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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 7 : A61N 5/10	A1	(11) International Publication Number: WO 00/24467
		(43) International Publication Date: 4 May 2000 (04.05.00)

(21) International Application Number: PCT/US99/24947

(22) International Filing Date: 22 October 1999 (22.10.99)

(30) Priority Data:
09/178,384 23 October 1998 (23.10.98) US

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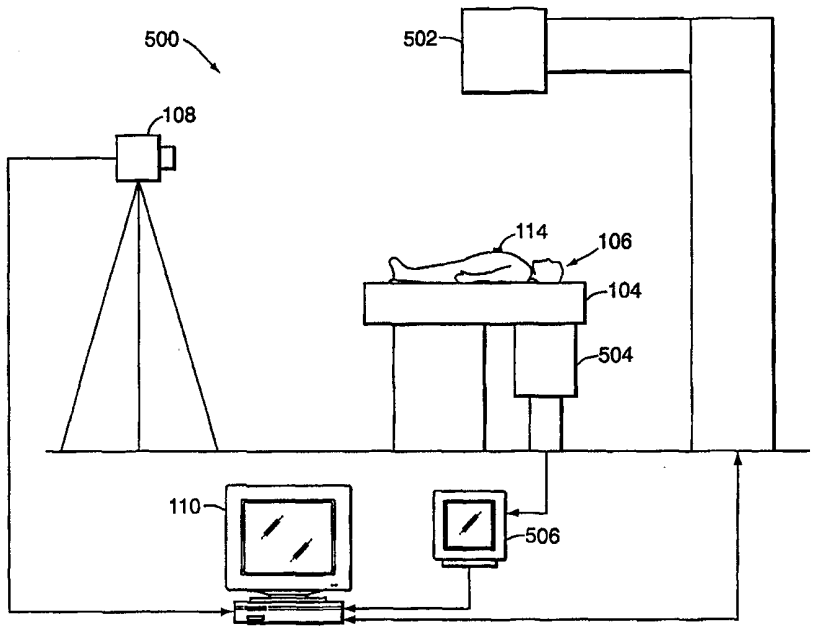
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(81) Designated States: AU, CA, IL, JP, KR, MX, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.

(54) Title: METHOD AND SYSTEM FOR PHYSIOLOGICAL GATING OF RADIATION THERAPY



(57) Abstract

A method and system for physiological gating for radiation therapy is disclosed. According to an aspect, the invention comprises the use of an optical or video image system to measure regular physiological movement of a patient's body. The image data can be used to quantify voluntary or involuntary motion of the patient that may affect the delivery of radiation to a target valve. A gating signal can be generated to suspend delivery of radiation upon certain threshold event detected in the motion cycle.

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METHOD AND SYSTEM FOR PHYSIOLOGICAL GATING OF RADIATION THERAPY

BACKGROUND OF THE INVENTION

Field Of The Invention

The present invention relates to medical methods and systems. More particularly, the invention relates to a method and system for physiological gating of radiation therapy.

Background

Radiation therapy involves medical procedures that selectively expose certain areas of a human body, such as cancerous tumors, to high doses of radiation. The intent of the radiation therapy is to irradiate the targeted biological tissue such that the harmful tissue is destroyed. In certain types of radiotherapy, the irradiation volume can be restricted to the size and shape of the tumor or targeted tissue region to avoid inflicting unnecessary radiation damage to healthy tissue. For example, conformal therapy is a radiotherapy technique that is often employed to optimize dose distribution by conforming the treatment volume more closely to the targeted tumor.

Normal physiological movement represents a limitation in the clinical planning and delivery of conventional radiotherapy and conformal therapy. Normal physiological movement, such as respiration or heart movement, can cause a positional movement of the tumor or tissue region undergoing irradiation. If the radiation beam has been shaped to conform the treatment volume to the exact dimensions of a tumor, then movement of that tumor during treatment could result in the radiation beam not being sufficiently sized or shaped to fully cover the targeted tumoral tissue.

To address this problem, the size and/or shape of the radiation beam can be expanded by a "movement margin" (i.e., the predicted movement distance in any direction of the targeted tumor) to maintain full irradiation of the targeted tissue. The drawback to this approach is that this increased irradiation volume results in radiation being applied to otherwise healthy tissue that is located within the area of the expanded volume. In other words, motion during treatment necessitates the application of a radiation field of an expanded size that could negatively affect an unacceptably large volume of normal tissue surrounding the targeted treatment volume.

Another approach to this problem involves physiological gating of the radiation beam during treatment, with the gating signal synchronized to the movement of the patient's body. In this approach, instruments are utilized to measure the physiological state of the patient with

reference to the particular physiological movement being examined. For example, respiration has been shown to cause movements in the position of a lung tumor in a patient's body. If radiotherapy is being applied to the lung tumor, then a temperature sensor, strain gauge or preumotactrograph can be attached to the patient to measure the patient's respiration cycle. The radiation beam can be gated based upon certain threshold points within the measured respiratory cycle, such that the radiation beam is disengaged during periods in the respiration cycle that correspond to excessive movement of the lung tumor.

Known methods for performing physiological gating typically require specialized instruments to be placed in contact with or invasively mounted on the patient. For instance, the known approaches to physiological gating synchronized with the respiratory cycle require a patient-contact instrument such as a strain gauge or spirometer to be attached to the patient's body. A known approach to gating synchronized to the cardiac cycle requires an electrocardiograph to be connected to the patient's body. Requiring an instrument to be placed in contact with, or invasively mounted in, the patient's body could cause problems under certain circumstances. For example, a spirometer is a pneumotachograph device that is mounted on a patient to measure the volume of air passing through the patient's airway during respiration. The discomfort associated with using a spirometer can limit the usefulness of that instrument in measuring a patient's respiration cycle, particularly if the gating procedure requires use of that instrument for an extended period of time. Moreover, many of these instruments have cumbersome wires or connections that limit the usability of these instruments within certain confined areas or with certain patient body configurations. Another drawback is that a specialized instrument is required for each body part that is being measured for movement. Not only does this require the use of a plurality of instruments for the multiplicity of body parts that may have to be measured for movement, but in some cases, the particular body part undergoing examination may not have an associated specialized instrument to detect its movement.

Therefore, there is a need for a system and method to address these and other problems of the related art. There is a need for a method and system of physiological gating which does not require instruments or probes to be mounted, either externally or invasively, on or in the patient's body. Moreover, there is a need for a method and system that can accurately and consistently allow planning for physiological gating of radiation treatments.

SUMMARY OF THE INVENTION

The present invention provides an improved method and system for physiological gating for radiation therapy. According to an aspect, the invention comprises the use of an optical or video imaging system to generate image data to measure regular physiological movement of a patient's body. An optical or video imaging system provides a non-invasive method for measuring motion on a patient's body. The image data can be used to quantify voluntary or involuntary motion of the patient that may affect the delivery of radiation to a target valve. A gating signal can be generated to suspend delivery of radiation upon certain threshold event detected in the motion cycle.

These and other aspects, objects, and advantages of the invention are described below in the detailed description, drawings, and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings are included to provide a further understanding of the invention and, together with the Detailed Description, serve to explain the principles of the invention.

Fig. 1 depicts the components of a system for physiological gating according to an embodiment of the invention.

Fig. 2 depicts an example of a respiratory motion signal chart.

Fig. 3 depicts a motion signal chart and a gating signal chart.

Fig. 4 is a flowchart showing process actions performed in an embodiment of the invention.

Fig. 5a depicts the components of a system for performing gating simulations according to an embodiment of the invention.

Fig. 5b depicts an embodiment of an user interface for gating simulation.

Fig. 6a depicts a side view an embodiment of a camera that can be utilized in the invention.

Fig. 6b depicts a front view of the camera of Fig. 6a.

Fig. 7a depicts a retro-reflective marker according to an embodiment of the invention.

Fig. 7b depicts a cross-sectional view of the retro-reflective marker of Fig. 7a.

Fig 8 depicts an apparatus for making a retro-reflective marker.

Fig. 9 depicts an embodiment of a marker block.

Fig. 10 depicts an alternate marker block.

DETAILED DESCRIPTION

Fig. 1 depicts the components of a system 100 for physiological gating of radiation therapy according to an embodiment of the invention. System 100 comprises a radiation beam source 102 (such as a conventional linear accelerator) which is positionally configured to direct a radiation beam at a patient 106 located on treatment table 104. A switch 116 is operatively coupled to the radiation beam source 102. Switch 116 can be operated to suspend the application of the radiation beam at patient 106. In an embodiment, switch 116 is part of the mechanical and electrical structure of radiation beam source 102. Alternatively, switch 116 comprises an external apparatus that is connected to the control electronics of radiation beam source 102.

An optical or video image apparatus, such as video camera 108, is aimed such that at least part of the patient 106 is within the camera's field of view. Camera 108 monitors patient

106 for motion relating to the particular physiological activity being measured. For example, if respiration movements of the patient is being monitored, then camera 108 can be configured to monitor the motion of the patient's chest. According to an embodiment, camera 108 is placed with its axis at approximately 45 degrees to the longitudinal axis of the patient 106. For measurement of respiration activity that could result in about 3-5 mm of chest motion, the video image field of view is preferably set to view an approximately 20 cm by 20 cm area of the patient's chest. For purposes of illustration only, a single camera 108 is shown in Fig. 1. However, the number of cameras 108 employed in the present invention can exceed that number, and the exact number to be used in the invention depends upon the particular application to which it is directed.

In an embodiment, one or more illumination sources (which are infrared sources in the preferred embodiment) project light at the patient 106 on treatment table 104. The generated light is reflected from one or more landmarks on the patient's body. The camera 108, which is directed at patient 106, captures and detects the reflected light from the one or more landmarks. The landmarks are selected based upon the physiological activity being studied. For example, for respiration measurements, landmarks are selected from one or more locations on the patient's chest.

The output signals of camera 108 are sent to a computer 110 or other type of processing unit having the capability to receive video images. According to a particular embodiment, computer 110 comprises an Intel Pentium-based processor running Microsoft Windows NT and includes a video frame grabber card having a separate channel for each video source utilized in the system. The images recorded by camera 108 are sent to computer 110 for processing. If camera 108 produces an analog output, the frame grabber converts the camera signals to a digital signal prior to processing by computer 110. Based upon the video signals received by computer 110, control signals can be sent from computer 110 to operate switch 116.

According to one embodiment, one or more passive markers 114 are located on the patient in the area to be detected for movement. Each marker 114 preferably comprises a reflective or retro-reflective material that can reflect light, whether in the visible or invisible wavelengths. If the illumination source is co-located with camera 108, then marker 114 preferably comprises a retro-reflective material that reflects light mostly in the direction of the illumination source. Alternatively, each marker 114 comprises its own light source. The marker 114 is used in place of or in conjunction with physical landmarks on the patient's body that is imaged by the camera 108 to detect patient movement. Markers 114 are preferably used instead of body landmarks because such markers 114 are easier to detect and track via the video image

generated by camera 108. Because of the reflective or retro-reflective qualities of the preferred markers 114, the markers 114 inherently provide greater contrast in a video image to a light detecting apparatus such as camera 108, particularly when the camera 108 and illumination source are co-located.

Utilizing a video or optical based system to track patient movement provides several advantages. First, a video or optical based system provides a reliable mechanism for repeating measurement results between uses on a given patient. Second, the method of the invention is noninvasive, and even if markers are used, no cables or connections must be made to the patient. Moreover, if the use of markers is impractical, the system can still be utilized without markers by performing measurements of physiological activity keyed to selected body landmarks. Finally, the method of the invention is more accurate because it is based upon absolute measurement of external anatomical physical movement.

A possible inefficiency in tracking the markers 114 is that the marker may appear anywhere on the video frame, and all of the image elements of the video frame may have to be examined to determine the location of the marker 114. Thus, in an embodiment, the initial determination of locations for the marker 114 involves an examination of all of the image elements in the video frame. If the video frame comprise 640 by 480 image elements, then all 307200 (640*480) image elements are initially examined to find the location of the markers 114.

For real-time tracking of the marker 114, examining every image element for every video frame to determine the location of the marker 114 in real-time could consume a significant amount of system resources. Thus, in an embodiment, the real-time tracking of marker 114 can be facilitated by processing a small region of the video frame, referred to herein as a "tracking gate", that is placed based on estimation of the location of the already-identified marker 114 in the video frame. The previously determined location of a marker 114 defined in the previous video frame is used to define an initial search range (i.e., the tracking gate) for that same marker in real-time. The tracking gate is a relatively small portion of the video frame that is centered at the previous location of the marker 114. The tracking gate is expanded only if it does not contain the new location of the marker 114. As an example, consider the situation when the previously determined location of a particular marker is image element (50,50) in a video frame. If the tracking gate is limited to a 50 by 50 area of the video frame, then the tracking gate for this example would comprise the image elements bound within the area defined by the coordinates (25,50), (75,50), (50,25), and (50,75). The other portions of the video frame are searched only if the marker 106 is not found within this tracking gate.

The video image signals sent from camera 108 to computer 110 are used to generate and track motion signals representative of the movement of marker 114 and/or landmark structures on the patient's body. Fig. 2 depicts an example of a motion signal chart 200 for respiratory movement that contains information regarding the movement of marker 114 during a given measurement period. The horizontal axis represents points in time and the vertical axis represents the relative location or movement of the marker 114.

An important aspect of physiological gating of radiotherapy is the determination of the boundaries of the "treatment intervals" for applying radiation. For gating purposes, threshold points can be defined over the amplitude range of the motion signal to determine the boundaries of the treatment intervals. Motion of the patient that fall outside the boundaries of the treatment intervals correspond to movement that is predicted to cause unacceptable levels of movement to the tumor or tissue targeted for irradiation. According to an embodiment, the treatment intervals correspond to the portion of the physiological cycle in which motion of the clinical target volume is minimized. Other factors for determining the boundaries of the treatment intervals include identifying the portion of the motion signals involving the least movement of the target volume or the portion of the motion signal involving the largest separation of the target volume from organs at risk. Thus, the radiation beam pattern can be shaped with the minimum possible margin to account for patient movement.

Radiation is applied to the patient only when the motion signal is within the designated treatment intervals. Referring to Fig. 3, depicted are examples of treatment intervals, indicated by signal range 302, that has been defined over the motion data shown in motion signal chart 200. In the example of Fig. 3, any movement of the measured body location that exceeds the value of 0.8 (shown by upper boundary line 304) or which moves below the value of 0.0 (shown by lower boundary line 306) falls outside the boundaries of the treatment intervals.

Shown in Fig. 3 is an example of a gating signal chart 300 that is aligned with motion signal chart 200. Any motion signal that falls outside the treatment interval signal range 302 results in a "beam hold" gating signal threshold 310 that stops the application of radiation to the patient. Any motion signal that is within the treatment interval signal range 302 results in a "beam on" gating signal threshold 312 that allows radiation to be applied to the patient. In an embodiment, digital signals that represent the information shown in motion signal chart 200 are processed by computer 110 and compared to the threshold levels of the treatment interval signal range 302 to generate gating signal thresholds 310 and 312. Alternatively, gating signal thresholds 310 and 312 can be obtained by feeding analog motion signals to a comparator to be compared with analog threshold signals that correspond to treatment interval signal range 302.

In any case, gating signal thresholds 310 and 312 are generated by computer 110 and are applied to the switch 116 that controls the operation of radiation beam source 102 (Fig. 1) to stop or start the application of a radiation beam at patient 106.

Fig. 4 is a flowchart of the process actions performed in an embodiment of the invention. The first process action is to define boundaries for the treatment intervals over the range of motion signals to be detected by a camera (402). As indicated above, any motion that fall outside the boundaries of the treatment intervals correspond to motion that is predicted to result in unacceptable levels of movement of the tumor or tissue targeted for irradiation. An optical or video imaging system, such as a video camera, is used to measure the physiological motion of the patient (404), and the output signals of the optical or video imaging system are processed to compare the measured motion signals with the threshold boundaries of the treatment intervals (406).

If the motion signal is outside the boundaries of the treatment intervals, then a "beam off" gating signal threshold is applied to a switch that is operatively coupled to the radiation beam source (408). If the radiation beam source is presently irradiating the patient (410), then the switch setting is operated to hold or stop the radiation beam (411). The process then returns back to process action 406.

If the motion signal is within the boundaries of the treatment intervals, then a "beam on" gating signal threshold is produced (412) and is applied to a switch that is operatively coupled to the radiation beam source. If the radiation beam source is presently not being applied to the patient (413), then the switch setting is operated to turn on or apply the radiation beam source to irradiate the patient (414). The process then returns back to process action 406.

According to one embodiment, the radiation beam source can be disengaged if a significant deviation is detected in the regular physiological movements of the patient. Such deviations can result from sudden movement or coughing by the patient. The position and/or orientation of the targeted tissue may unacceptably shift as a result of this deviation, even though the amplitude range of the motion signal still falls within the boundaries of the treatment intervals during this deviation. Thus, detection of such deviations helps define the appropriate time periods to gate the radiation treatment. A process for detecting deviations from regular physiological movements of a patient is disclosed in copending U.S. Patent Application Ser. No. [Not Yet Assigned] (Varian Docket No. 98-34, Attorney Docket No. 236/222), filed concurrently herewith, which is hereby incorporated by reference in its entirety.

During the planning phase of the radiation treatment, gating simulations can be performed to determine the optimum boundaries of the treatment intervals. Fig. 5a depicts a

system 500 that can be employed to perform gating simulation. As with the system 100 shown in Fig. 1, system 500 comprises a camera 108 that is directed at a patient on a treatment table 104. The output signals of camera 108 are sent to a computer 110 for processing. System 500 additionally includes an imaging system capable of generating images of internal structures within the patient's body. In an embodiment, system 500 comprises a digital fluoroscopic imaging system having an x-ray source 502 and fluoroscopic x-ray detection apparatus 504. The resulting fluoro video can be displayed on a fluoro display device 506. In addition, the output signals from the fluoroscopic x-ray detection apparatus 504 can be sent to the computer 110.

During gating simulation, the movement of one or more landmarks or markers 114 on the patient's body is optically measured using camera 108. The detected motion of the landmark or marker 114 results in the generation of motion signals according to the process discussed with reference to Fig. 2. While motion data is being collected, the fluoroscopic video system generates imaging data for the tumor or tissue that is targeted for irradiation. In an embodiment, the positional geometry of the fluoroscopic imaging system is configured to correspond to the projection geometry of the radiation beam source that will be used in applying radiation beams for treatment. This allows accurate simulation of the target volume to be achieved during actual treatment.

Fig. 5b depicts an embodiment of a user interface 510 for presenting the recorded data of the fluoro images and motion signals. A portion of user interface 510 displays a chart 512 of the measured motion signals. Another portion of user interface 510 displays a fluoro video 514. During the planning phase of treatment, the fluoro video 514 of the targeted tumor or tissue can be displayed in synchronization with the display of the motion signals. Simultaneous display of both sets of data allow a visual manner of determining the proper boundaries of the treatment intervals, based upon the range of movements of the tumor or target tissue during particular portions of the motion signals.

Gating simulations can be effected by performing "gated playback." Gated playback involves setting simulated threshold boundaries for the treatment intervals. During the gated playback, the user interface can be configured to only display the fluoro image when the motion signal is within the boundaries of the simulated treatment intervals. The fluoro video can be turned off or frozen if the motion signal is outside the simulated treatment intervals. The gating threshold can be dynamically adjusted while both the fluoro video and the motion signals are displayed in the user interface. The playback/adjustment procedure can be performed until the physician is satisfied with the gating thresholds of the treatment window. The display rate can be dynamically adjusted to speed or slow down the visual playback of the fluoro video.

In an embodiment, a visual display border can be formed around region(s) of interest in the fluoro video 514. For example, a box-like display border can be drawn around a tumor shown in fluoro video 514. Alternatively, a display border generally matching the shape of a tumor can be drawn around that tumor. The visual display border can be used to simulate the shape of an applied radiation beam. During playback, the movement of the tumor in relation to the visual display border at particular points in the motion signal range can help determine the proper boundaries of the treatment intervals.

The recorded fluoro image allows digital analysis and quantification of the amount of tumor motion resulting from regular physiological movement. For each image frame, the image data corresponding to the tumor or targeted tissue can be highlighted or otherwise selected by the computer 110. Calculations can be performed upon this image data to analyze motion of the tumor or tissue during the regular physiological movements.

According to an embodiment, this calculation can be performed by digital subtraction of image frames. When using digital subtraction, a first image frame is selected that corresponds to a first time point in a movement cycle. A second image frame is selected that corresponds to a second time point in the movement cycle. Digital subtraction is performed between the image elements of the first and second image frames to obtain the difference over the portion of the image frames corresponding to the tumor or targeted tissue. In an embodiment, the strength of the difference is computed using standard deviation of pixel values of the subtraction results. The distribution area over the area of subtraction is analyzed to determine the amount of positional movement experienced by the tumor or targeted tissue between the first and second time points in the movement cycle. This calculation can be performed over full recording periods to accurately quantify tumor or targeted tissue movement at various stages within the movement cycle.

The quantified movement data of the tumor or targeted tissue allows precise determination of gating thresholds for the treatment intervals. For example, if the physician desires the treatment intervals to include periods of movements that will not exceed a certain threshold movement margin, then the quantified movement data can be analyzed to determine the exact boundaries of the treatment intervals that achieves the desired movement margin. Alternatively, certain preset movement margin thresholds can be programmed into the computer 110. Based upon the preset movement margins, the system can perform an analysis of the movement data to determine the optimal gating thresholds of the treatment intervals to achieve the preset movement margins. This gating threshold can be designated as the default or suggested treatment intervals for the corresponding patient.

Verification can be performed to validate the gating threshold settings of the treatment intervals. This is particularly useful during delivery of fractionated treatment. This can be done as a second simulation procedure, by repeating the gating simulation employed during the planning phase. Alternatively, gated verification imaging can be performed during a treatment session scheduled for the patient with the radiation beam source. Gated electronic portal images can be obtained during delivery of the fractionated radiation treatments. To accomplish this, the gating system triggers a single exposure or a sequence of exposures which can be visually or automatically compared to the original reference images. The verification can be repeated at any point deemed clinically appropriate during the treatment schedule.

Figs. 6a and 6b depict an embodiment of a camera 108 that can used in the present invention. Camera 108 is a charge-couple device ("CCD") camera having one or more photoelectric cathodes and one or more CCD devices. A CCD device is a semiconductor device that can store charge in local areas, and upon appropriate control signals, transfers that charge to a readout point. When light photons from the scene to be images are focussed on the photoelectric cathodes, electrons are liberated in proportion to light intensity received at the camera. The electrons are captured in charge buckets located within the CCD device. The distribution of captured electrons in the charge buckets represents the image received at the camera. The CCD transfers these electrons to an analog-to-digital converter. The output of the analog-to-digital converter is sent to computer 410 to process the video image and to calculate the positions of the retro-reflective markers 406. According to an embodiment of the invention, camera 108 is a monochrome CCD camera having RS-170 output and 640x480 pixel resolution. Alternatively, camera 408 can comprise a CCD camera having CCIR output and 756x567 pixel resolution.

In a particular embodiment of the invention, an infra-red illuminator 602 ("IR illuminator") is co-located with camera 108. IR illuminator 602 produces one or more beams of infrared light that is directed in the same direction as camera 108. IR illuminator 602 comprises a surface that is ringed around the lens 606 of camera body 608. The surface of IR illuminator 602 contains a plurality of individual LED elements 604 for producing infrared light. The LED elements 604 are arranged in a spiral pattern on the IR illuminator 602. Infrared filters that may be part of the camera 108 are removed or disabled to increase the camera's sensitivity to infrared light.

According to an embodiment, digital video recordings of the patient in a session can be recorded via camera 108. The same camera 108 used for tracking patient movement can be used to record video images of the patient for future reference. A normal ambient light image

sequence of the patient can be obtained in synchronization with the measured movement signals of markers 114.

Figs. 7a and 7b depict an embodiment of a retro-reflective marker 700 that can be employed within the present invention. Retro-reflective marker 700 comprises a raised reflective surface 702 for reflecting light. Raised reflective surface 702 comprises a semi-spherical shape such that light can be reflected regardless of the input angle of the light source. A flat surface 704 surrounds the raised reflective surface 702. The underside of flat surface 704 provides a mounting area to attach retro-reflective marker 700to particular locations on a patient's body. According to an embodiment, retro-reflective marker 700 is comprised of a retro-reflective material 3M#7610WS available from 3M Corporation. In an embodiment, marker 700 has a diameter of approximately .5 cm and a height of the highest point of raised reflective surface 702 of approximately .1 cm.

Fig. 8 depicts an apparatus 802 that can be employed to manufacture retro-reflective markers 700. Apparatus 802 comprises a base portion 804 having an elastic ring 806 affixed thereto. Elastic ring 806 is attached to bottom mold piece 808 having a bulge protruding from its center. A control lever 810 can be operated to move top portion 812 along support rods 814. Top portion 812 comprises a spring-loaded top mold piece 814. Top mold piece 814 is formed with a semi-spherical cavity on its underside. In operation, a piece of retro-reflective material is placed on bottom mold piece 808. Control lever 810 is operated to move top portion 812 towards base portion 804. The retro-reflective material is compressed and shaped between the bottom mold piece 808 and the top mold piece 814. The top mold piece 814 forms the upper exterior of the retro-reflective material into a semi-spherical shape.

In an alternate embodiment, marker 114 comprises a marker block having one or more reference locations on its surface. Each reference location on the marker block preferably comprises a retro-reflective or reflective material that is detectable by an optical imaging apparatus, such as camera 108.

Fig. 9 depicts an embodiment of a marker block 900 having a cylindrical shape with multiple reference locations comprised of retro-reflective elements 902 located on its surface. Marker block 900 can be formed as a rigid block (e.g., from Styrofoam). Blocks made in this fashion can be reused a plurality of times, even with multiple patients. The retro-reflective elements 902 can be formed from the same material used to construct retro-reflective markers 114 of Figs. 7a and 7b. The marker block is preferably formed from a material that is light-weight enough not to interfere with normal breathing by the patient.

A marker block can be formed into any shape or size, as long as the size, spacing, and positioning of the reference locations are configured such that a camera or other optical imaging apparatus can view and generate an image that accurately shows the positioning of the marker block. For example, Fig. 10 depicts an alternate marker block 1000 having a hemispherical shape comprised of a plurality of retro-reflective elements 1002 attached to its surface.

The marker block can be formed with shapes to fit particular body parts. For example, molds or casts that match to specific locations on the body can be employed as marker blocks. Marker blocks shaped to fit certain areas of the body facilitate the repeatable placement of the marker blocks at particular locations on the patient. Alternatively, the marker blocks can be formed to fit certain fixtures that are attached to a patient's body. For example, a marker block can be formed within indentations and grooves that allow it to be attached to eyeglasses. In yet another embodiment, the fixtures are formed with integral marker block(s) having reflective or retro-reflective markers on them.

An alternate embodiment of the marker block comprises only a single reference location/reflective element on its surface. This embodiment of the marker block is used in place of the retro-reflective marker 406 to detect particular locations on a patient's body with an optical imaging apparatus.

In the foregoing specification, the invention has been described with reference to specific embodiments thereof. It will, however, be evident that various modifications and changes may be made thereto without departing from the broader spirit and scope of the invention. For example, the operations performed by computer 110 can be performed by any combination of hardware and software within the scope of the invention, and should not be limited to particular embodiments comprising just a particular definition of "computer". The specification and drawings are, accordingly, to be regarded in an illustrative rather than restrictive sense.

CLAIMS

What is claimed is:

1. A system for applying radiation comprising:

a radiation source;

a switch that is operatively coupled to said radiation source;

an optical imaging apparatus, the optical imaging apparatus having a output signal comprising image data;

the image data comprising motion information relating to movement detected by the optical imaging apparatus; and

the switch actuatable as a result of particular levels of movement indicated by the motion information.

2. The system of information 1 further comprising a marker, wherein the motion information relates to motion of the marker.

3. The system of claim 2 in which the marker comprises a retro-reflective material.

4. The system of claim 2 in which the marker comprises a marker block having one or more reflective elements.

5. The system of claim 1 in which the optical imaging apparatus is a video camera and the image data comprises video data.

6. The system of claim 1 in which the optical imaging apparatus comprises a CCD camera.

7. The system of claim 1 in which an infrared light source is co-located with the optical imaging apparatus.

8. The system of claim 1 in which a treatment interval is defined over the motion information.

9. The system of claim 8 in which boundaries of the treatment interval are defined to correspond with motion that is predicted to result in unacceptable levels of movement of tissue targeted for radiation.

10. The system of claim 8 in which a gating signal is applied to the switch based upon a comparison of the motion information with the treatment interval.

11. The system of claim 1 in which the particular levels of movement indicated by the motion information that can operatively actuate the switch correspond with motion that is predicted to result in unacceptable levels of movement of tissue targeted for radiation.

12. The system of claim 1 in which the particular levels of movement indicated by the motion information that can operatively actuate the switch correspond with motion that is predicted to result in reduced target volume for irradiation.

13. The system of claim 1 in which the particular levels of movement indicated by the motion information that can operatively actuate the switch correspond with motion that is predicted to result in largest separation of irradiation volume from organs at risk.

14. A method for determining treatment intervals for radiation therapy comprising:
recording image data representative of tissue targeted for irradiation;
generating motion data representative of physiological movement; and
synchronously displaying the image data with the motion data.

15. The method of claim 14 further comprising:
selecting a simulated treatment interval;
displaying the image data only when the motion data is within the simulated treatment interval.

16. The method of claim 15 in which the image data is frozen when the motion data is outside the simulated treatment interval.

17. The method of claim 15 further comprising:
adjusting the simulated treatment interval to view a different quantity of image data.

18. The method of claim 14 further comprising:

analyzing the image data to quantify an amount of motion of the targeted tissue during the physiological movement.

19. The method of claim 14 further comprising:

forming a display border around a region of the image data.

20. A system for determining treatment intervals for radiation therapy comprising:

an imaging system at which image data representative of internal regions of a patient's body is generated;

an instrument having an output signal comprising motion information relating to regular physiological movement of the patient's body; and

a user interface comprising a display for the image data synchronized with a display of the motion information.

21. The system of claim 20 in which the imaging system comprises a fluoroscopic imaging system.

22. The system of claim 20 in which the instrument comprises one or more cameras configured to detect the regular physiological movement.

23. The system of claim 20 in which a simulated treatment interval is defined over the motion information, and in which the image data is displayed during the simulated treatment interval.

24. The system of claim 23 in which the simulated treatment interval is dynamically adjustable.

25. The system of claim 20 further comprising digital analysis signals, said digital analysis signals comprising results of digital analysis to quantify motion of an internal structure shown in the image data.

26. The system of claim 25 in which the digital analysis signals is generated with digital subtraction of image frames.

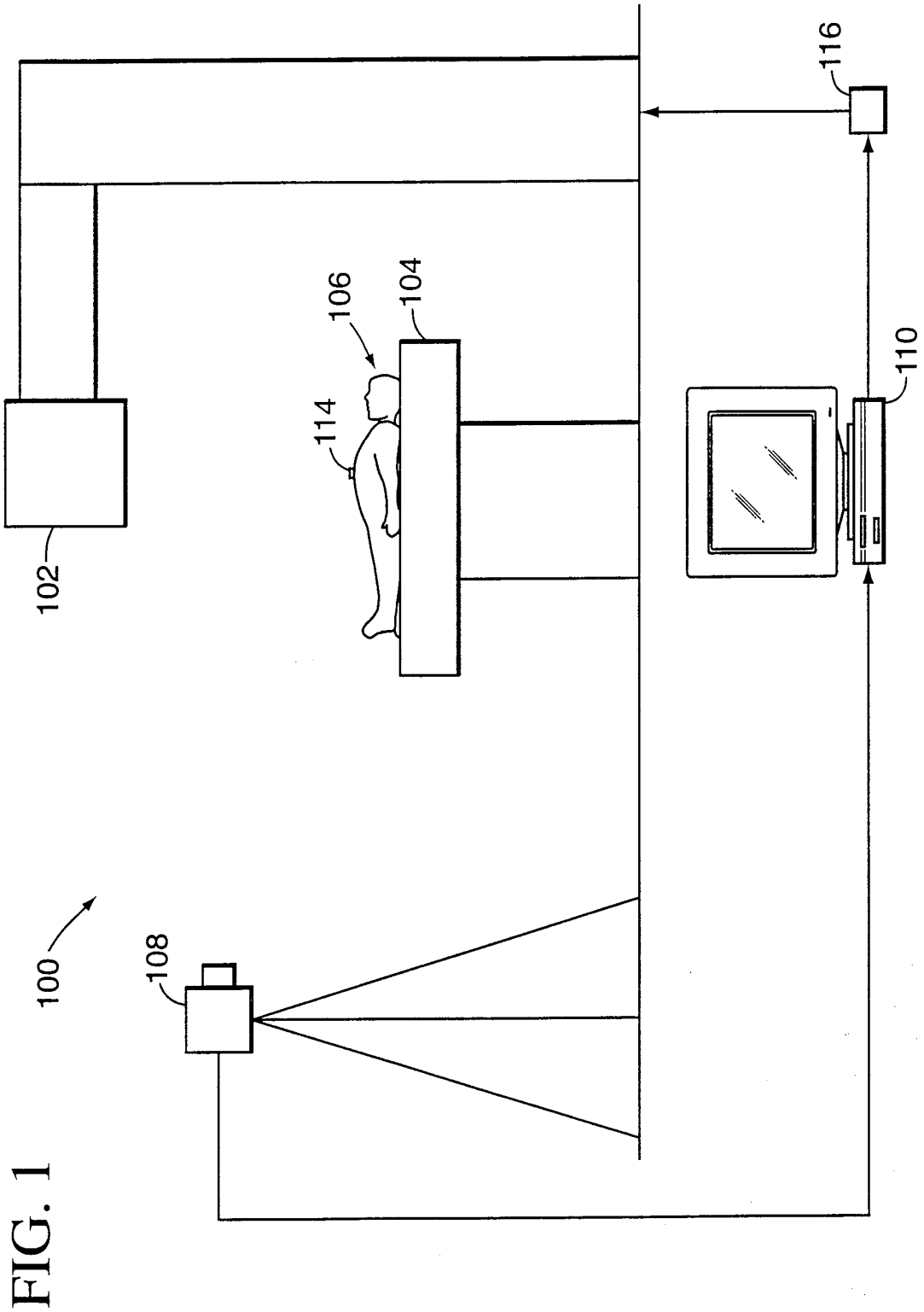


FIG. 1

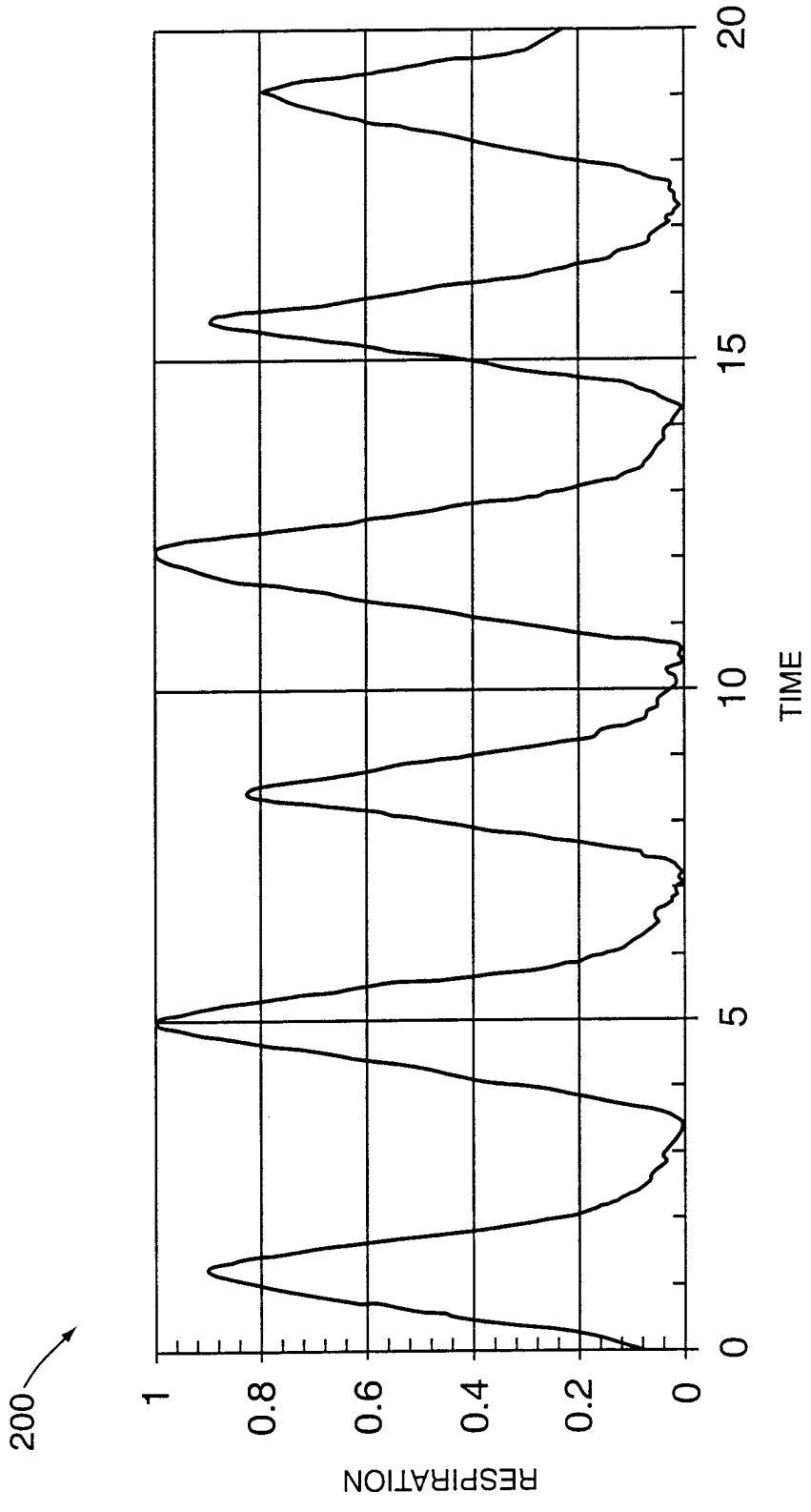


FIG. 2

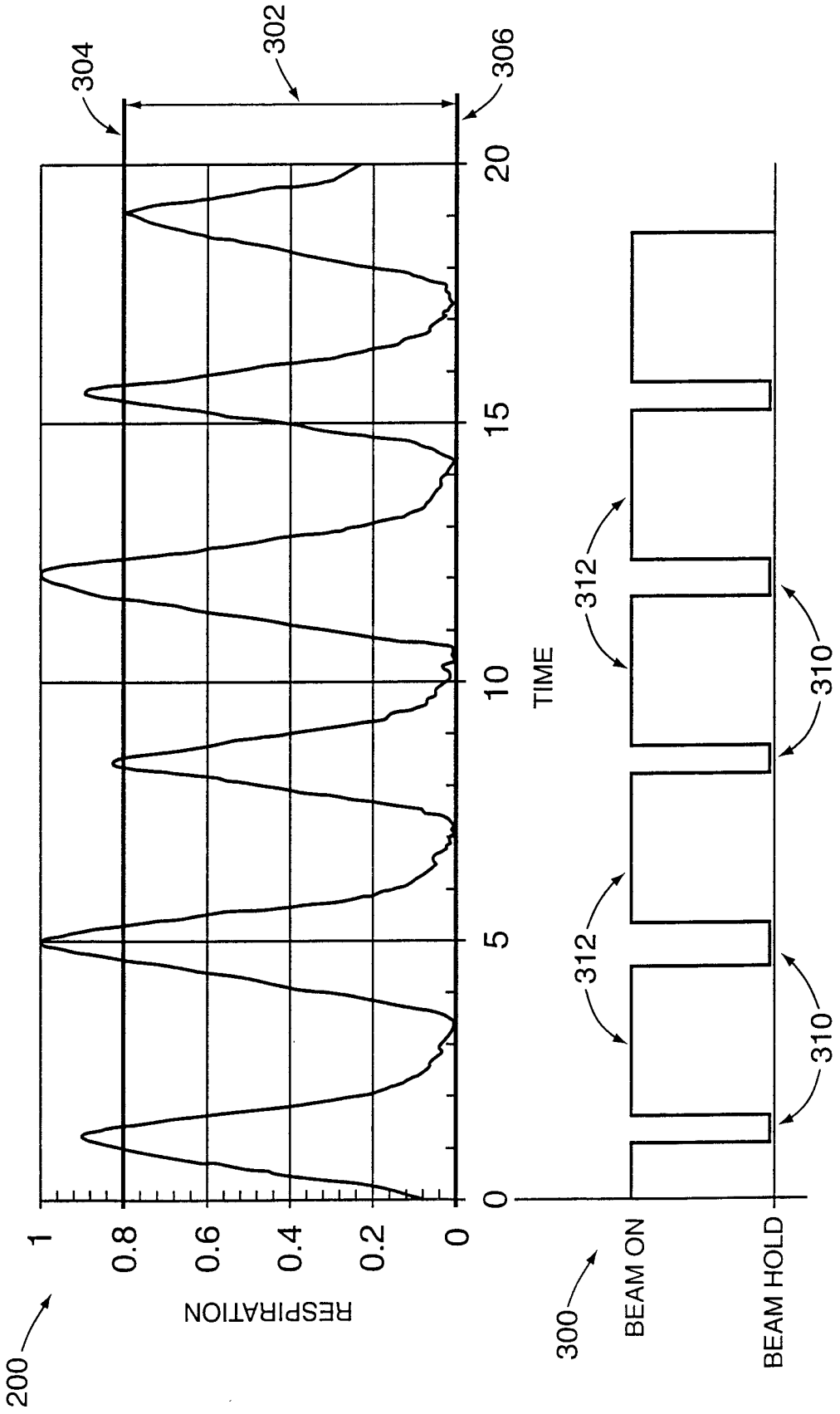

304
302
306
RESPIRATION
1
0.8
0.6
0.4
0.2
0
0
5
10
15
20
TIME
200
300
BEAM ON
BEAM HOLD
312
312
310
310

FIG. 3

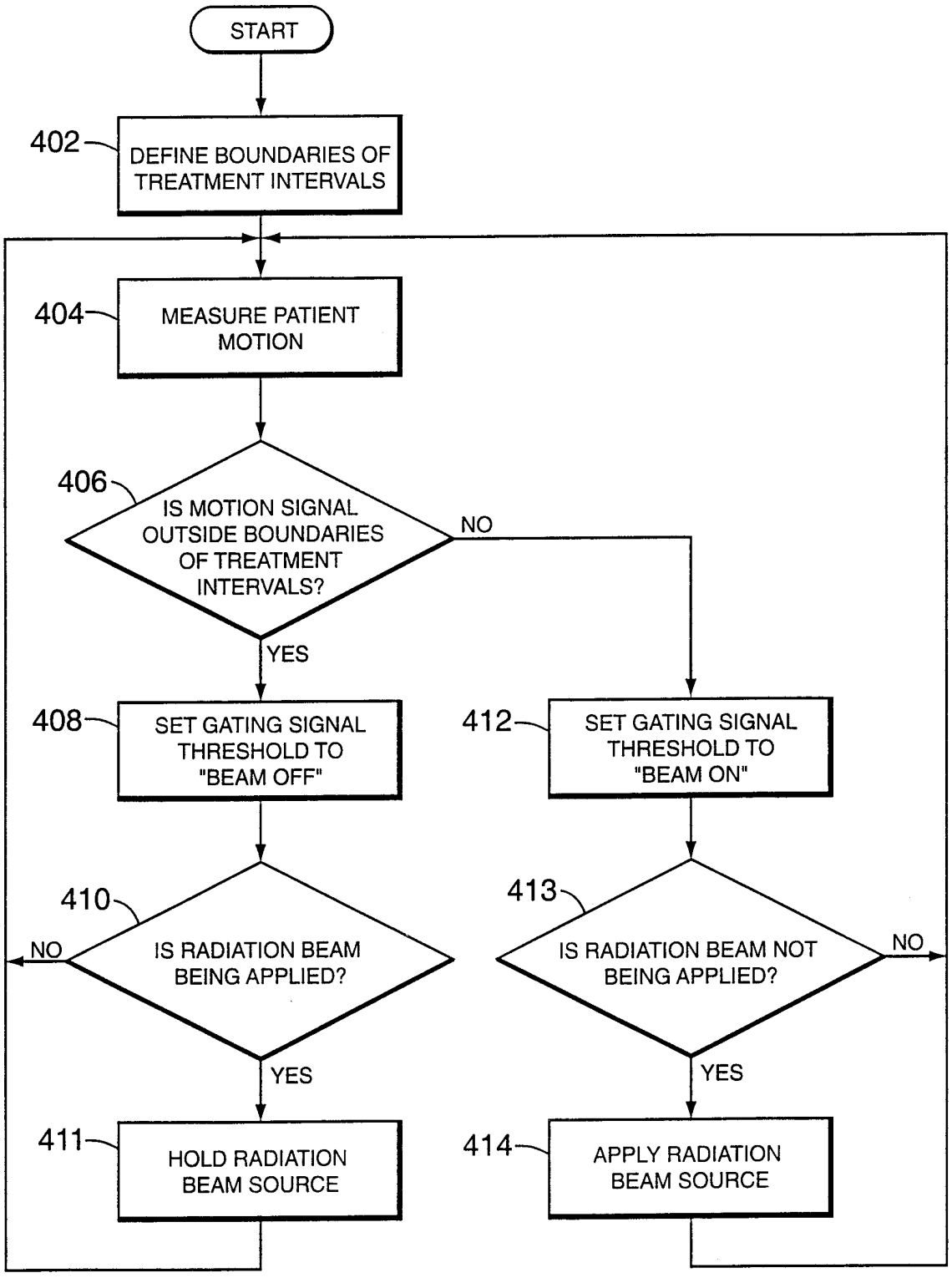

START
402
DEFINE BOUNDARIES OF TREATMENT INTERVALS
404
MEASURE PATIENT MOTION
406
IS MOTION SIGNAL OUTSIDE BOUNDARIES OF TREATMENT INTERVALS?
NO
YES
408
SET GATING SIGNAL THRESHOLD TO "BEAM OFF"
412
SET GATING SIGNAL THRESHOLD TO "BEAM ON"
410
IS RADIATION BEAM BEING APPLIED?
NO
YES
413
IS RADIATION BEAM NOT BEING APPLIED?
NO
YES
411
HOLD RADIATION BEAM SOURCE
414
APPLY RADIATION BEAM SOURCE

FIG. 4

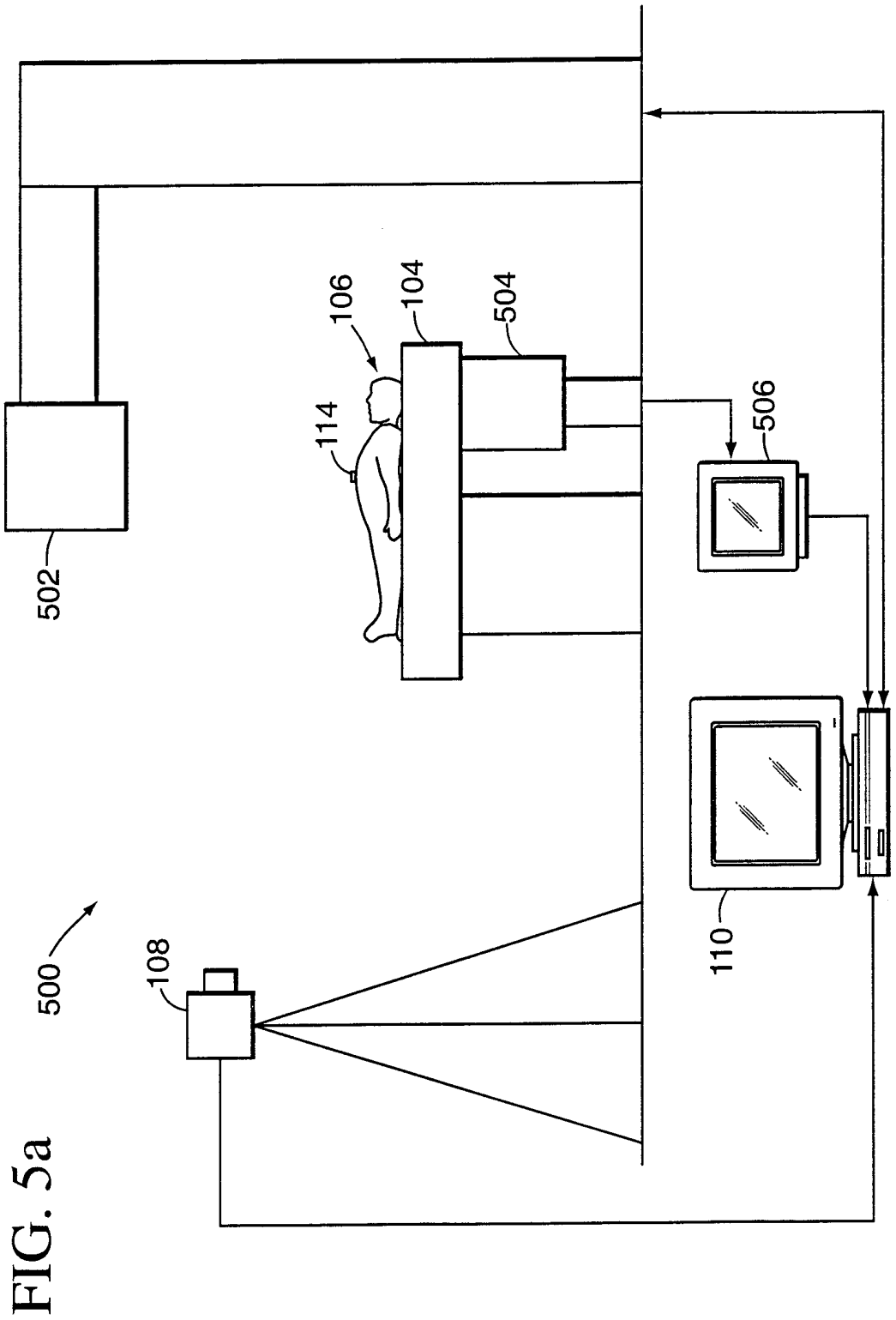


FIG. 5a

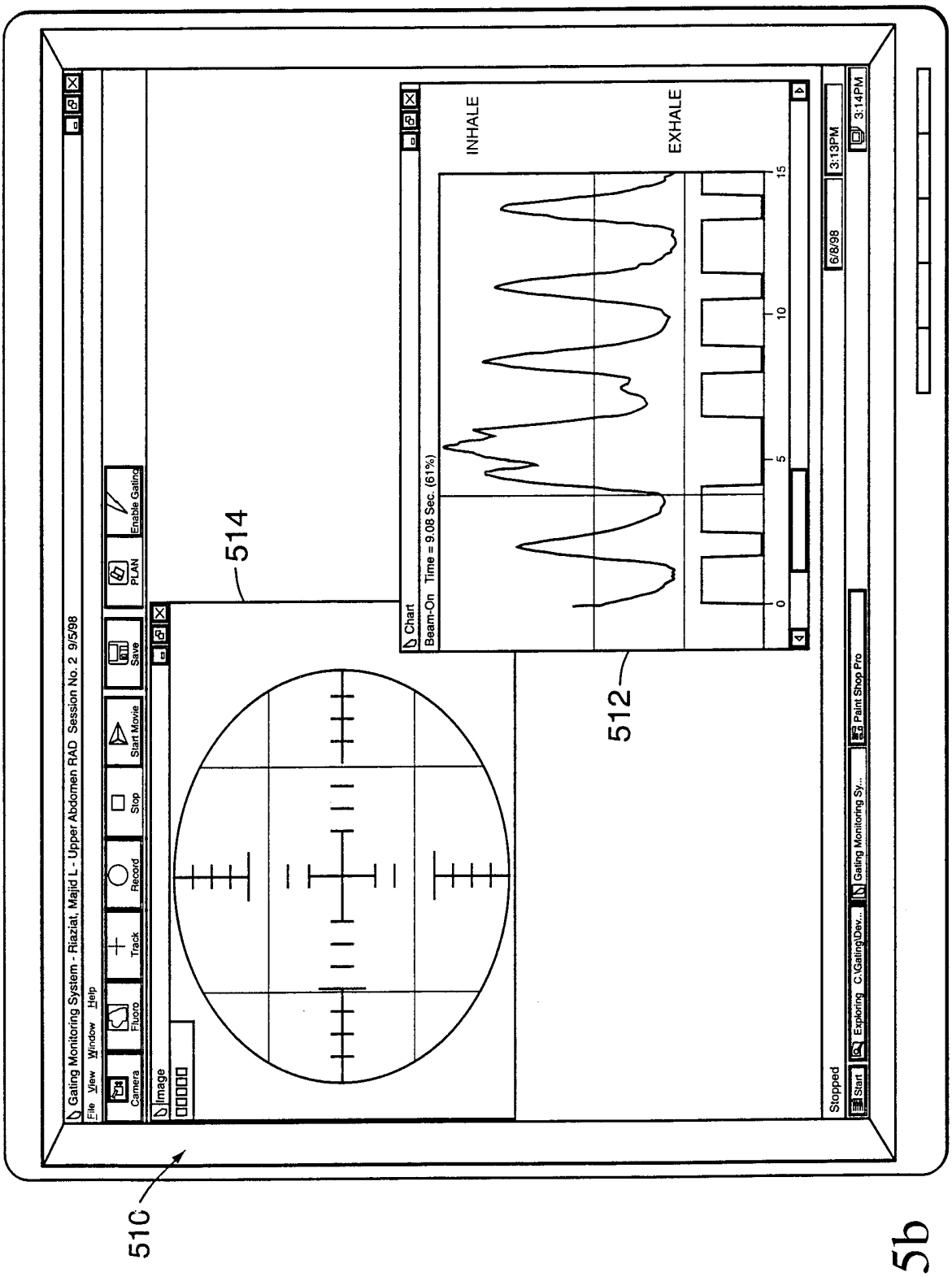

Gating Monitoring System - Riaziat, Majid L - Upper Abdomen RAD Session No. 2 9/5/98
File View Window Help
Camera
Fluoro
Track
Record
Stop
Start Movie
Save
PLAN
Enable Gating
Image
Chart
Beam-On Time = 9.08 Sec. (61%)
INHALE
EXHALE
0
5
10
15
Stopped
Start
Exploring C:\Gating\Dew...
Gating Monitoring Sy...
Paint Shop Pro
6/8/98
3:13PM
3:14PM
510
512
514

FIG. 5b

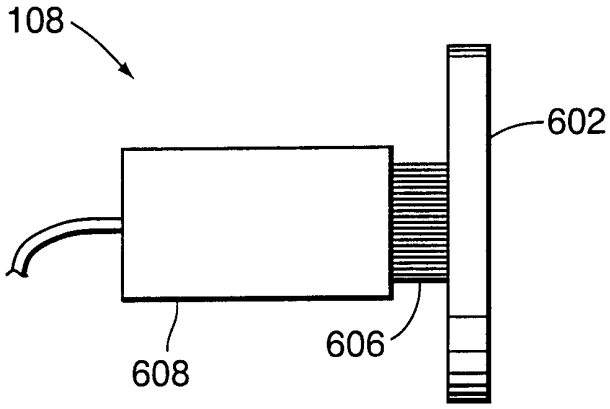


FIG. 6a

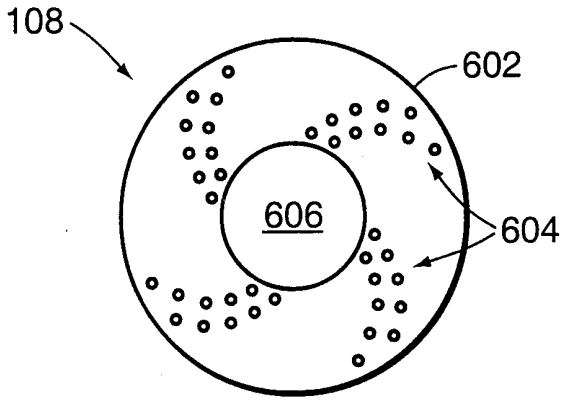


FIG. 6b

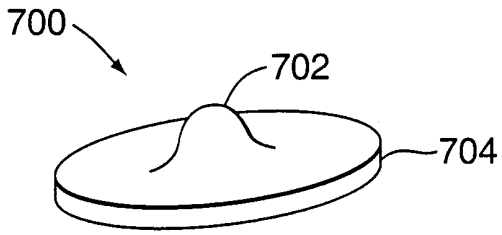


FIG. 7a

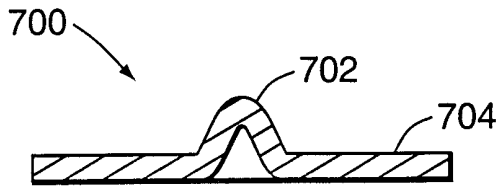


FIG. 7b

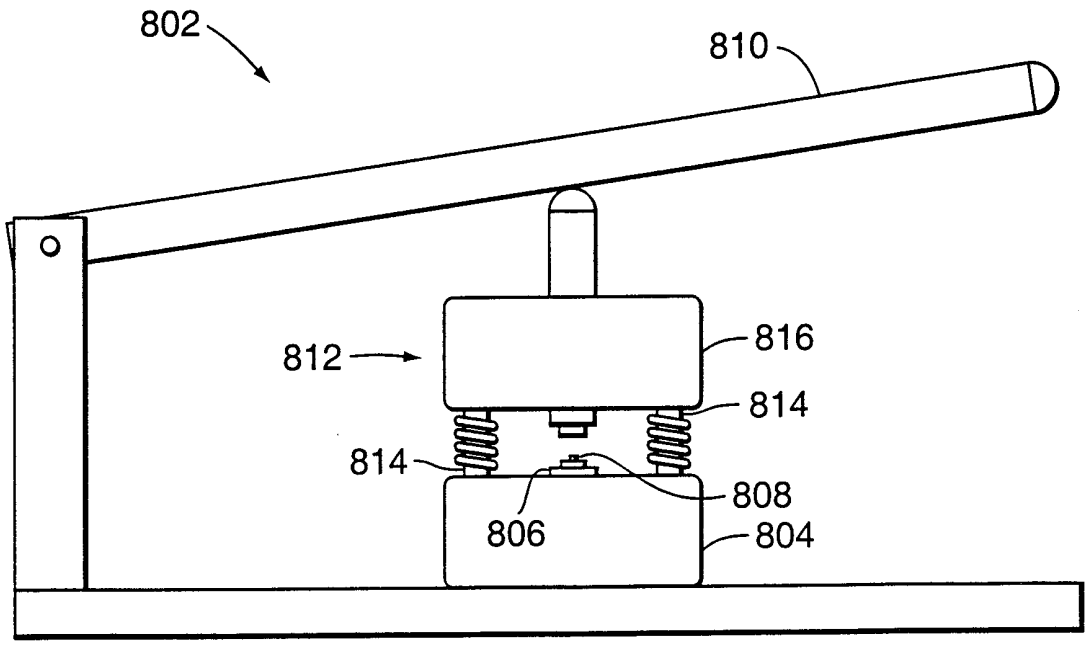


FIG. 8

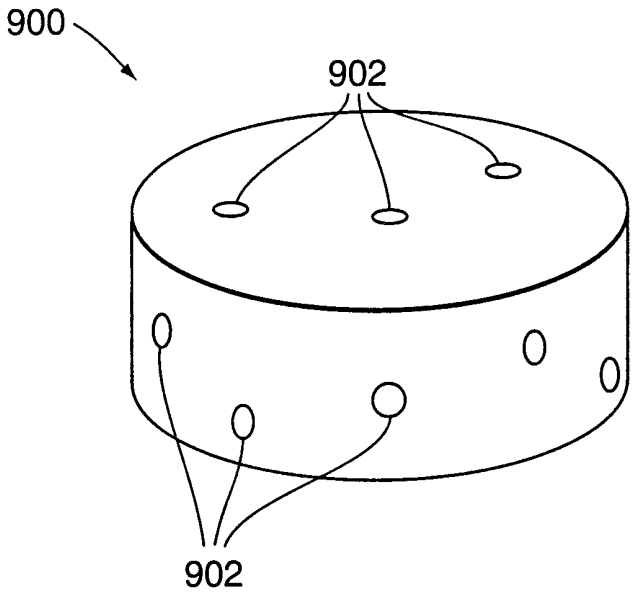


FIG. 9

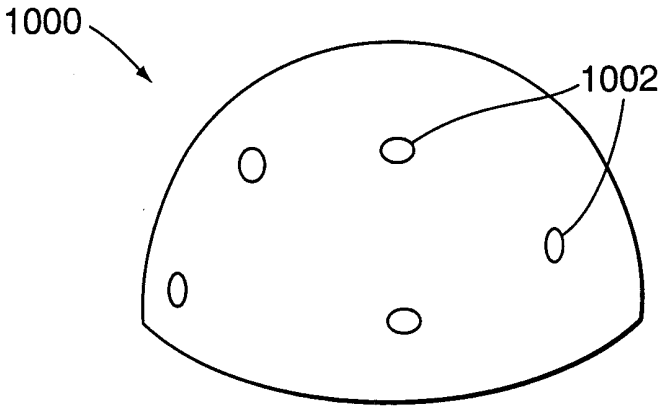


FIG. 10

INTERNATIONAL SEARCH REPORT

Inte\ onal Application No
PCT/US 99/24947

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 A61N5/10

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 A61N A61B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 727 554 A (ATHANASSIOU CHARALAMBOS N ET AL) 17 March 1998 (1998-03-17) column 2, line 13 - line 21 column 4, line 21 - line 47 column 8, line 7 - line 18 ---	1-14, 18-20, 22,25,26
X	US 5 446 548 A (GERIG LEE H ET AL) 29 August 1995 (1995-08-29) column 2, line 3 -column 4, line 21 column 5, line 34 - line 43 column 7, line 10 - line 57 column 11, line 5 - line 23; claims 1,2,7,8 --- -/--	1-14,18, 20,22, 25,26

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
1 February 2000	11/02/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Petter, E

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INTERNATIONAL SEARCH REPORT

Inte .onal Application No
PCT/US 99/24947

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
X	KUBO H D ET AL: "RESPIRATION GATED RADIOTHERAPY TREATMENT: A TECHNICAL STUDY" PHYSICS IN MEDICINE AND BIOLOGY,GB,TAYLOR AND FRANCIS LTD. LONDON, vol. 41, no. 1, 1 January 1996 (1996-01-01), pages 83-91, XP000548771 ISSN: 0031-9155 Section 2.2 Fluoroscopic images Section 2.3 Accelator gate Section 3.2 Fluoroscopic images Section 4.2 Fluoroscopic images	14,18-21
A	US 5 538 494 A (MATSUDA KOJI) 23 July 1996 (1996-07-23) column 4, line 31 -column 5, line 27; figures 4,5 column 6, line 60 -column 7, line 51; figures 9,10,20,22	1,14,20
A	DE 43 41 324 A (SIEMENS AG) 8 June 1995 (1995-06-08) abstract; claim 7	14,20
A	WO 98 16151 A (UNIV COLUMBIA) 23 April 1998 (1998-04-23) page 3, line 10 -page 5, line 13 page 11, line 6 - line 14 page 13, line 3 - line 12	1,14,20

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

Inte. onal Application No
PCT/US 99/24947

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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WO 9816151 A	23-04-1998	US 5764723 A	09-06-1998
		AU 4821797 A	11-05-1998