishable region 54 having an elevated temperature relative to its surrounding tissues. Figure 5b illustrates the spatial profile of two heat signals 56 and 58, where signal 56 is acquired while the body is in shape 52 and signal 58 is acquired while the body is in shape 50. As shown, heat signal 58 is narrower than heat signal 56. This is because the location of region 54 is closer to the surface of the body when the body is in shape 50 relative to its location when the body is in shape 52.

[0088] Figure 6a illustrates shapes 50 and 52 with two representative points P_1 and P_2 marked on surface 50, where as a result of the deformation, the thermal path between P_1 and region 54 shortened and the thermal path between P_2 and region 54 lengthened. Figure 6b is a graph showing the heat signal as measured at P_1 as a function of the time, and Figure 6c is a graph showing the heat signal as measured at P_2 as a function of the time. As shown, the heat signal at P_1 increases with time

since in the deformed shape P_1 is closer to region 54 hence receives more heat therefrom, and the heat signal at P_2 decreases with time since in the deformed shape P_2 is farther from region 54 hence receives less heat therefrom. Marked on the time axis of Figure 6b is an instant t_1 designating the onset of steady state at P_1 . The period of time from the deformation time to t_1 is referred to herein as "thermal stabilization period." Marked on the time axis of Figure 6c is an instant t_2 designating the onset of temperature change at P_2 . The period of time from the deformation time t_0 to t_2 is referred to herein as "thermal response delay."

[0089] In various exemplary embodiments of the invention the method utilizes the above information for estimating the location of region 54.

[0090] In some embodiments of the present invention the method selects a collection of points over the surface and determines, for each point in the collection, whether the temperature at the point remained unchanged, increased or decreased as a result of the transient state. These embodiments are particularly useful when the body section is deformed between two successive acquisitions. Once the direction of change (increment, decrement or none) of change is known, the method can determine for each point in the collection, if the point moved closer to or farther from the thermally distinguishable region. For example, when the thermally distinguishable region has a temperature which is above the temperature of the surrounding tissues, temperature increment at a particular surface point indicates that the surface point has moved closer to the thermally distinguishable region and temperature decrement at a particular surface point indicates that the surface point has moved farther from the thermally distinguishable region, as further detailed hereinunder.

[0091] It was found by the present inventor that this information can be utilized to estimate the location of the thermally distinguishable region. Specifically, each point in the collection imposes a constraint that the region is closer or farther (as the case may be) from the point in the deformed shape than in the undeformed shape. Thus, a set of constraints is constructed and the method can search over the thermospatial representation for an internal region satisfying all the constraints.

[0092] In some embodiments of the present invention the location of the internal thermally distinguishable region is estimated by determining amount of temperature change for each point of the collection. Specifically, for each point in the collection, the method uses the amount of temperature change to define a quantity which is proportional to the distance between the point and the thermally distinguishable region. For example, when the thermally distinguishable region is a tumor characterized by elevated temperature relative to its neighboring tissues, higher temperature change corresponds to a point being closer to the tumor while lower temperature change corresponds to a point being farther from the tumor. Optionally, the method utilizes the calculated thermal conduc-

tivity for defining the quantity.

[0093] By defining the quantity for all points in the collection the method acquires sufficient information regarding distance proportions between the points and the thermally distinguishable region. The location of the thermally distinguishable region can then be estimated by searching over the thermospatial representation for an internal region which satisfies all distance proportions.

[0094] In some embodiments of the present invention the location of the internal thermally distinguishable region is estimated by determining a temperature change rate for each point in the collection. The temperature change rate is equivalent to a mathematical operation of a first derivative of the temperature with respect to the time. Since such derivative correlates to the length of a thermal path between a surface point and a thermally distinguishable region, the method can use the temperature change rate to define a quantity which is proportional to the distance between the point and the thermally distinguishable region. Once quantities are defined for all points in the collection, the location of the thermally distinguishable region can be estimated as further detailed hereinabove.

[0095] In some embodiments of the present invention the location of the internal thermally distinguishable region is estimated by comparing the temperature change rate of one point of the collection to a temperature change rate of another point of the collection. Such procedure allows determining thermal length proportions, whereby a lower temperature change rate indicates a longer thermal length and vice versa. Thermal proportions can be defined between pair of points in the collection or alternatively by selecting a reference point and comparing temperature change rates of all other points in the collection to the temperature change rate of the reference point. Thus, each point in the collection is associated with a thermal length proportion and the method can search over the thermospatial representation for an internal region satisfying all thermal length proportions.

[0096] In some embodiments of the present invention, the location of the internal thermally distinguishable region is estimated by determining a thermal stabilization period for each point in the collection. Such a procedure allows defining a quantity which is proportional to the distance between the point and the thermally distinguishable region, whereby a longer thermal stabilization period indicates a shorter distance and vice versa. Similarly to the above embodiment, once quantities are defined for all points in the collection, the location of the thermally distinguishable region can be estimated as further detailed hereinabove. In some embodiments of the present invention, the location of the internal thermally distinguishable region is estimated by comparing the thermal stabilization period of one point in the collection to the thermal stabilization period of another point in the collection, hence to acquire more information.

[0097] In some embodiments of the present invention the location of the internal thermally distinguishable re-

gion is estimated by determining thermal response delay (elapsed time to the onset of temperature change at the point). Such procedure allows defining a quantity which is proportional to the distance between the point and the thermally distinguishable region, whereby a longer thermal response delay indicates a longer distance and vice versa. Similarly to the above embodiment, once quantities are defined for all points in the collection, the location of the thermally distinguishable region can be estimated as further detailed hereinabove. In some embodiments of the present invention, the location of the internal thermally distinguishable region is estimated by comparing the thermal response delay of one point in the collection to the thermal response delay of another point in the collection, hence to acquire more information.

[0098] In some embodiments, as stated, the transient thermal condition is ensured by changing the ambient temperature at the surface of the body of the subject. This can be done irrespectively whether or not the shape of the body section is deformed. When the ambient temperature is changed the location of the thermally distinguishable region can be estimated using principles which are similar to the principles described above. More specifically, a collection of points over the surface is selected and the location of the internal thermally distinguishable region can be estimated by determining a temperature change rate, thermal stabilization period and/or thermal response delay for each point in the collection. Any of these quantities can be used singly or in combination with one or more quantities, and any of these quantities can be used independently for each point and/or exploited for comparison with respective quantities associated with other points of the collection.

[0099] When the ambient temperature is changed and the shape of the body section remains substantially undeformed, the deformation function is preferably, but not obligatorily, not calculated, and the estimation of the location of the thermally distinguishable region is based on transient thermal data and static spatial data. It was found by the present Inventor that changes in ambient temperature can provide a sufficiently informative signal for the purpose of estimating the location.

[0100] The above embodiments can be employed either singly or in combination or subcombination.

[0101] The method ends at step **24**.

[0102] Any of the above embodiments can also be utilized for determining the size of the thermally distinguishable region. This can readily be achieved by calculating the number of picture-elements representing the thermally distinguishable region and correlating the number to the volume of the region within the body. The method according to some embodiments can thus be utilized for monitoring the evolution of a tumor in a body section. Specifically, selected steps of the method described above can be executed a plurality of times to estimate a size of the tumor at each execution, hence to monitor the evolution of the tumor.

[0103] The method according to some embodiments

can be utilized for treating a tumor in a body section. In these embodiments, selected steps of the method described above are executed so as to estimate the size of the tumor. Subsequently, a destructive treatment is applied to the tumor. The treatment can be radiative or it may include chemotherapy. Following the destructive treatment, selected steps of the method described above are executed again so as to re-estimate the size of the tumor. The destructive treatment can then be repeated until a predetermined criterion is met, which predetermined criterion can be a maximal dosage for the treated subject or tumor size threshold. The tumor size threshold can be expressed in absolute value or as a percentage of the size of the tumor before treatment.

[0104] Reference is now made to Figure 7 which is a schematic illustration of an apparatus **60** for analyzing thermal data, according to various exemplary embodiments of the present invention. Apparatus **60** can be implemented in a computing platform **61**, such as a data processor or a computer system and can be used for executing one or more of the method steps described above. Data flow channels between the various components of apparatus **60** are shown as arrows in Figure 7.

[0105] Apparatus **60** comprises an input unit **62** for receiving a series of thermospatial representations describing a section of the living body, and a computing platform **61** which estimates the location or presence of the thermally distinguishable region in the body section. In various exemplary embodiments of the invention apparatus **60** comprises a thermal history extractor **64** configured for extracting transient thermal history of the body section as further detailed hereinabove. In some embodiments of the present invention apparatus **60** comprises a deformation function calculator **70** configured for calculating a deformation function as further detailed hereinabove.

[0106] In some embodiments of the present invention apparatus **60** comprises a heat conduction estimator **72** for estimating characteristic heat conduction of body section based on series as further detailed hereinabove.

[0107] Apparatus **60** further comprises a location estimator **66** configured for estimating a location of an internal thermally distinguishable region in body section based on transient thermal history, as further detailed hereinabove. In some embodiments of the present invention apparatus **60** comprises a size estimator **68**, configured for estimating the size of the internal thermally distinguishable region, as further detailed hereinabove. Apparatus **60** preferably comprises an output unit **74** which issues a report regarding the location and/or size of the thermally distinguishable region.

[0108] Reference is now made to Figure 8 which is a schematic illustration of an imaging and processing system **80**, according to some embodiments of the present invention. System **80** comprises a thermospatial imaging system **82** which provides a series of thermospatial representations of the body section, and an analysis apparatus **84** for analyzing the thermospatial representations.

The principles and operations of apparatus **84** are similar to the principles and operations of apparatus **60** described above. In some embodiments of the present invention apparatus **84** is apparatus **60**.

[0109] The following description is of techniques for obtaining the thermospatial representation, according to various exemplary embodiments of the present invention. The techniques described below can be employed by any of the method and apparatus described above.

[0110] A thermospatial representation or image can be generally obtained by acquiring one or more thermographic images and mapping the thermographic image(s) on a 3D spatial representation.

[0111] Reference is now made to Figure 9a which is a schematic illustration of a thermospatial imaging system **120** in accordance with preferred embodiments of the present invention. As shown in Figure 9a, a living body **210** or a part thereof of a person **212** is located in front of an imaging device **214**. The person **212**, may be standing, sitting or in any other suitable position relative to imaging device **214**. Person **212** may initially be positioned or later be repositioned relative to imaging device **214** by positioning device **215**, which typically comprises a platform moving on a rail, by force of an engine, or by any other suitable force. Additionally, a thermally distinguishable object **216**, such as a tumor, may exist in body **210** of person **212**. For example, when body **210** comprises a breast, object **216** can be a breast tumor such as a cancerous tumor.

[0112] In accordance with a preferred embodiment of the present invention, person **212** may be wearing a clothing garment **218**, such as a shirt. Preferably, clothing garment **218** may be non-penetrable or partially penetrable to visible wavelengths such as 400-700 nanometers, and may be penetrable to wavelengths that are longer than visible wavelengths, such as infrared wavelengths. Additionally, a reference mark **220** may be located close to person **212**, preferably directly on the body of person **212** and in close proximity to body **210**. Optionally and preferably, reference mark **220** is directly attached to body **210**. Reference mark **220** may typically comprise a piece of material, a mark drawn on person **212** or any other suitable mark, as described herein below.

[0113] Imaging device **214** typically comprises at least one visible light imaging device **222** that can sense at least visible wavelengths and at least one thermographic imaging device **224** which is sensitive to infrared wavelengths, typically in the range of as 3-5 micrometer and/or 8-12 micrometer. Typically imaging devices **222** and **224** are capable of sensing reference mark **220** described hereinabove.

[0114] Optionally, a polarizer **225** may be placed in front of visible light imaging device **222**. As a further alternative, a color filter **226**, which may block at least a portion of the visible wavelengths, may be placed in front of visible light imaging device **222**.

[0115] Typically, at least one visible light imaging de-

vice **222** may comprise a black-and-white or color stills imaging device, or a digital imaging device such as CCD or CMOS. Additionally, at least one visible light imaging device **222** may comprise a plurality of imaging elements, each of which may be a three-dimensional imaging element.

[0116] Optionally and preferably, imaging device **214** may be repositioned relative to person **212** by positioning device **227**. As a further alternative, each of imaging devices **222** and **224** may also be repositioned relative to person **212** by at least one positioning device **228**. Positioning device **227** may comprise an engine, a lever or any other suitable force, and may also comprise a rail for moving imaging device **214** thereon. Preferably, repositioning device **228** may be similarly structured.

[0117] Data acquired by visible light imaging device **222** and thermographic imaging device **224** is output to a data processor **230** via a communications network **232**, and is typically analyzed and processed by an algorithm running on the data processor. The resulting data may be displayed on at least one display device **234**, which is preferably connected to data processor **230** via a communications network **236**. Data processor **230** typically comprises a PC, a PDA or any other suitable data processor. Communications networks **232** and **236** typically comprise a physical communications network such as an internet or intranet, or may alternatively comprise a wireless network such as a cellular network, infrared communication network, a radio frequency (RF) communications network, a blue-tooth (BT) communications network or any other suitable communications network.

[0118] In accordance with a preferred embodiment of the present invention display **234** typically comprises a screen, such as an LCD screen, a CRT screen or a plasma screen. As a further alternative display **234** may comprise at least one visualizing device comprising two LCDs or two CRTs, located in front of a user's eyes and packaged in a structure similar to that of eye-glasses. Preferably, display **234** also displays a pointer **238**, which is typically movable along the X, Y and Z axes of the displayed model and may be used to point to different locations or elements in the displayed data.

[0119] Reference is now made to Figures 9b-f and 10a-e which illustrate the various operation principles of thermospatial imaging system **120**, in accordance with various exemplary embodiments of the invention.

[0120] The visible light imaging is described first, with reference to Figures 9b-f, and the thermographic imaging is described hereinafter, with reference to figures 10a-e. It will be appreciated that the visible light image data acquisition described in Figures 9b-f may be performed before, after or concurrently with the thermographic image data acquisition described in Figures 10a-e.

[0121] Referring to Figures 9b-f, person **212** comprising body **210** is located on positioning device **215** in front of imaging device **214**, in a first position **240** relative to the imaging device. First image data of body **210** is acquired by visible light imaging device **222**, optionally

through polarizer **225** or as an alternative option through color filter **226**. The advantage of using a color filter is that it can improve the signal-to-noise ratio, for example, when the person is illuminated with a pattern or mark of specific color, the color filter can be used to transmit only the specific color thereby reducing background readings. Additionally, at least second image data of body **210** is acquired by visible light imaging device **222**, such that body **210** is positioned in at least a second position **242** relative to imaging device **214**. Thus, the first, second and optionally more image data are acquired from at least two different viewpoints of the imaging device relative to body **210**.

[0122] The second relative position **242** may be configured by repositioning person **212** using positioning device **215** as seen in Figure 9b, by repositioning imaging device **214** using positioning device **227** as seen in Figure 9c or by repositioning imaging device **222** using positioning device **228** as seen in Figure 9d. As a further alternative, second relative position **242** may be configured by using two separate imaging devices **214** as seen in Figure 9e or two separate visible light imaging device **222** as seen in Figure 9f.

[0123] Referring to Figures 10a-e, person **212** comprising body **210** is located on positioning device **215** in front of imaging device **214**, in a first position **244** relative to the imaging device. First thermographic image data of body **210** is acquired by thermographic imaging device **224**. Optionally and preferably at least second thermographic image data of body **210** is acquired by thermographic imaging device **224**, such that body **210** is positioned in at least a second position **242** relative to imaging device **214**. Thus, the first, second and optionally more thermographic image data are acquired from at least two different viewpoints of the thermographic imaging device relative to body **210**.

[0124] The second relative position **246** may be configured by repositioning person **212** using positioning device **215** as seen in Figure 10a, by repositioning imaging device **214** using positioning device **227** as seen in Figure 10b, or by repositioning thermographic imaging device **224** using positioning device **228** as seen in Figure 10c. As a further alternative, the second relative position **246** may be configured by using two separate imaging devices **214** as seen in Figure 10d or two separate thermographic imaging devices **224** as seen in Figure 10e.

[0125] Image data of body **210** may be acquired by thermographic imaging device **224**, by separately imaging a plurality of narrow strips of the complete image of body **210**. Alternatively, the complete image of body **210** is acquired by the thermographic imaging device, and the image is sampled in a plurality of narrow strips or otherwise shaped portions for processing. As a further alternative, the imaging of body **210** may be performed using different exposure times.

[0126] The thermographic and visible light image data obtained from imaging device **214** is preferably analyzed and processed by data processor **230** as follows. Image

data acquired from imaging device **222** is processed by data processor **230** to build a three-dimensional spatial representation of body **210**, using algorithms and methods that are well known in the art, such as the method described in U.S. Patent No. 6,442,419. The 3D spatial representation preferably comprises the location of reference marker **220** (cf. Figure 1a). Optionally and preferably, the 3D spatial representation comprises information relating to the color, hue and tissue texture of body **210**. Thermographic image data acquired from imaging device **224** is processed by data processor **230** to build a thermographic three-dimensional model of body **210**, using algorithms and methods that are well known in the art, such as the method described in U.S. Patent No. 6,442,419. The thermographic 3D model preferably comprises reference marker **220** (cf. Figure 1b). The thermographic 3D model is then mapped by processor **230** onto the 3D spatial representation, e.g., by aligning reference marker **220**, to form the thermospatial image.

[0127] As used herein the term "about" refers to $\pm 10\%$.

[0128] The terms "comprises", "comprising", "includes", "including", "having" and their conjugates mean "including but not limited to".

[0129] As used herein, the singular form "a", "an" and "the" include plural references unless the context clearly dictates otherwise. For example, the term "a compound" or "at least one compound" may include a plurality of compounds, including mixtures thereof.

[0130] Throughout this application, various embodiments of this invention may be presented in a range format. It should be understood that the description in range format is merely for convenience and brevity and should not be construed as an inflexible limitation on the scope of the invention. Accordingly, the description of a range should be considered to have specifically disclosed all the possible subranges as well as individual numerical values within that range. For example, description of a range such as from 1 to 6 should be considered to have specifically disclosed subranges such as from 1 to 3, from 1 to 4, from 1 to 5, from 2 to 4, from 2 to 6, from 3 to 6 etc., as well as individual numbers within that range, for example, 1, 2, 3, 4, 5, and 6. This applies regardless of the breadth of the range.

[0131] Whenever a numerical range is indicated herein, it is meant to include any cited numeral (fractional or integral) within the indicated range. The phrases "ranging/ranges between" a first indicate number and a second indicate number and "ranging/ranges from" a first indicate number "to" a second indicate number are used herein interchangeably and are meant to include the first and second indicated numbers and all the fractional and integral numerals therebetween.

[0132] It is appreciated that certain features of the invention, which are, for clarity, described in the context of separate embodiments, may also be provided in combination in a single embodiment. Conversely, various features of the invention, which are, for brevity, described

in the context of a single embodiment, may also be provided separately or in any suitable subcombination or as suitable in any other described embodiment of the invention. Certain features described in the context of various embodiments are not to be considered essential features of those embodiments, unless the embodiment is inoperative without those elements.

[0133] Although the invention has been described in conjunction with specific embodiments thereof, it is evident that many alternatives, modifications and variations will be apparent to those skilled in the art. Accordingly, it is intended to embrace all such alternatives, modifications and variations that fall within the scope of the appended claims.

[0134] In addition, citation or identification of any reference in this application shall not be construed as an admission that such reference is available as prior art to the present invention. To the extent that section headings are used, they should not be construed as necessarily limiting.

Claims

1. Apparatus (60) for locating a thermally distinguishable region (54) within a living body, comprising:

an input unit (62) for receiving a series of thermospatial representations describing a section of a living body, wherein at least two thermospatial representations of said series describe said body section while having at least two different shapes (50, 52); and
a computing platform (61) configured for:

extracting transient thermal history of said body section based on thermal variations present in said series, and
estimating a location or presence of an internal thermally distinguishable region (54) in said body section based on said transient thermal history

characterized in that:

each thermospatial representation is defined over a three-dimensional spatial representation of said body and has thermal data associated with a surface of the three-dimensional spatial representation, and said computing platform is further configured for calculating a deformation function which maps one shape (50) of said at least two different shapes to another shape (52) of said at least two different shapes.

2. An imaging and processing system (80), comprising the apparatus (60, 84) of claim 1 and a thermospatial

imaging system (82) operable to provide said input unit with said series of thermospatial representations.

3. The apparatus (60) or system (80) of claim 1, wherein said apparatus (60) further comprises a size estimator, configured for estimating a size of said internal thermally distinguishable region (54), based on said transient thermal history.

4. The apparatus (60) or system (80) of claim 1, wherein said computing platform (61) is configured for comparing said transient thermal history to a reference transient thermal history, so as to determine the likelihood for said presence of said thermally distinguishable region (54).

5. The apparatus (60) or system (80) of claim 1 or 2, wherein a change in an ambient temperature at a surface of said body section is imposed between at least two successive thermospatial representations of said series.

6. The apparatus (60) or system (80) of claim 1 or 2, wherein said location of said internal thermally distinguishable region (54) is estimated by determining amount of temperature change for each point of a plurality of points over a surface of said body section.

7. The apparatus (60) or system (80) of claim 6, wherein said location of said internal thermally distinguishable region (54) is estimated by determining a temperature change rate for said point.

8. The apparatus (60) or system (80) of claim 7, wherein said location of said internal thermally distinguishable region (54) is estimated by comparing a temperature change rate of one point of said plurality of points to a temperature change rate of another point of said plurality of points.

9. The apparatus (60) or system (80) of claim 6, wherein said location of said internal thermally distinguishable region (54) is estimated by determining onset of a steady thermal state for said point.

10. The apparatus (60) or system (80) of claim 6, wherein said location of said internal thermally distinguishable region (54) is estimated by determining onset of temperature change for said point.

11. The apparatus (60) or system (80) of claim 1, wherein said extraction of said transient thermal history is done by selecting a set of points belonging to one thermospatial representation of said series, utilizing said deformation function for determining a corresponding set of points belonging to another thermospatial representation of said series, and determining

an individual thermal variation for each point in said set.

12. The apparatus (60) or system (80) of claim 1 or 2, wherein said computing platform (61) is configured for estimating characteristic heat conduction of said body section based on said series.

13. The apparatus (60) or system (80) of any of claims 1-12, wherein said body section is a breast of a woman.

Patentansprüche

1. Vorrichtung (60) zum Lokalisieren einer thermisch unterscheidbaren Region (54) in einem lebenden Körper, umfassend:

eine Eingabeeinheit (62) zum Empfangen einer Serie von thermisch-räumlichen Darstellungen, die einen Teil eines lebenden Körpers beschreiben, wobei mindestens zwei thermisch-räumliche Darstellungen der Serie den Körperteil beschreiben, während er mindestens zwei verschiedene Formen (50, 52) aufweist; eine Computerplattform (61), die konfiguriert ist zum:

Extrahieren eines transienten Temperaturverlaufs des Körperteils basierend auf thermischen Abweichungen, die in der Serie vorhanden sind, und Schätzen einer Stelle oder eines Vorhandenseins einer inneren, thermisch unterscheidbaren Region (54) im Körperteil basierend auf dem transienten Temperaturverlauf,

dadurch gekennzeichnet, dass:

jede thermisch-räumliche Darstellung über eine dreidimensionale räumliche Darstellung des Körpers definiert ist und thermische Daten aufweist, die mit einer Fläche der dreidimensionalen räumlichen Darstellung assoziiert sind, und die Computerplattform ferner zum Berechnen einer Verformungsfunktion konfiguriert ist, die eine Form (50) der mindestens zwei verschiedenen Formen auf eine andere Form (52) der mindestens zwei verschiedenen Formen abbildet.

2. Bildgebungs- und Verarbeitungssystem (80), umfassend die Vorrichtung (60, 84) nach Anspruch 1 und ein System (82) zur thermisch-räumlichen Bildgebung, das so betrieben werden kann, dass es die

Eingabeeinheit mit der Serie von thermisch-räumlichen Darstellungen versieht.

3. Vorrichtung (60) oder System (80) nach Anspruch 1, wobei die Vorrichtung (60) ferner einen Größenschätzer umfasst, der zum Schätzen einer Größe der inneren, thermisch unterscheidbaren Region (54) basierend auf dem transienten Temperaturverlauf konfiguriert ist.

4. Vorrichtung (60) oder System (80) nach Anspruch 1, wobei die Computerplattform (61) zum Vergleichen des transienten Temperaturverlaufs mit einem transienten Referenz-Temperaturverlauf konfiguriert ist, um die Wahrscheinlichkeit des Vorhandenseins der thermisch unterscheidbaren Region (54) zu bestimmen.

5. Vorrichtung (60) oder System (80) nach Anspruch 1 oder 2, wobei eine Änderung einer Umgebungstemperatur an einer Oberfläche des Körperteils zwischen mindestens zwei aufeinander folgenden thermisch-räumlichen Darstellungen der Serie erzwungen wird.

6. Vorrichtung (60) oder System (80) nach Anspruch 1 oder 2, wobei die Stelle der inneren, thermisch unterscheidbaren Region (54) durch Bestimmen eines Ausmaßes der Temperaturänderung für jeden Punkt einer Mehrzahl von Punkten über eine Oberfläche des Körperteils geschätzt wird.

7. Vorrichtung (60) oder System (80) nach Anspruch 6, wobei die Stelle der inneren, thermisch unterscheidbaren Region (54) durch Bestimmen einer Temperaturänderungsrate für den Punkt bestimmt wird.

8. Vorrichtung (60) oder System (80) nach Anspruch 7, wobei die Stelle der inneren, thermisch unterscheidbaren Region (54) durch Vergleichen einer Temperaturänderungsrate eines Punkts der Mehrzahl von Punkten mit einer Temperaturänderungsrate eines anderen Punkts der Mehrzahl von Punkten geschätzt wird.

9. Vorrichtung (60) oder System (80) nach Anspruch 6, wobei die Stelle der inneren, thermisch unterscheidbaren Region (54) durch Bestimmen eines Anfangs eines thermischen Dauerzustands für den Punkt bestimmt wird.

10. Vorrichtung (60) oder System (80) nach Anspruch 6, wobei die Stelle der inneren, thermisch unterscheidbaren Region (54) durch Bestimmen eines Anfangs einer Temperaturänderung für den Punkt bestimmt wird.

11. Vorrichtung (60) oder System (80) nach Anspruch 1, wobei die Extraktion des transienten Temperaturverlaufs durch Auswählen eines Satzes von Punkten, die zu einer thermisch-räumlichen Darstellung der Serie gehören, Verwenden der Verformungsfunktion zum Bestimmen eines entsprechenden Satzes von Punkten, die zu einer anderen thermisch-räumlichen Darstellung gehören, und Bestimmen einer einzelnen thermischen Abweichung für jeden Punkt in dem Satz erfolgt.
12. Vorrichtung (60) oder System (80) nach Anspruch 1 oder 2, wobei die Computerplattform (61) zum Schätzen einer charakteristischen Wärmeleitung des Körperteils basierend auf der Serie konfiguriert ist.
13. Vorrichtung (60) oder System (80) nach einem der Ansprüche 1 bis 12, wobei der Körperteil eine Brust einer Frau ist.

Revendications

1. Appareil (60) destiné à localiser une région thermiquement distinctive (54) à l'intérieur d'un corps vivant, comprenant :

une unité d'entrée (62) destinée à recevoir une série de représentations thermospatiales décrivant une partie d'un corps vivant, au moins deux représentations thermospatiales de ladite série décrivant ladite partie du corps tout en ayant au moins deux formes différentes (50, 52) ; et une plateforme de calcul (61) conçue pour :

extraire un historique thermique transitoire de ladite partie du corps sur la base des variations thermiques présentes dans ladite série, et estimer l'emplacement ou la présence d'une région interne thermiquement distinctive (54) dans ladite partie du corps sur la base dudit historique thermique transitoire

caractérisé en ce que :

chaque représentation thermospatiale est définie par-dessus une représentation spatiale tridimensionnelle dudit corps et comporte des données thermiques associées à une surface de la représentation spatiale tridimensionnelle, et ladite plateforme de calcul est conçue en outre pour calculer une fonction de déformation qui associe une première forme (50) desdites au moins deux formes différentes à une autre forme (52) desdites au moins

deux formes différentes.

2. Système d'imagerie et de traitement (80), comprenant l'appareil (60, 84) selon la revendication 1 et un système d'imagerie thermospatiale (82) utilisable pour fournir ladite série de représentations thermospatiales à ladite unité d'entrée.
3. Appareil (60) ou système (80) selon la revendication 1, dans lequel ledit appareil (60) comprend en outre un estimateur de dimension, conçu pour estimer la dimension de ladite région interne thermiquement distinctive (54), sur la base dudit historique thermique transitoire.
4. Appareil (60) ou système (80) selon la revendication 1, dans lequel ladite plateforme de calcul (61) est conçue pour comparer ledit historique thermique transitoire à un historique thermique transitoire de référence, de manière à déterminer la probabilité de ladite présence de ladite région thermiquement distinctive (54).
5. Appareil (60) ou système (80) selon la revendication 1 ou 2, dans lequel on impose un changement de température ambiante à la surface de ladite partie du corps entre au moins deux représentations thermospatiales successives de ladite série.
6. Appareil (60) ou système (80) selon la revendication 1 ou 2, dans lequel on estime ledit emplacement de ladite région interne thermiquement distinctive (54) en déterminant la quantité de changement de température pour chaque point d'une pluralité de points sur une surface de ladite partie du corps.
7. Appareil (60) ou système (80) selon la revendication 6, dans lequel on estime ledit emplacement de ladite région interne thermiquement distinctive (54) en déterminant la vitesse de changement de température dudit point.
8. Appareil (60) ou système (80) selon la revendication 7, dans lequel on estime ledit emplacement de ladite région interne thermiquement distinctive (54) en comparant la vitesse de changement de température d'un premier point de ladite pluralité de points à la vitesse de changement de température d'un autre point de ladite pluralité de points.
9. Appareil (60) ou système (80) selon la revendication 6, dans lequel on estime ledit emplacement de ladite région interne thermiquement distinctive (54) en déterminant le début d'un état thermique stable dudit point.
10. Appareil (60) ou système (80) selon la revendication 6, dans lequel on estime ledit emplacement de ladite

région interne thermiquement distinctive (54) en déterminant le début d'un changement de température dudit point.

11. Appareil (60) ou système (80) selon la revendication 1, dans lequel on effectue l'extraction dudit historique thermique transitoire en choisissant un ensemble de points appartenant à une première représentation thermospatiale de ladite série, en utilisant ladite fonction de déformation pour déterminer un ensemble de points correspondants appartenant à une autre représentation thermospatiale de ladite série, et en déterminant une variation thermique individuelle de chaque point dudit ensemble.
12. Appareil (60) ou système (80) selon la revendication 1 ou 2, dans lequel ladite plateforme de calcul (61) est conçue pour estimer la conduction thermique caractéristique de ladite partie du corps sur la base de ladite série.
13. Appareil (60) ou système (80) selon l'une quelconque des revendications 1 à 12, dans lequel ladite partie du corps est un sein de femme.

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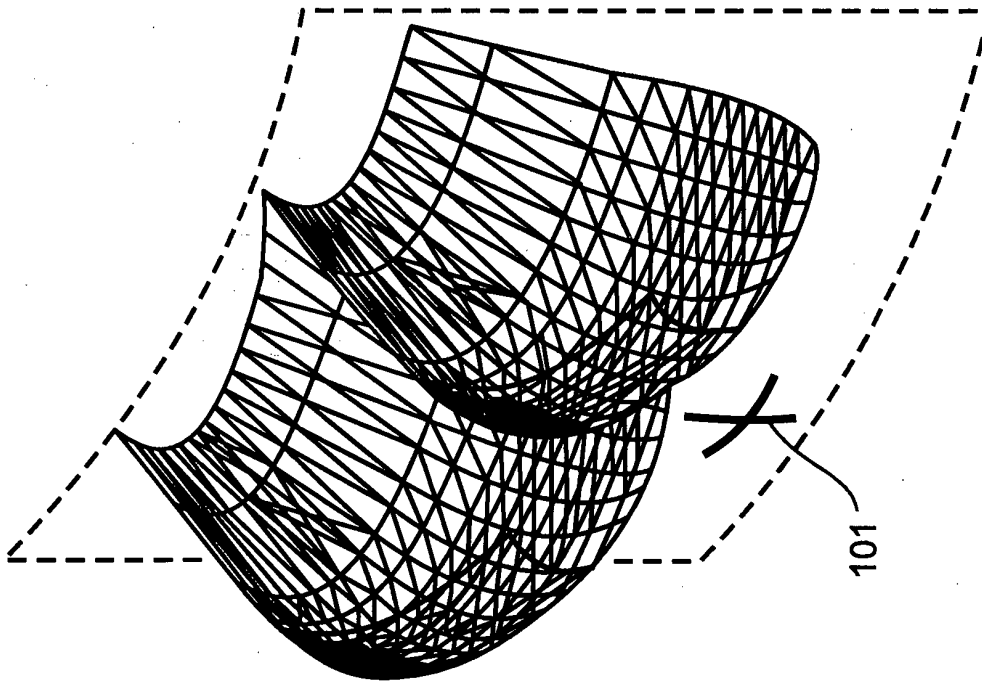


FIG. 1A

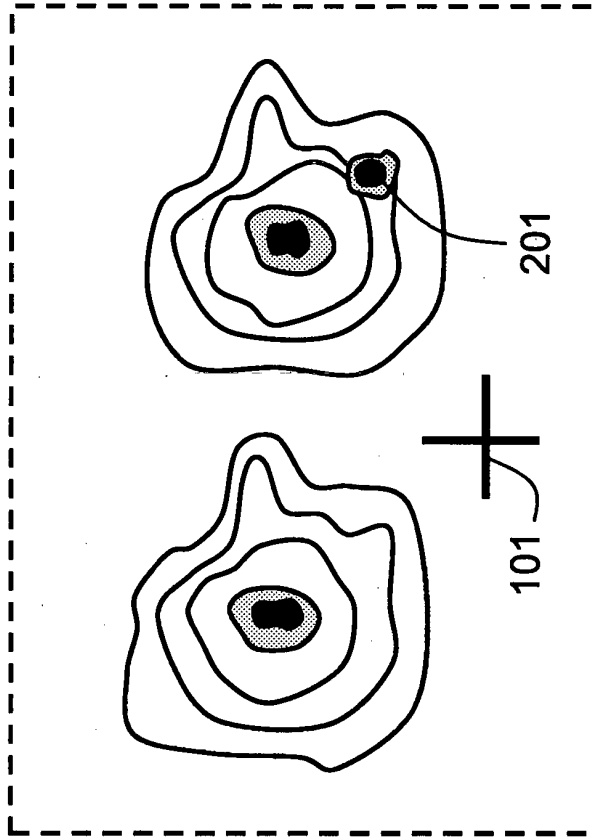


FIG. 1B

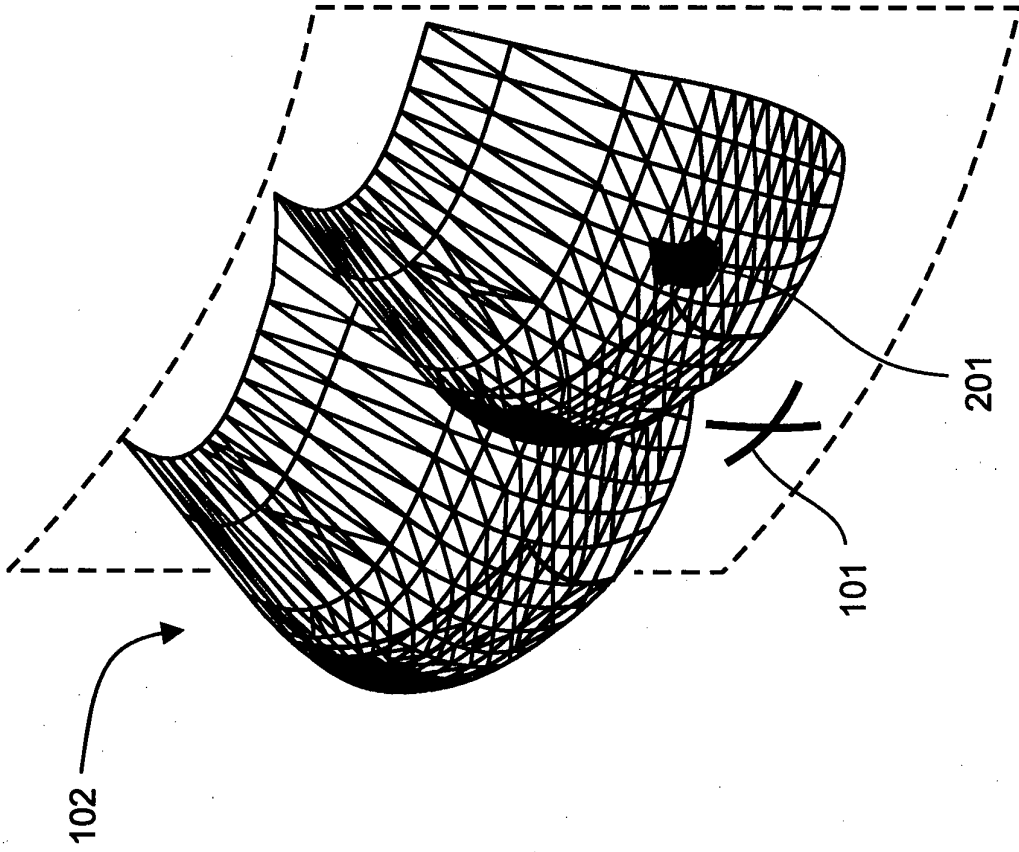


FIG. 1C

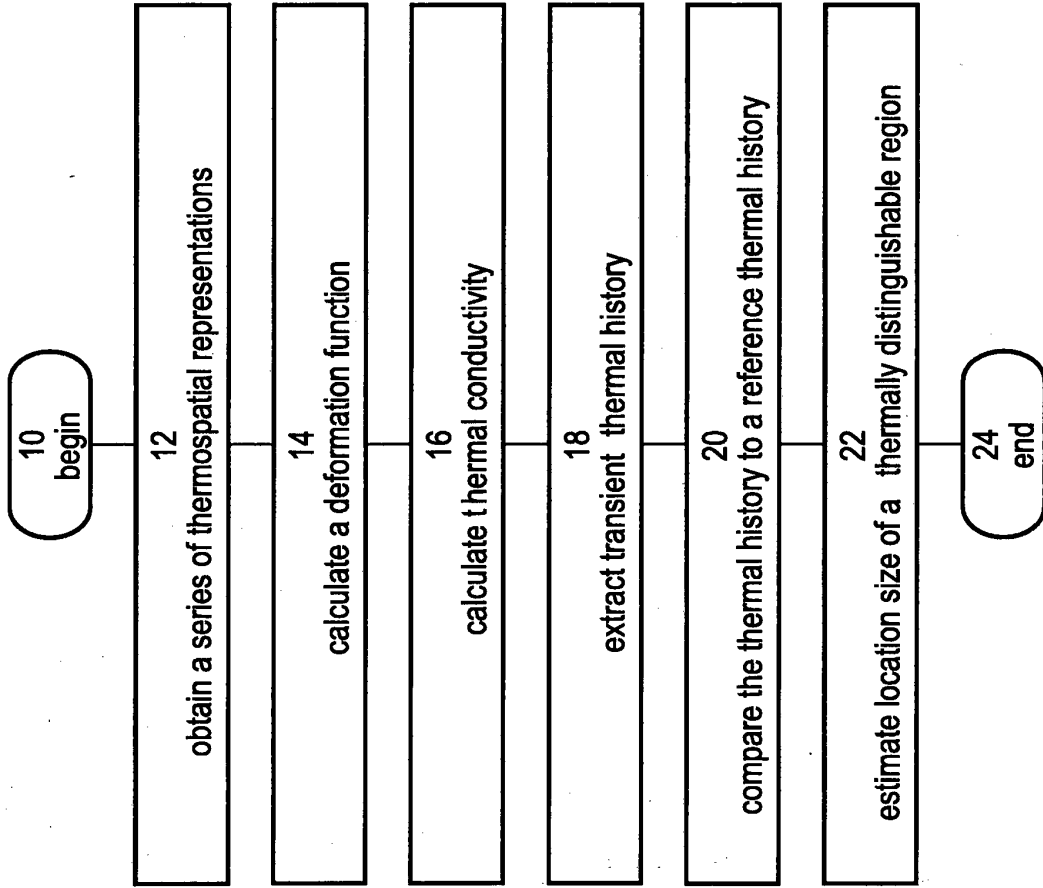


FIG. 2

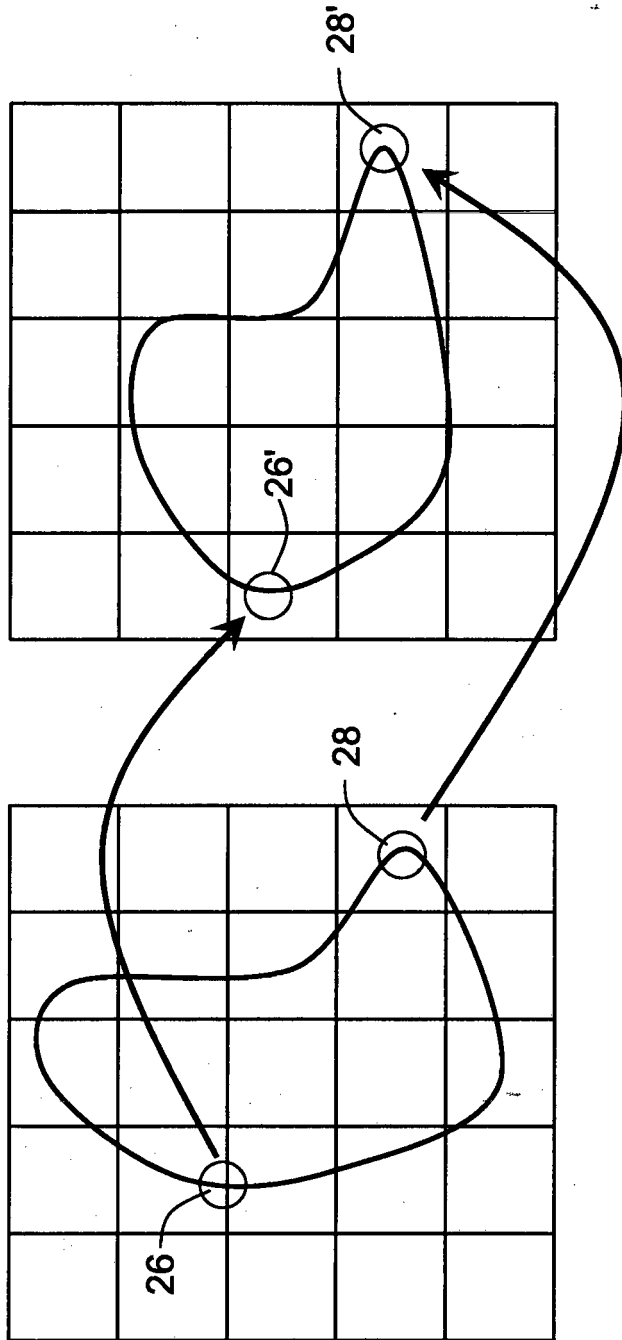


FIG. 3

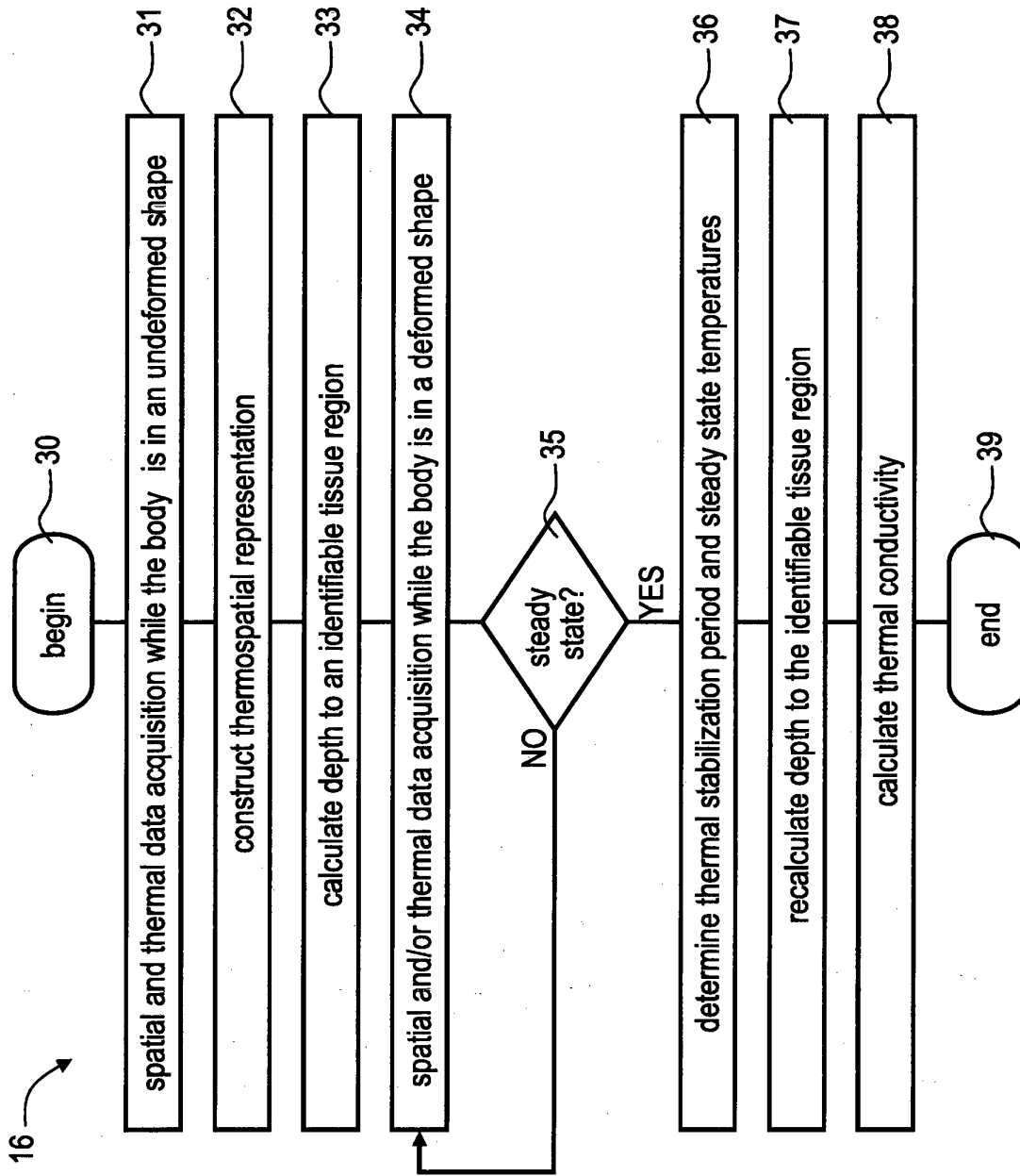


FIG. 4

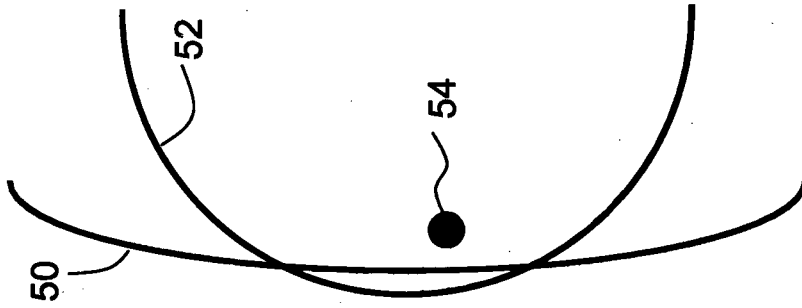


FIG. 5A

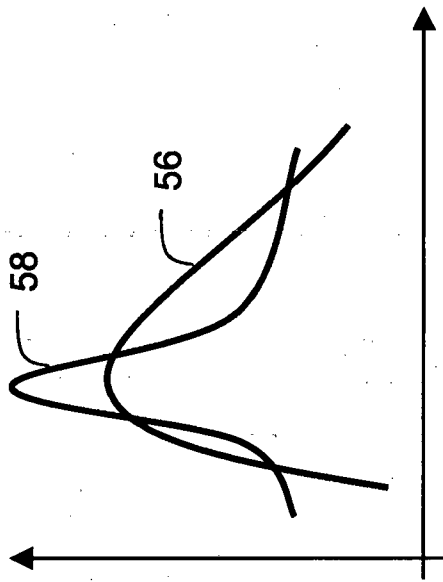


FIG. 5B

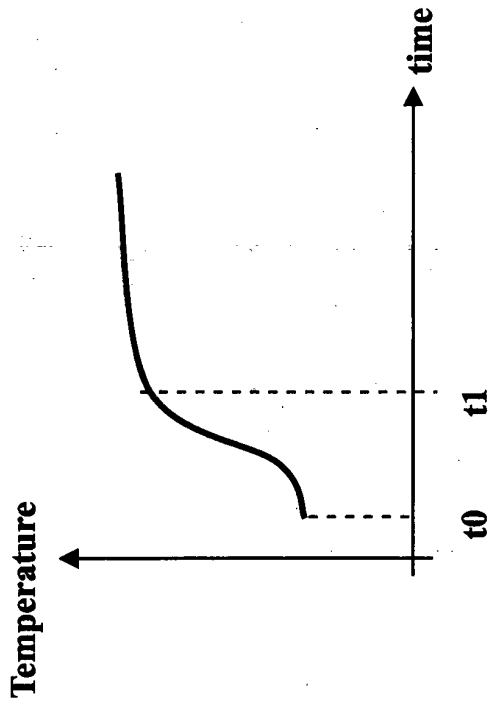


FIG. 6B

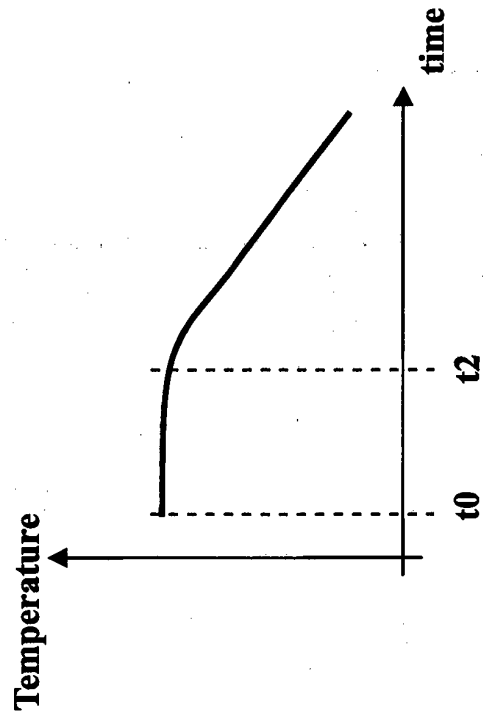


FIG. 6C

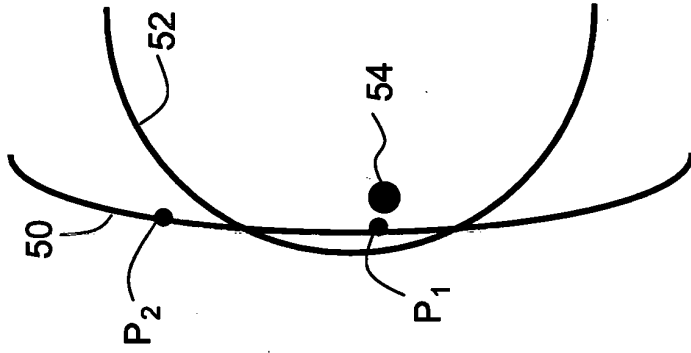


FIG. 6A

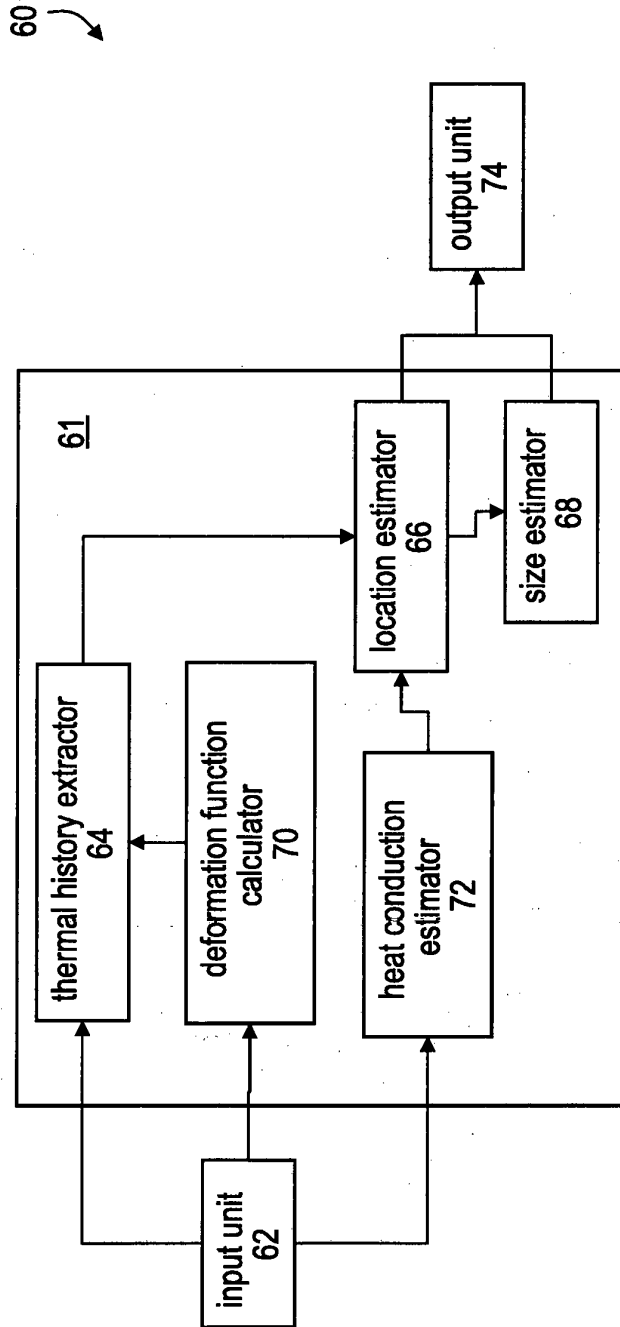


FIG. 7

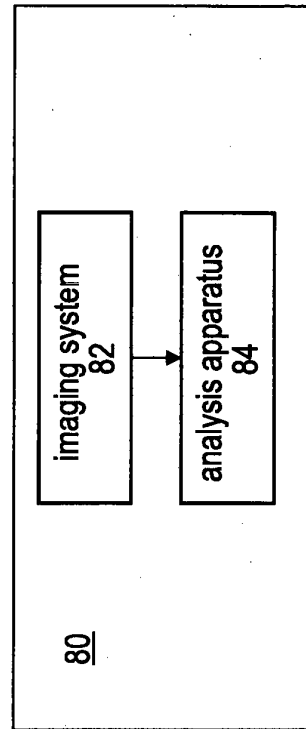
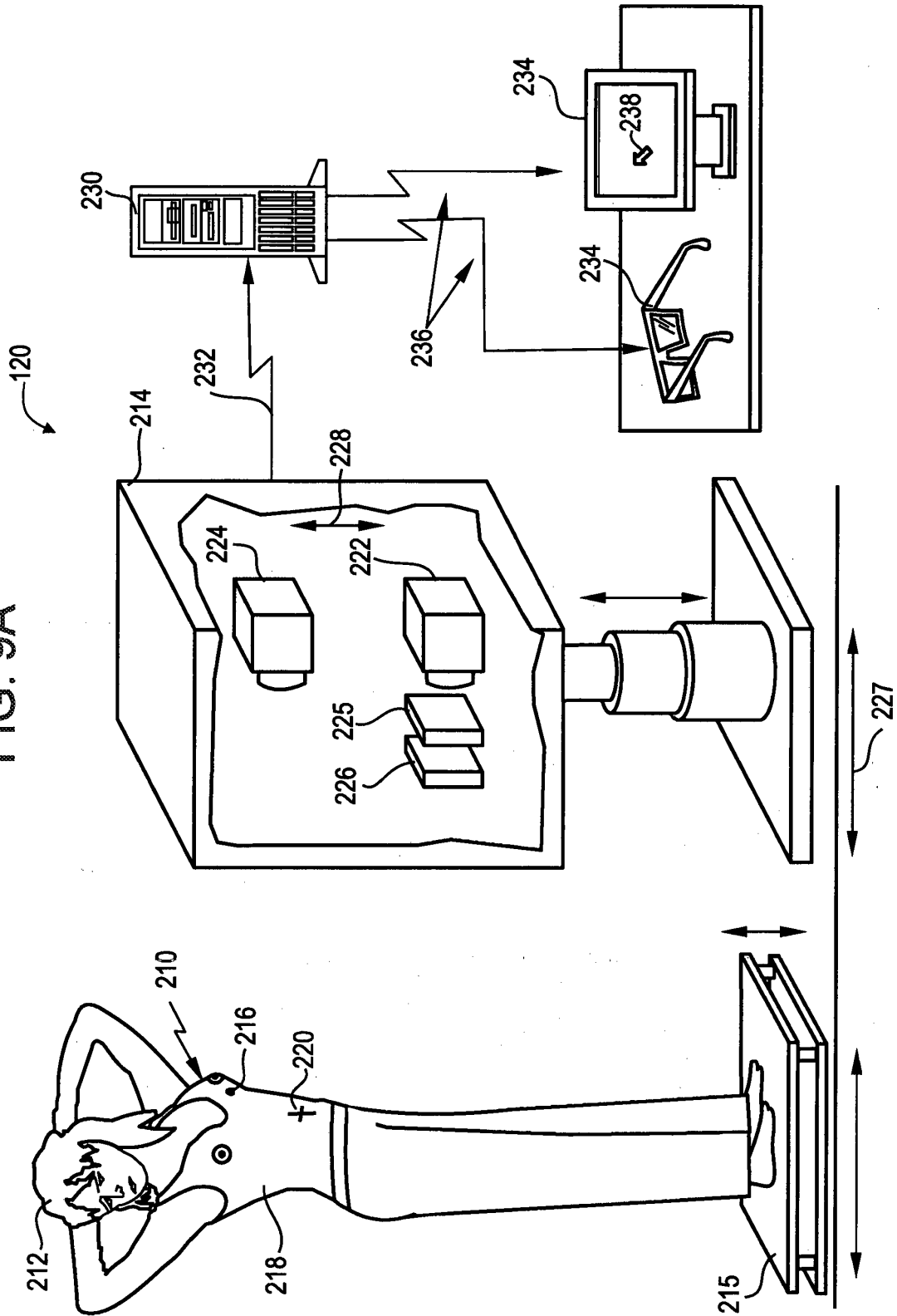


FIG. 8

FIG. 9A



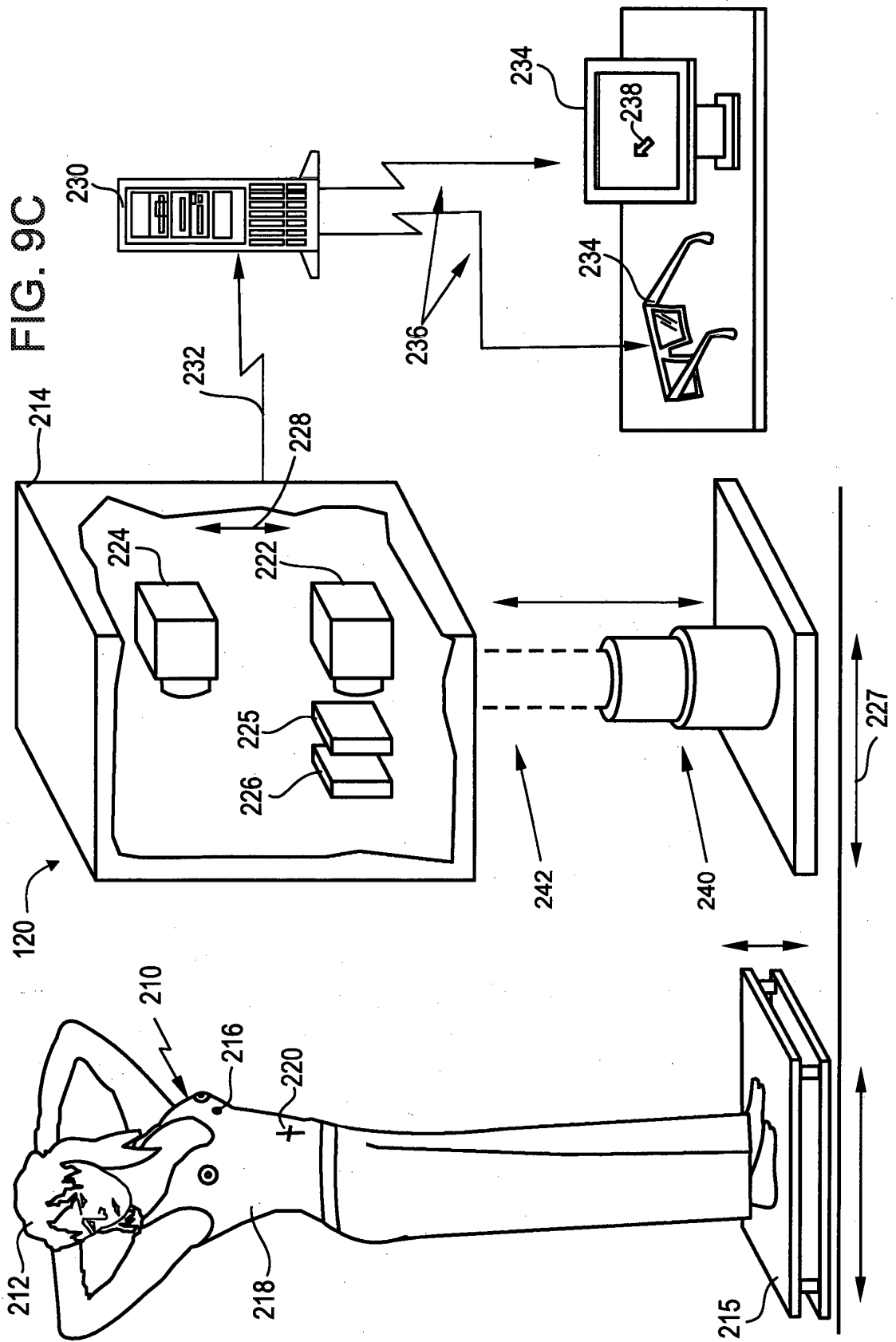


FIG. 9D

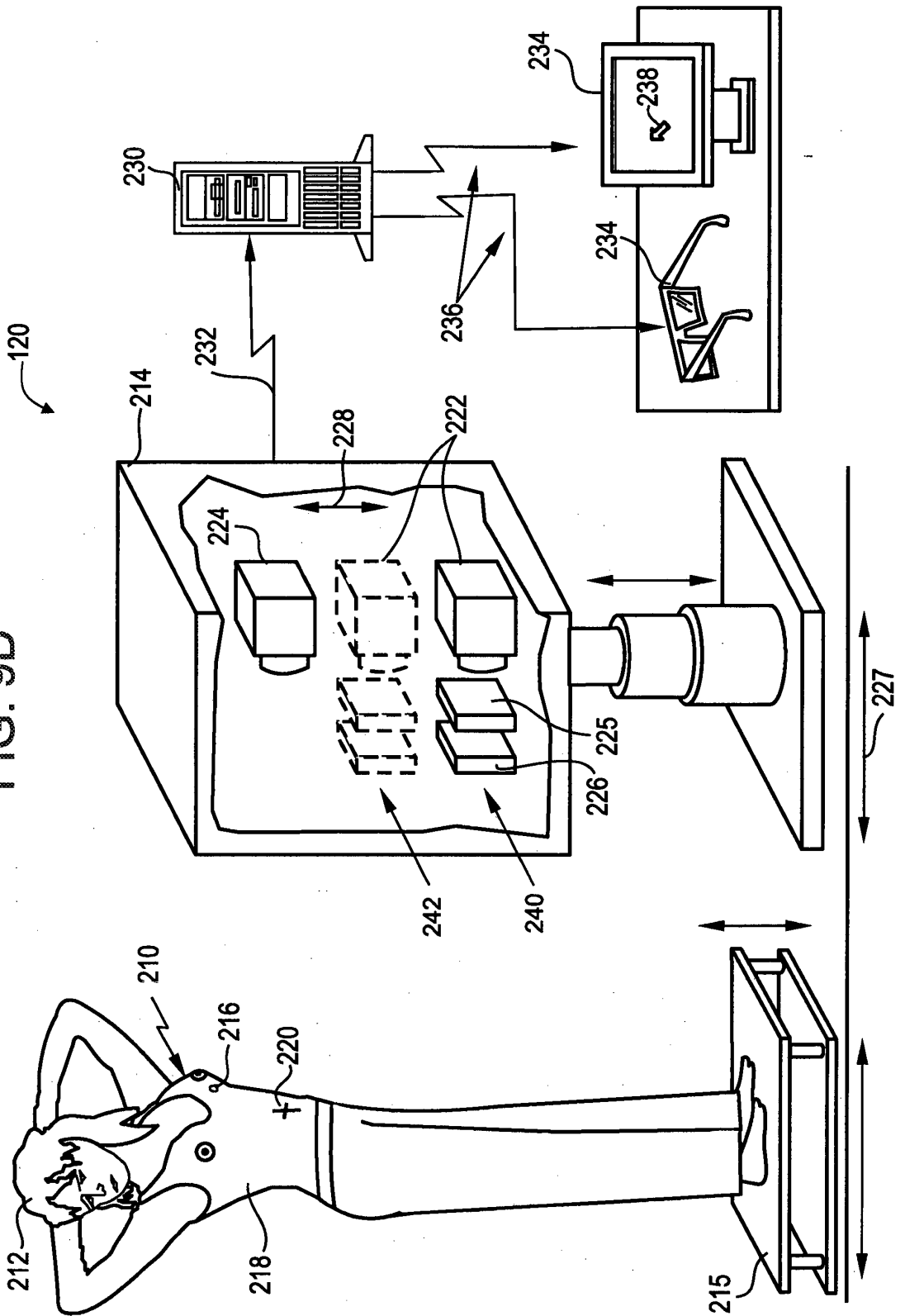


FIG. 9E

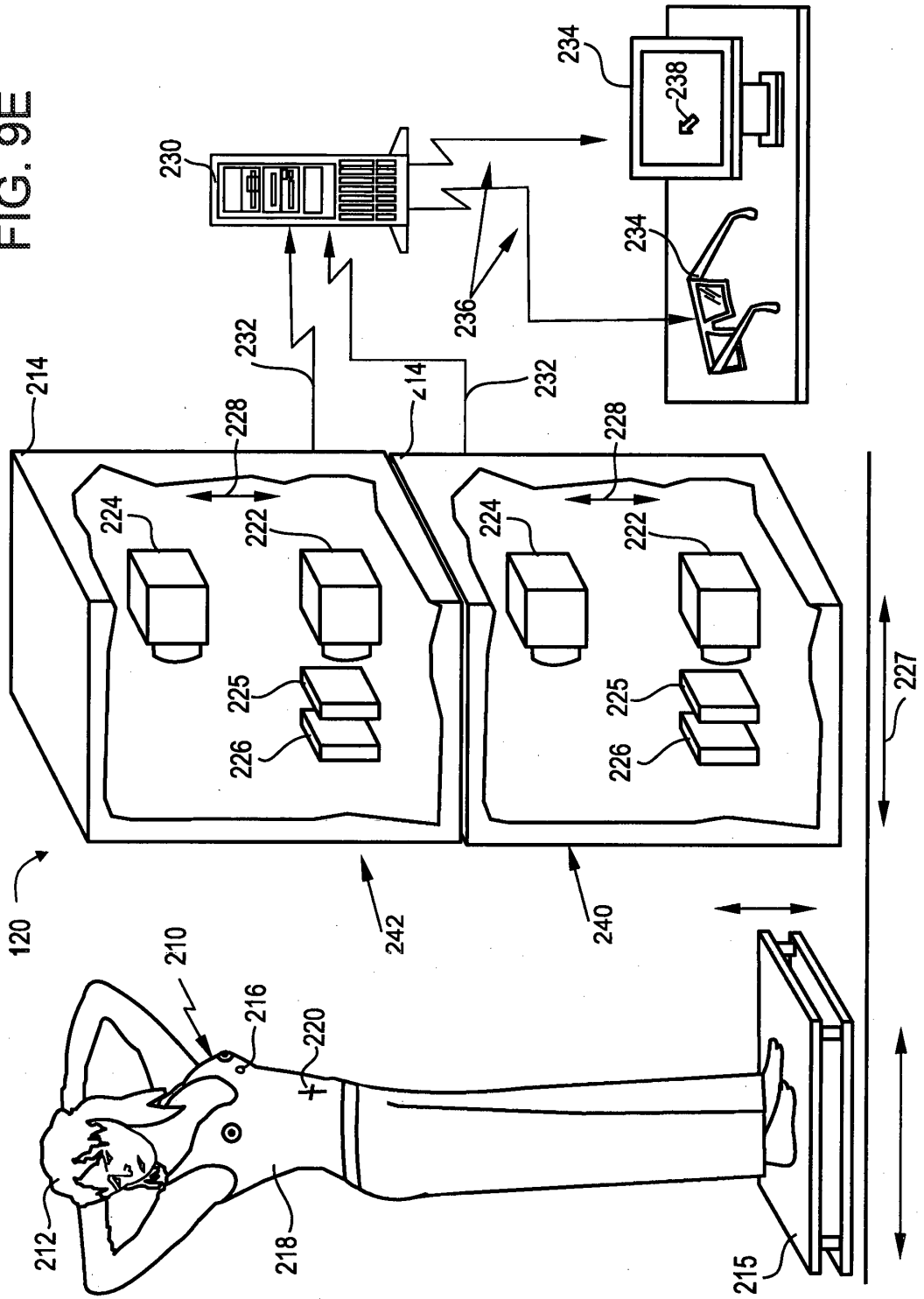


FIG. 9F

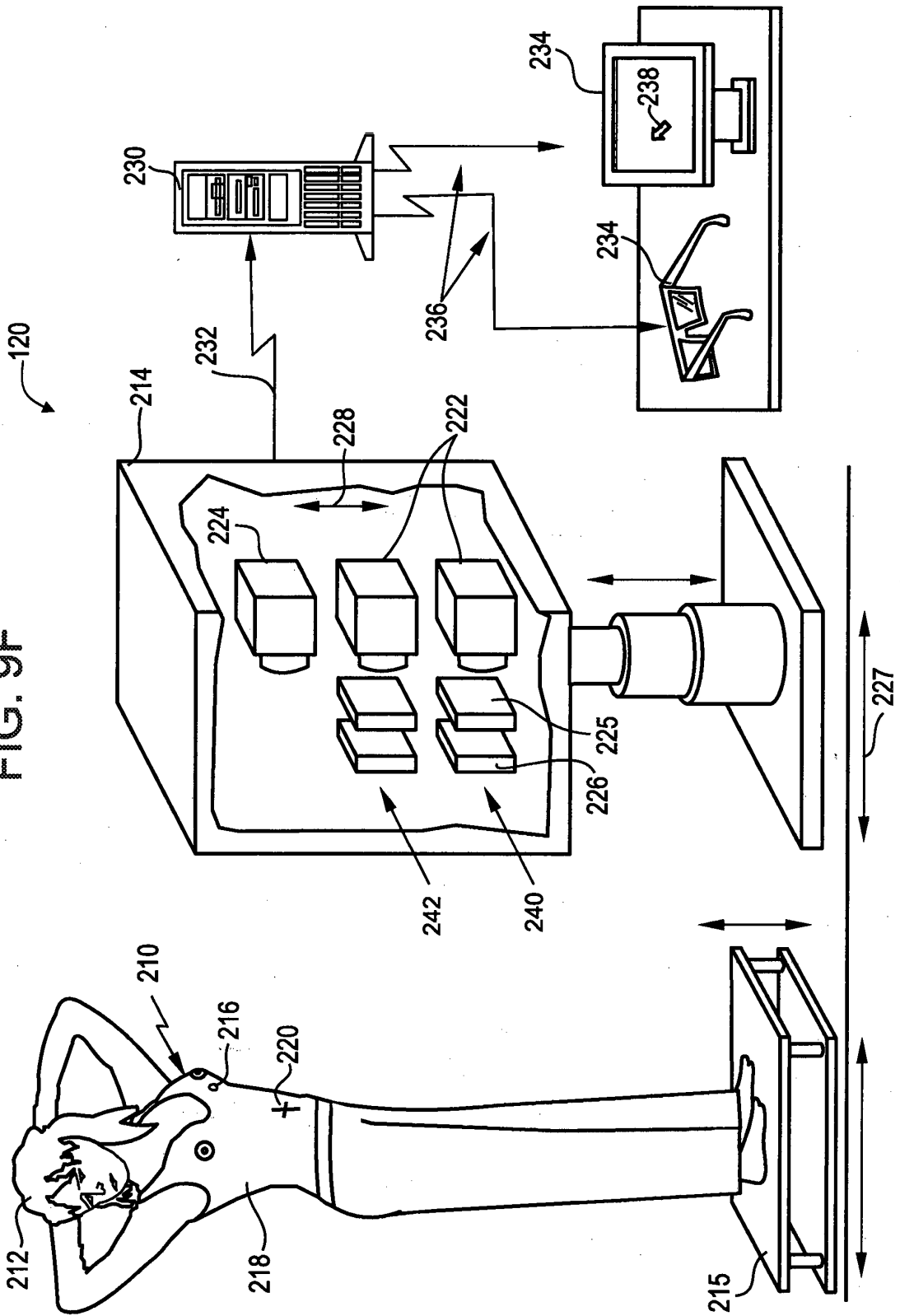
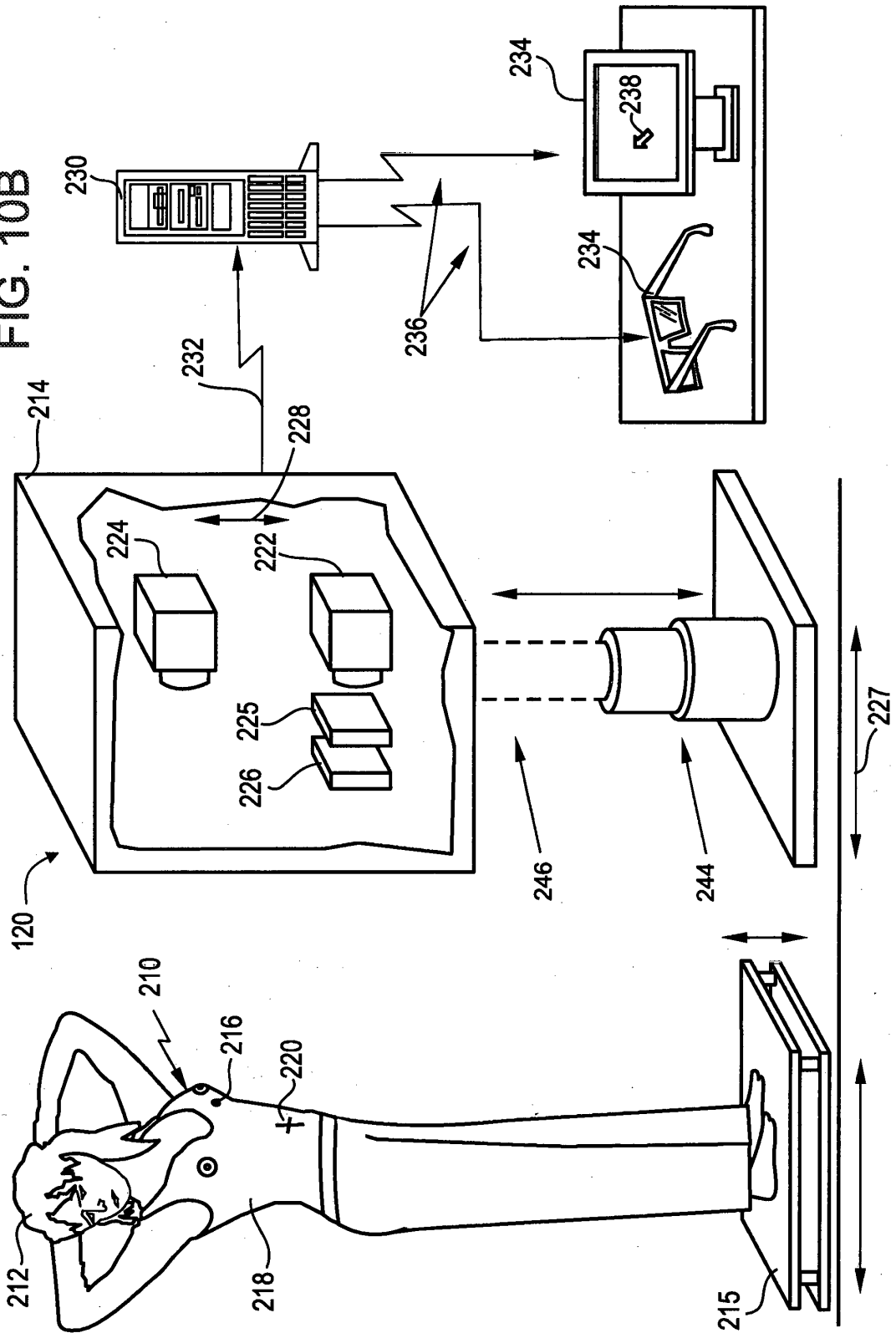


FIG. 10B



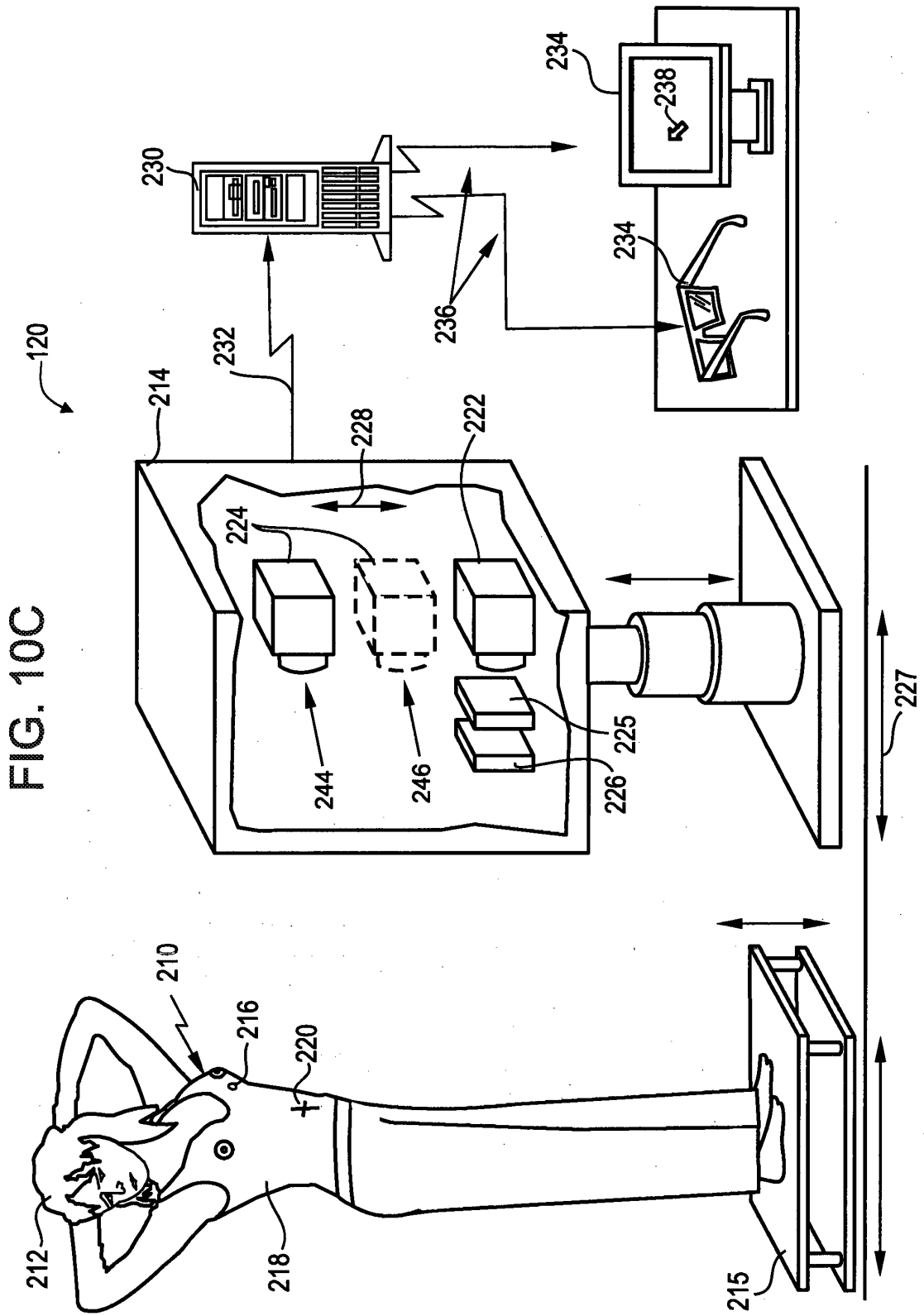


FIG. 10D

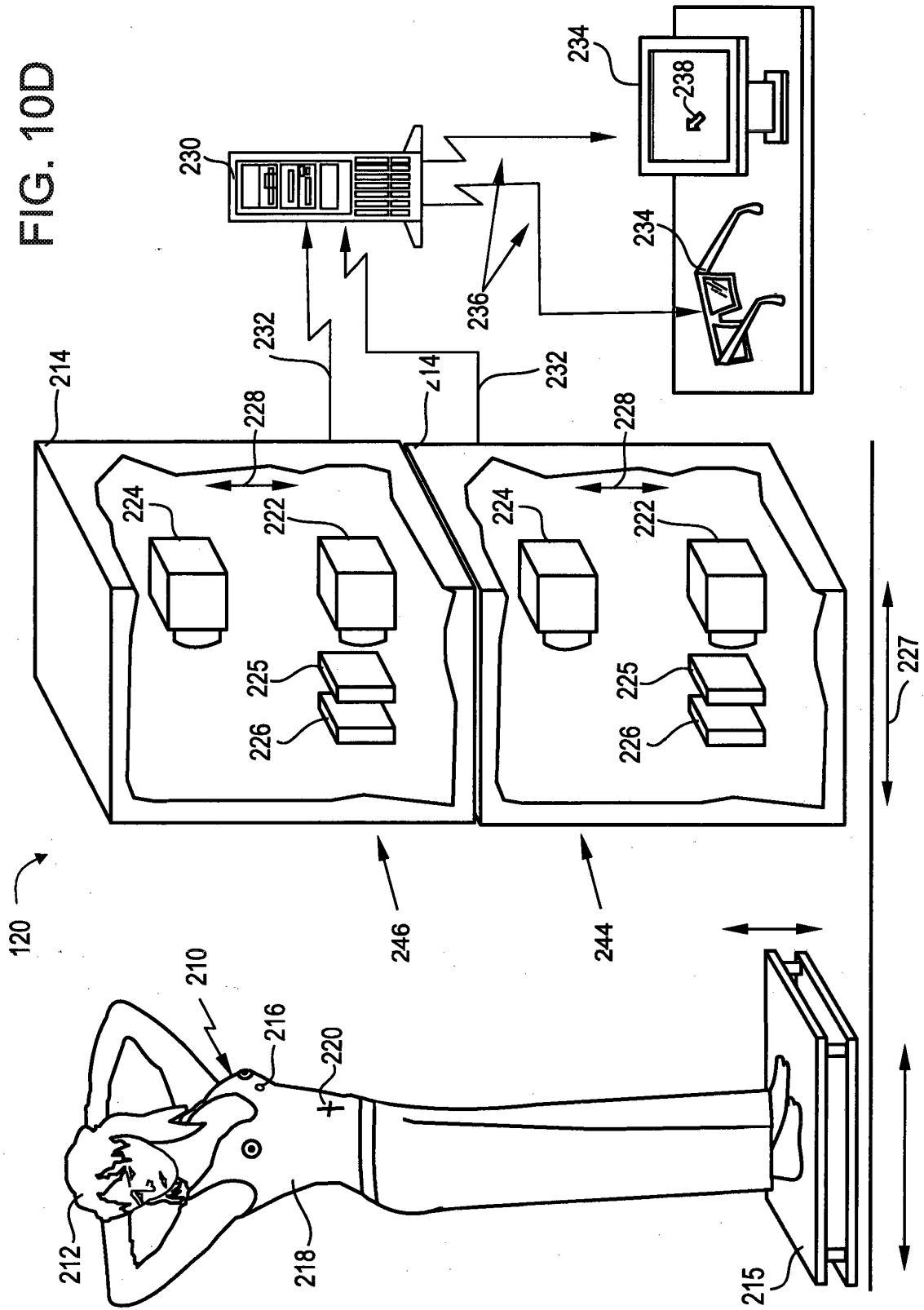


FIG. 10E

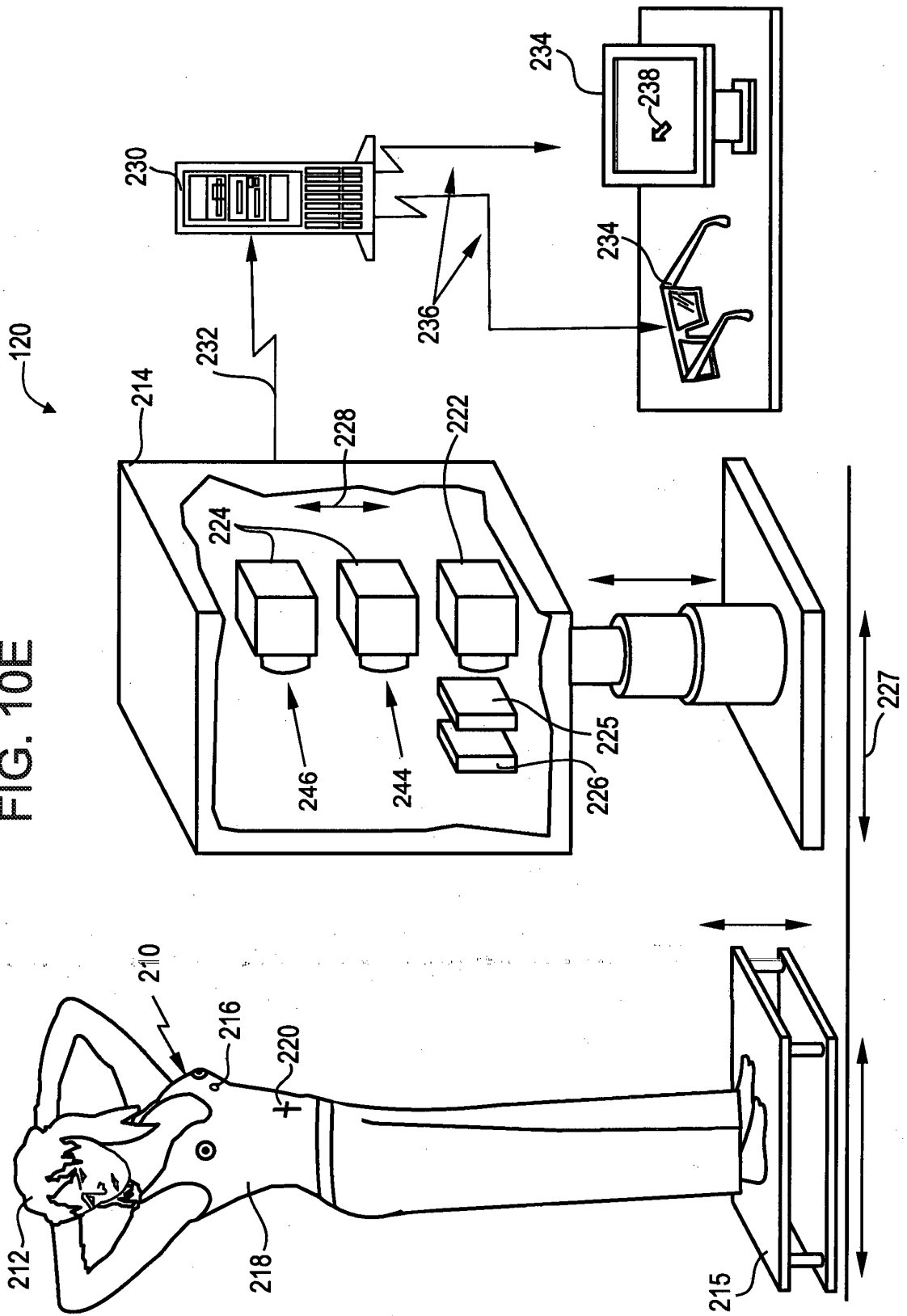


FIG. 11A



FIG. 11B



FIG. 11C

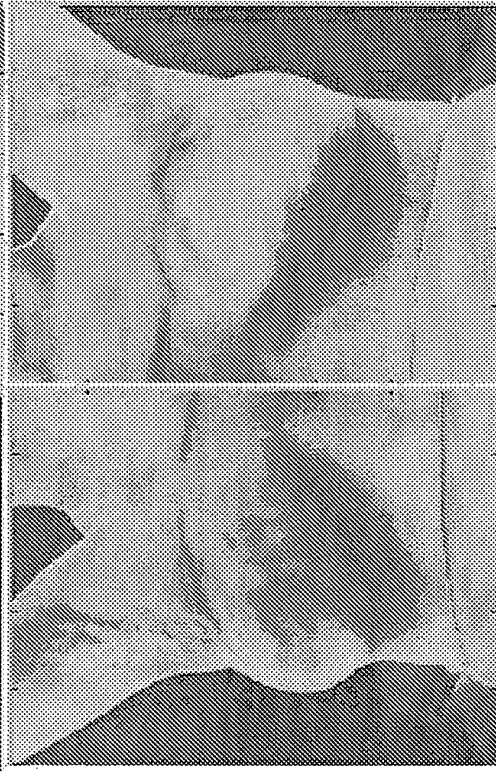
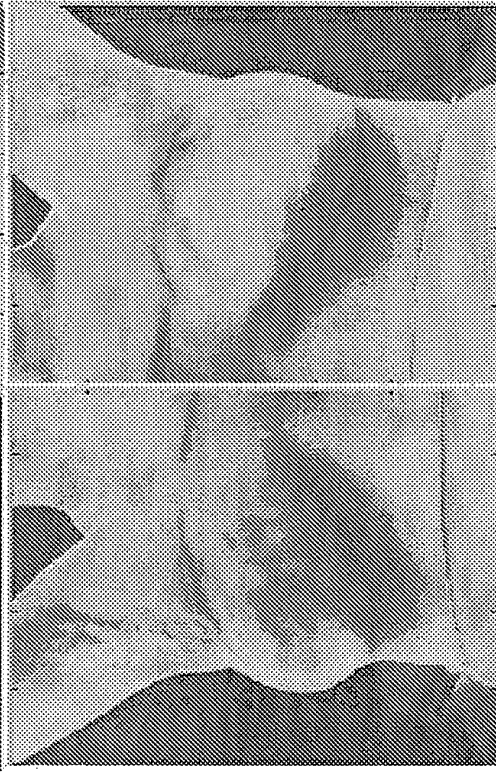


FIG. 11D



REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- US 7072504 B [0005]
- US 7292719 B [0007] [0049] [0055]
- US 6442419 B [0008] [0049] [0055] [0126]
- US 6850862 B [0009]
- US 5961466 A [0009]
- US 20070213617 A [0010]
- WO 2006003658 A [0049] [0055]
- US 20010046316 A [0049] [0055]
- US 6765607 B [0049] [0055]
- US 6965690 B [0049] [0055]
- US 6701081 B [0049] [0055]
- US 6801257 B [0049] [0055]
- US 6201541 B [0049] [0055]
- US 6167151 A [0049] [0055]
- US 6094198 A [0049] [0055]

专利名称(译)	用于分析图像的方法设备和系统		
公开(公告)号	EP2265163B1	公开(公告)日	2014-06-04
申请号	EP2008873559	申请日	2008-12-28
[标]申请(专利权)人(译)	真实成像有限公司		
申请(专利权)人(译)	真实影像有限公司.		
当前申请(专利权)人(译)	真实影像有限公司.		
[标]发明人	ARNON ISRAEL BOAZ ARIELI YOEL		
发明人	ARNON, ISRAEL, BOAZ ARIELI, YOEL		
IPC分类号	A61B5/00		
CPC分类号	A61B5/015		
代理机构(译)	丹麦美国律师协会		
优先权	61/064823 2008-03-28 US		
其他公开文献	EP2265163A1		
外部链接	Espacenet		

摘要(译)

公开了一种识别活体中的热可区分区域的方法。该方法包括确定活体表面的瞬态热历史，并基于瞬态热历史估计活体中的热可区分区域的位置或存在。

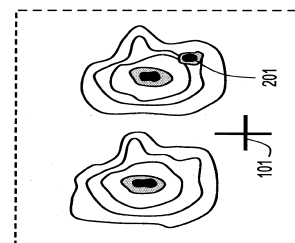


FIG. 1B

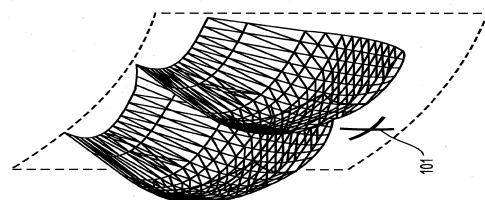


FIG. 1A