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(54) Title: INTERACTIVE COMPUTER-AIDED EDITOR FOR COMPENSATORS USED IN RADIOTHERAPY TREATMENT PLANNING

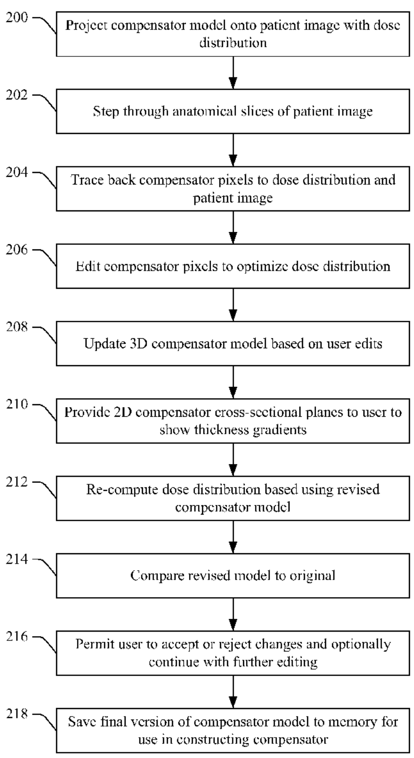

FIG. 9

(57) Abstract: When constructing compensators for radiation therapy using ion or proton radiation beams, a computer-aided compensator editing method includes overlaying an initial 3D compensator model on an anatomical image of a target mass (e.g., a tumor) in a patient, along with radiation dose distribution information. A user manipulates pixels or voxels in the compensator model on a display, and a processor automatically adjusts the dose distribution according to the user edits. The user iteratively adjusts the compensator model until the dose distribution is optimized, at which time the optimized compensator model is stored to memory and/or output to a machining device that constructs a compensator from the optimized model.

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INTERACTIVE COMPUTER-AIDED EDITOR FOR COMPENSATORS USED IN RADIOTHERAPY TREATMENT PLANNING

DESCRIPTION

The present application finds particular utility in radiotherapy treatment planning (RTP) systems. However, it will be appreciated that the described technique(s) may also find application in other types of therapy planning systems, other computer-aided editing systems, and/or other therapeutic applications.

In proton and heavy-ion therapy, the particles have the property of "stopping" in the medium after a certain depth based on the energy and properties of the medium, particle, and delivery machine. The maximum dose delivered to the medium is delivered at the so called "Bragg Peak" at the end of the particles' range.

In proton and ion beam radiotherapy, a compensator is typically disposed between the radiation source and the subject. The compensator is custom manufactured for each patient. It typically takes the form of a plexiglass layer with different thicknesses in different regions in order to compensate for the different tissues between the beam and the target at different beam angles such that a uniform dose is delivered to the target, i.e. to position the Bragg Peak on the target.

In external beam radiotherapy treatment planning, the compensator is custom-designed for each patient to adjust the radiation dose delivered to that patient. The initial design is typically calculated and optimized within the treatment planning system and displayed via a matrix-style representation of the thickness values of the compensator. This matrix provides little useful feedback to the user in regard to the compensator's design. Generally, the user is allowed to change the values of any one of the individual pixels in a spreadsheet-entry manner. However, these changes are difficult to justify and quantify. The user may want to edit the compensator for reasons such as: to eliminated hot or cold spots of radiation dose within the patient; to soften the gradient between neighboring pixels which, if too steep, could cause vast changes in dose delivered to the target or organs at risk in the event of slight patient setup errors; to widen or narrow the compensator shape to cover more or less of the target organ; or because the dose distribution provided by the initial computer algorithm is not acceptable.

Proton and ion therapy have many clinical advantages compared to gamma radiation photons, for example. Proton and ion beams can be combined in novel ways to deliver a uniform dose distribution to a complex target in medium. One of these techniques is the so called “Patch Field” technique in which two or more beams are essentially perpendicular to each other. For example, the “through” beam irradiates longitudinally and the “patch” beam irradiates laterally. The mechanical properties of the patch and the through beams are adjusted to provide a uniform dose in the overlap region, i.e. to the target. The patch system is a known technique used in radiotherapy. However, the tools to implement and optimize this technique are not advanced.

In ion or proton based therapy (henceforth collectively referred to as “ion therapy”) specifically, the initial design is typically calculated and optimized within the treatment planning system with a single objective—to conform the dose to the distal edge of the target tissue. This limits the user’s ability to shape the dose distribution from the ion therapy source to the patient. Although manual edits may be made to the compensator pixels, such edits are based on trial and error and would be considered a forward planning approach to the compensator design. The initial compensator design in ion therapy may not be ideal when multiple factors are considered. For example, if the target tissue is in close proximity to an organ-at-risk (OAR), then the uniform coverage of the target may force too much dose to spill into the OAR. Further, any margins that are added to the target’s shape may cause further increases to the dose within the OAR. Ideally, the user may want to examine certain trade-offs to the dose distribution to the target with respect to the dose to the surrounding tissues.

Complex target coverage is another major concern in radiotherapy treatment planning. The radiation dose delivered to the target anatomy needs to be adequate while minimizing the dose to neighboring organs at risk. When the shape of the target is complex, multiple beams may be used to cover separate portions of the target. In this case, overlapping dose from the beams may create an unwanted hotspot and reduced uniformity within the target tissue.

There is an unmet need in the art for systems and methods that facilitate interactively displaying the compensator in 3 dimensions, including the patient anatomy and dose distribution, to aid the user in manually adjusting the compensator pixels, and the like, thereby overcoming the deficiencies noted above.

In accordance with one aspect, a system that facilitates optimizing a computer-generated 3D compensator model for use in radiotherapy treatment planning includes a graphical user interface (GUI) including a display and a user input device, and a processor that executes computer-executable instructions stored in a memory. The instructions include displaying on the display, to a user, a compensator model, receiving user input from the user input device comprising edits to the compensator model, optimizing the compensator model based on the user input, and storing the optimized compensator model to the memory or computer-readable storage medium.

In accordance with another aspect, a method of computer-aided compensator model optimization for compensators used in radiotherapy treatment includes displaying a compensator model on a patient image of an anatomical region of a patient, receiving user input edits to the compensator model, and updating the compensator model based on the user input. The instructions further include storing the updated compensator model to memory or computer-readable storage medium.

In accordance with another aspect, a method of optimizing radiation dose distribution for an irregularly-shaped target mass in a patient while mitigating radiation dose to a nearby organ includes identifying lateral and distal sections of a computerized model of the target mass and a junction between the lateral and distal sections, and making a virtual cut in the model along the junction. The method further includes iteratively adjusting contours of the lateral and distal sections in order to optimize a radiation dose distribution, and displaying dose distribution overlaid on a patient image that includes the target mass for user evaluation during dose distribution optimization.

One advantage is that compensator manufacture is improved.

Another advantage resides in minimizing unnecessary radiation dose to the patient.

Another advantage resides in simplifying compensator design, which improves design precision.

Still further advantages of the subject innovation will be appreciated by those of ordinary skill in the art upon reading and understand the following detailed description.

The drawings are only for purposes of illustrating various aspects and are not to be construed as limiting.

FIGURE 1 illustrates a system for editing a compensator used during radiotherapy planning and radiation dose application to a patient

FIGURE 2 is an example of a compensator editing graphical user interface (GUI) such as may be displayed on the display of Figure 1.

FIGURE 3 is an example of a compensator editing GUI that includes a generally L-shaped target mass in a patient's cranium, wherein the mass is divided into a through (distal) region and a patch (lateral) region to be individually irradiated during a radiotherapy treatment.

FIGURE 4 is a screenshot of a GUI showing a top-down view of the virtual compensator model, which comprises a plurality of pixels.

FIGURE 5 is a screenshot of a GUI in which a substantially L-shaped target mass is positioned in close proximity to an organ at risk.

FIGURE 6 is a screenshot of a GUI including a "patch" tool that a user selects to cause the processor of Figure 1 to execute beam configuration algorithms and adjust beam configuration data to generate patch beam data and through beam data, which are used to irradiate a patch portion of the target mass and a through portion of the target mass, respectively.

FIGURE 7 is a screenshot of a GUI showing a dose distribution of radiation in the patch section and the through section, while preserving the organ, prior to execution of the patch algorithm by the system.

FIGURE 8 is a screenshot of a GUI showing optimized dose distribution of radiation in the patch section and the through section, while preserving the organ, after to execution of the patch algorithm by the system.

FIGURE 9 illustrates a method for computer-aided editing of a 3D compensator model, in accordance with various aspects set forth herein.

FIGURE 10 illustrates a method for optimizing radiation dose for an irregularly-shaped target mass while mitigating unwanted irradiation of a nearby organ or the like, in accordance with various aspects described herein.

FIGURE 11 illustrates a method for performing inverse optimization and design of compensators used in radiotherapy treatments, in accordance with various aspects set forth herein.

The systems and methods described herein, in one embodiment, relate to a computerized system that displays dose distribution of a radiotherapy beam overlaid onto a projection of the compensator pixels and patient anatomy for detailed visualization. Additionally, editing tools are provided to adjust and edit the compensator based on the user intent while interactively displaying the changes to the dose distribution.

In another embodiment, a computerized algorithm accounts for the target shape, beam dose, and properties of the delivered particles to provide a uniform dose distribution. A graphical user interface and editing tools facilitate manipulation of the beam parameters to ensure acceptable target irradiation.

In another embodiment, computerized editing tools and algorithms are provided for compensator design and optimization. The algorithms factor in user-specified goals and/or objectives for the desired dose to the patient, target and surrounding tissues in proton and ion based therapy.

FIGURE 1 illustrates a system **10** for editing a compensator used during radiotherapy planning and radiation dose application to a patient. The system includes a processor **12** that executes, and a memory **14** or other computer-readable media that stores, computer-executable instructions for carrying out the various methods and/or techniques described herein. The processor and memory are coupled to each other via a bus **15**, which is also coupled to an imaging device **16** (e.g., a computed tomography device, a magnetic resonance imaging device, a nuclear scanning device, etc.) and a display **18**. The imaging device generates scan data of a subject or patient, which is reconstructed by a reconstruction processor to generate patient image data **20** that is stored in the memory **14** and displayed on the display **18**. In one embodiment, the processor(s) **12** include a reconstruction processor that executes reconstruction algorithms or the like.

The memory **14** also stores one or more 3D compensator models **22**. A user selects a compensator model **22** using an editing tool **24**, which may include a mouse, stylus, keyboard, or other input device. The memory additionally stores compensator pixel data **26**, 2D cross-sectional plane data **28** corresponding to slices of the compensator model **22**, and compensator gradient thickness data **30**. Additionally, beam configuration data **32** is stored in the memory, and includes patch parameters **34** and/or algorithms and through parameters **36** and/or algorithms for the radiation beam to be applied to a target mass in the patient. The beam configuration data is provided to a therapy device **40** that generates the radiation beam when irradiating the target tissue in the patient.

The memory further stores one or more algorithms (e.g., computer-executable instructions) for compensator design and optimization. For instance, the 3D compensator models can be pre-generated or can be generated specifically for each patient therapy treatment. Using the editing tools, the user adjusts a selected model on the display, and the revisions are stored **22** as different versions of the compensator model. Each edit input by the user causes the processor to execute the optimization algorithm(s) and adjust the model accordingly. The user then reviews the edited model(s) and accepts or rejects the changes. If the user accepts the changes, the revised model is stored to the memory for use during the radiation treatment event.

According to one embodiment, a user-selected compensator **22** is projected onto the patient anatomy image displayed on the display **18**, along with a dose distribution map **42** in a beam's eye view display. Using the editing tools **24**, the user steps through anatomical slices of the patient anatomy image **20**, and the projection of the compensator **22** is adjusted accordingly by the processor **12**. In this manner, an individual compensator pixel can be traced back to the dose distribution and anatomical features.

The editing tools **24** permit the user to edit the compensator pixels **26** in the beam's eye view representation. The user may change the compensator pixels by adding, subtracting, averaging, etc. a value. Furthermore, the user-entered changes will be updated in the 3-dimensational model of the compensator. In addition to the beam's eye view and 3-dimensional model, the 2-dimensional cross-sectional planes **28** of the compensator aid the user in visualization of the thickness gradients **30** of the compensator **22**. After the user edits the compensator, the processor **12** recomputes the dose distribution **42** of the beam with the revised compensator, and the user compares the results to the original. The user may then "undo" changes or continue with further editing. When completed, the edits can then be saved and copied to the original beam meant for delivery.

According to another embodiment, one or more beam control algorithm(s) **44** are executed by the processor **12** to automatically adjust the beam configuration **32** and corresponding therapy device **38** (e.g., an ion beam generator, a proton beam generator, or the like) parameters to account for the target shape, beam dose, and properties of the delivered particles to provide a uniform dose distribution to the target. The "patch" junction in the target tissue is determined, and a 3 dimensional "cut" of the target is made by the beam control algorithm **44**. The contours for the patch and the through beam's targets are treated separately and may be manually or automatically adjusted by the beam control algorithm based on the dose distribution and properties of either the patch or through beams. The user interacts with the region of interest (ROI) contours that outline the target, as well as with the beam parameters, to tailor the dose until the user is satisfied. The user can display the updated dose distribution map **42**, which shows radiation dose delivered to the target with each compensator edit, for evaluation and re-optimization.

In another embodiment, the user is provided with the display **18** and editing tools **24** (e.g., a graphical user interface (GUI)) with which to set goals or objectives for the dose distribution to certain points, organs or regions of the patient. The user can specify dose intensity as a range, uniformity, or as a biological equivalent effect that a particular region should receive, as well as a rank for each one of these objectives, which conveys the relative importance of meeting that objective. The processor **12** then executes the compensator design and optimization algorithms **40** to design a compensator, and/or adjusts the beam configuration parameters including, but not limited to, the range and modulation, margins, and energy of the beam to attempt to meet the objectives. Further, the user may include certain uncertainties such as patient motion and density conversion. After the processor is finished calculating, the user is given the opportunity to review the results and adjust the parameters further, which may necessitate a re-optimization.

The GUI allows user interaction with the software code and algorithms used to optimize the therapy treatment. The algorithms can be coded to determine a solution to the user-defined objectives by computing the dose distribution and adjusting the compensator pixels and therapy device parameters. A review interface allows the user to view the results of the optimization.

In another embodiment, instead of entering in objectives in a “text-based” manner, the user can “draw” the desired dose distribution on the display screen (e.g., using an input device such as a mouse or stylus), and the algorithm matches the graphical representation of the dose by adjusting and optimizing the aforementioned parameters relating to the dose delivery, such as the compensator, modulation, etc.

The system **10** also includes a compensator machine **46** that receives finalized compensator models that have been approved by the user, and which constructs the actual compensators according to the design parameters of the models. In one embodiment, the compensator machine is located at the same site as the system **10** and the compensators are generated on site. In another embodiment, the compensator machine is located remotely from the system **10** (e.g., in a different room, building, city, state, country, etc.), and approved compensator model data is stored to a computer-readable storage medium (e.g., a disk, a memory stick, or some other suitable storage medium) at the system site and transported to the compensator machine site where the model data is uploaded into the compensator machine. Alternatively, 3D compensator model data can be electronically transferred to the compensator machine, such as by email, wireless communication link, infrared, radio frequency, or the like.

As mentioned above, the system includes the processor(s) **12** that executes, and the memory **14** that stores, computer executable instructions for carrying out the various functions and/or methods described herein. The memory **14** may be a computer-readable medium on which a control program is stored, such as a disk, hard drive, or the like. Common forms of computer-readable media include, for example, floppy disks, flexible disks, hard disks, magnetic tape, or any other magnetic storage medium, CD-ROM, DVD, or any other optical medium, RAM, ROM, PROM, EPROM, FLASH-EPROM, variants thereof, other memory chip or cartridge, or any other tangible medium from which the processor **12** can read and execute. In this context, the system **10** may be implemented on or as one or more general purpose computers, special purpose computer(s), a programmed microprocessor or microcontroller and peripheral integrated circuit elements, an ASIC or other integrated circuit, a digital signal processor, a hardwired electronic or logic circuit such as a discrete element circuit, a programmable logic device such as a PLD, PLA, FPGA, Graphical card CPU (GPU), or PAL, or the like.

FIGURE 2 is an example of a compensator editing GUI **60** such as may be displayed on the display **18** of Figure 1. The GUI includes a one or more patient images **20a**, **20b**. The patient image **20a** shows a virtual compensator **62** overlaid on the patient image **20a**. The patient image **20b** shows a beam's eye view of a radiation beam **64** projected into the patient to irradiate a target mass through the compensator **62**. Also shown are a 2D vertical slice **66** through the compensator, and a 2D horizontal slice **68** through the compensator. The GUI permits a user to adjust the virtual compensator so achieve a desired radiation dose to the target mass. Once the user is satisfied that the compensator has been refined to successfully apply an appropriate dose of radiation to the target mass, while mitigating radiation dose to organs at risk or other tissue for which radiation dose is undesirable, the virtual compensator model **62** configuration is saved to memory and used for constructing a physical compensator for use during radiotherapy treatment of the patient.

FIGURE 3 is an example of a compensator editing GUI **80** that includes a generally L-shaped target mass **82** in a patient's cranium **83**, wherein the mass is divided into a through region **84** and a patch (lateral) region **86** to be individually irradiated during a radiotherapy treatment.

FIGURE 4 is a screenshot of a GUI **100** showing a top-down view of the virtual compensator model **62**, which comprises a plurality of pixels **102**. Each pixel corresponds to a point on a real compensator that is to be generated using the model (e.g., by the compensator machine **46** of Figure 1). Once the model **62** is approved by a user, it is stored to memory and output to the compensator machine.

FIGURE 5 is a screenshot of a GUI **120** in which a substantially L-shaped target mass **122** is positioned in close proximity to an organ at risk **124** (e.g., an organ that is not to be irradiated during irradiation of the target mass). An ion beam **126** is shown as covering the entire target mass, in which case the organ at risk will be unnecessarily irradiated. However, with an appropriately designed compensator, the Bragg Peak will be positioned in the arm of the target region and few ions will reach the organ at risk.

FIGURE 6 is a screenshot of a GUI **140** including a “patch” tool **142** that a user selects (e.g., clicks on, etc.) to cause the processor **12** of Figure 1 to execute beam configuration algorithms and adjust beam configuration data **32** to generate patch beam data **34** and through beam data **36** (see Fig. 1), which together deliver a substantially uniform dose to both the patch region **84** and the through region **86**. The patch and through technique more precisely irradiates the target mass **122** while sparing the organ at risk **124**.

Using the patch and through technique, multiple beams are employed to cover a complicated target mass with good conformity and minimal dose to organs at risk. The algorithm includes delineating the target mass, which may be performed by a user by marking or outlining the mass on a patient image (e.g., using a stylus, a mouse, or some other input tool). The patch tool **142** is initiated and automatically splits the target mass into the patch and through portions. Alternatively, this step can be performed manually by the user. In one embodiment, 50% of the total irradiation beam is provided laterally through the through portion **86**, and the remaining 50% is provided distally through the patch portion **84**. However, the user is permitted to adjust these proportions as needed to achieve a desired dose density or pattern.

In another embodiment, the system automatically adjusts the patch and through beams to optimize dose uniformity through the target mass. The user is permitted to adjust the boundaries of the patch and through portions of the target mass, which causes the system to re-optimize the beam parameters and thereby change the shape and/or thickness of a compensator model being generated for the target mass.

FIGURE 7 is a screenshot of a GUI **160** showing a dose distribution **162** of radiation in the patch section **84** and the through section **86**, while preserving the organ **124**, prior to execution of the patch algorithm (e.g., selection of the patch tool **142** of Figure 6) by the system.

FIGURE 8 is a screenshot of a GUI **180** showing optimized dose distribution **162** of radiation in the patch section **84** and the through section **86**, while preserving the organ **124**, after to execution of the patch algorithm (e.g., selection of the patch tool **142** of Figure 6) by the system.

FIGURE 9 illustrates a method for computer-aided editing of a 3D compensator model, in accordance with various aspects set forth herein. At **200**, the compensator is projected onto a patient image along with dose distribution in a beam's eye view **64** display (as seen in Fig. 2). At **202**, the user may step through anatomical slices of the patient image, and the projection of the compensator is adjusted accordingly. In this manner, an individual compensator pixel is traced back to the dose distribution and anatomical features, at **204**. At **206**, the user employs editing tools to edit the compensator pixels in the beam's eye view representation. The user changes the compensator pixels by adding, subtracting, averaging, etc. a value. At **208**, the user-entered changes cause an update in a 3-dimensational model of the compensator. 2-dimensional cross-sectional planes of the compensator are presented to the user to aid the user in visualization of the thickness gradients, at **210**. After the user edits the compensator, the dose distribution of the beam with the new compensator is re-computed, at **212**. At **214**, the re-computed dose distribution is compared to the original dose distribution. At **216**, the user can "undo" changes, accept changes, and/or or continue with further editing. At **218**, when completed, the edits can be saved as a final version of the compensator model, which can be used to construct the compensator.

FIGURE 10 illustrates a method for optimizing radiation dose for an irregularly-shaped target mass while mitigating unwanted irradiation of a nearby organ or the like, in accordance with various aspects described herein. At **230**, the target mass is segmented into a "patch" (e.g., distal) region and a "through" (e.g., lateral) region, and a junction therebetween is determined. At **232**, a three-dimensional "cut" of the target is made by the algorithm. The contours for the patch and the through beam's targets (e.g., the patch section and the beam section of the target mass, respectively) are treated separately and may be manually or automatically adjusted by the algorithm based on the dose distribution and properties of either the patch or through beams. The user can interact with the regions of interest contours that outline the target as well as the beam parameters to tailor the dose until satisfied, at **234**. The user can furthermore display the dose delivered to the target for evaluation and re-optimization, at **236**.

FIGURE 11 illustrates a method for performing inverse optimization and design of compensators used in radiotherapy treatments, in accordance with various aspects set forth herein. At **250**, a user sets goals or objectives for the dose distribution to certain points, organs or regions of the patient (e.g., a target mass and/or surrounding area). The user can specify how much dose as a range, uniformity, or biological equivalent effect a particular region should receive. At **252**, the user specifies a rank for each one of the objectives, which conveys the relative importance of meeting that objective. A computer system designs a compensator model and/or adjusts beam parameters including, but not limited to, the range and modulation, margins, and energy of the beam to meet the objectives, at **254**. At **256**, the user optionally includes uncertainties such as patient motion and image pixel-to-stopping power or density conversion for consideration during compensator design. After the computer system is finished calculating the compensator model, the user is given the opportunity to review the results and adjust the parameters further, which may necessitate a re-optimization, at **258**. The method is performed iteratively until the user is satisfied that the compensator model has been optimized, at which point the model is stored and/or output to a compensator machine that constructs the compensator.

The innovation has been described with reference to several embodiments. Modifications and alterations may occur to others upon reading and understanding the preceding detailed description. It is intended that the innovation be construed as including all such modifications and alterations insofar as they come within the scope of the appended claims or the equivalents thereof.

CLAIMS

Having thus described the preferred embodiments, the invention is now claimed to be:

1. A system (10) that facilitates optimizing a computer-generated 3D compensator model for use in radiotherapy treatment planning, including:

a graphical user interface (GUI) including a display (18) and a user input device (24);

a processor (12) that executes computer-executable instructions stored in a memory (14), the instructions including:

displaying on the display (18), to a user, a compensator model (22, 62);

receiving user input from the user input device (24) comprising edits to the compensator model (22, 62);

optimizing the compensator model (22, 62) based on the user input; and

storing the optimized compensator model to the memory (14) or computer-readable storage medium.

2. The system according to claim 1, the instructions further including:

displaying a plurality of editing tools to a user;

re-computing the radiation dose distribution based on the optimized compensator model; and

displaying the re-computed radiation dose distribution on the display;

wherein the compensator model (22, 62) is projected onto an anatomical patient image (20) with radiation dose distribution (42) overlaid on the patient image (20);

wherein the optimized compensator model is stored to the memory (14) or computer-readable storage medium upon user approval of the optimized compensator model.

3. The system according to any one of claims 1-2, the instructions further including:

stepping through and displaying a plurality of anatomical slices of the patient image (20); and

in response to receiving the user input edits, editing pixels (102) in the compensator model for each slice of the patient image (20).

4. The system according to any one of claims 1-3, the instructions further including:

displaying to the user, on the display, a plurality of 2D cross-sectional planes (66, 68) of the compensator model (22, 62) showing thickness gradients of the compensator model (22, 62) during optimization.

5. The system according to any one of claims 1-4, the instructions further including:

displaying, on the display, the optimized compensator model and an original compensator model to the user for comparison;

permitting the user to accept or reject changes to the original compensator model; and

in response to input from the user on the user input device, iteratively editing the compensator model.

6. The system according to any one of claims 1-5, the instructions further including:

outputting an optimized compensator model to a machine (46) that constructs a compensator according to the optimized compensator model.

7. The system according to any one of claims 1-6, the instructions further including:

inputting ranked radiation dose distribution objectives with the user input device;

optimizing the compensator model to meet the dose distribution objectives in the ranked order; and

displaying the optimized compensator model and dose distribution to the user on the display.

8. The system according to any one of claims 1-7, further including:

a compensator constructed using the optimized compensator model.

9. The system according to any one of claims 1-8, further including:

a radiation beam generator that generates a radiation beam that is passed through the compensator when treating a patient for whom the compensator is constructed;

wherein the radiation beam generator generates one of an ion beam and a proton beam.

10. A method of computer-aided compensator model optimization for compensators used in radiotherapy treatment, including:

displaying a compensator model on a patient image (20) of an anatomical region of a patient;

receiving user input edits to the compensator model (22, 62);

updating the compensator model (22, 62) based on the user input; and

storing the updated compensator model to memory (14) or computer-readable storage medium.

11. The method according to claim 10, further including:

computing a radiation dose distribution (42) for ion or proton beam radiation passing through the compensator model into the anatomical region;

displaying to a user the compensator model (22, 62) projected onto anatomical patient image (20) with the radiation dose distribution (42) overlaid on the patient image (20);

re-computing the radiation dose distribution based on the updated compensator model;

displaying the re-computed radiation dose distribution overlaid on the patient image; and

storing the updated compensator model to memory (14) or computer-readable storage medium upon user approval of the updated compensator model.

12. The method according to any one of claims 10-11, further including:

stepping through and displaying a plurality of anatomical slices of the patient image (20); and

receiving the user input comprising edits to pixels (102) in each slice of the patient image (20).

13. The method according to any one of claims 10-12, further including:

displaying to the user a plurality of 2D cross-sectional planes (66, 68) of the compensator model (22, 62) showing thickness gradients of the compensator model (22, 62).

14. The method according to any one of claims 10-13, further including:

displaying the updated compensator model and an original compensator model to the user for comparison;

permitting the user to accept or reject changes to the original compensator model; and

iteratively editing the compensator model until the compensator model is optimized.

15. The method according to claim 14, further including:

outputting an optimized compensator model to a machine that constructs a compensator according to the optimized compensator model.

16. The method according to any one of claims 10-15, further including:

receiving user input comprising ranked radiation dose distribution objectives;

optimizing the compensator model to meet the dose distribution objectives in the order in which they are ranked; and displaying the optimized compensator model and dose distribution to the user.

17. The method according to any one of claims 10-16, further including:

identifying lateral and distal sections of a computerized model of the target mass and a junction between the lateral and distal sections;

making a virtual cut in the model along the junction;

iteratively adjusting contours of the lateral and distal sections in order to optimize dose distribution; and

displaying dose distribution overlaid on a patient image that includes the target mass for user evaluation during dose distribution optimization.

18. A method of optimizing radiation dose distribution for an irregularly-shaped target mass in a patient while mitigating radiation dose to a nearby organ, including:

identifying lateral and distal sections of a computerized model of the target mass and a junction between the lateral and distal sections;

making a virtual cut in the model along the junction;

iteratively adjusting contours of the lateral and distal sections in order to optimize a radiation dose distribution (42); and

displaying dose distribution overlaid on a patient image that includes the target mass for user evaluation during dose distribution optimization.

19. The method according to claim 18, further including:

adjusting radiation beam parameters according to the optimized dose distribution; and

applying a proton or ion beam to the target mass in the patient according to the adjusted radiation beam parameters.

20. The method according to claim 18, further including:

overlaying a compensator model (22, 62) on a patient image (20) of an anatomical region of a patient;

computing the radiation dose distribution (42) for ion or proton beam radiation passing through the compensator model (22, 62) into the anatomical region;

displaying to a user the compensator model (22, 62) projected onto the patient image (20) with the radiation dose distribution (42) overlaid on the patient image (20);

receiving user input edits to pixels (102) in the compensator model (22, 62);

updating the compensator model (22, 62) based on the user input;

storing the updated compensator model to memory (14) upon user approval of the updated compensator model.

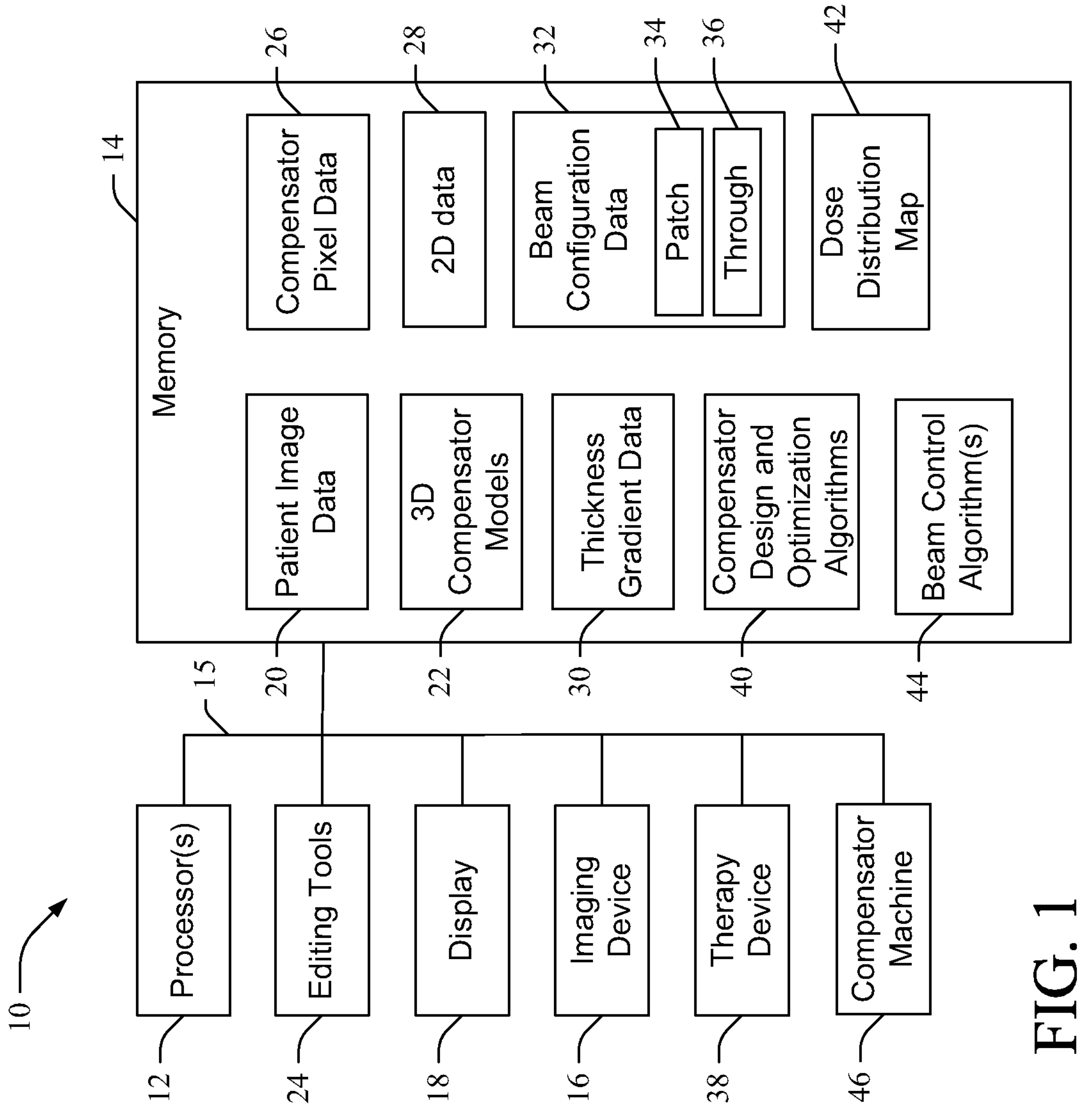

10
Processor(s)
Editing Tools
Display
Imaging Device
Therapy Device
Compensator Machine
12
24
18
16
38
46
15
Memory
14
Patient Image Data
3D Compensator Models
Thickness Gradient Data
Compensator Design and Optimization Algorithms
Beam Control Algorithm(s)
20
22
30
40
44
Compensator Pixel Data
2D data
Beam Configuration Data
Patch
Through
Dose Distribution Map
26
28
32
34
36
42

FIG. 1

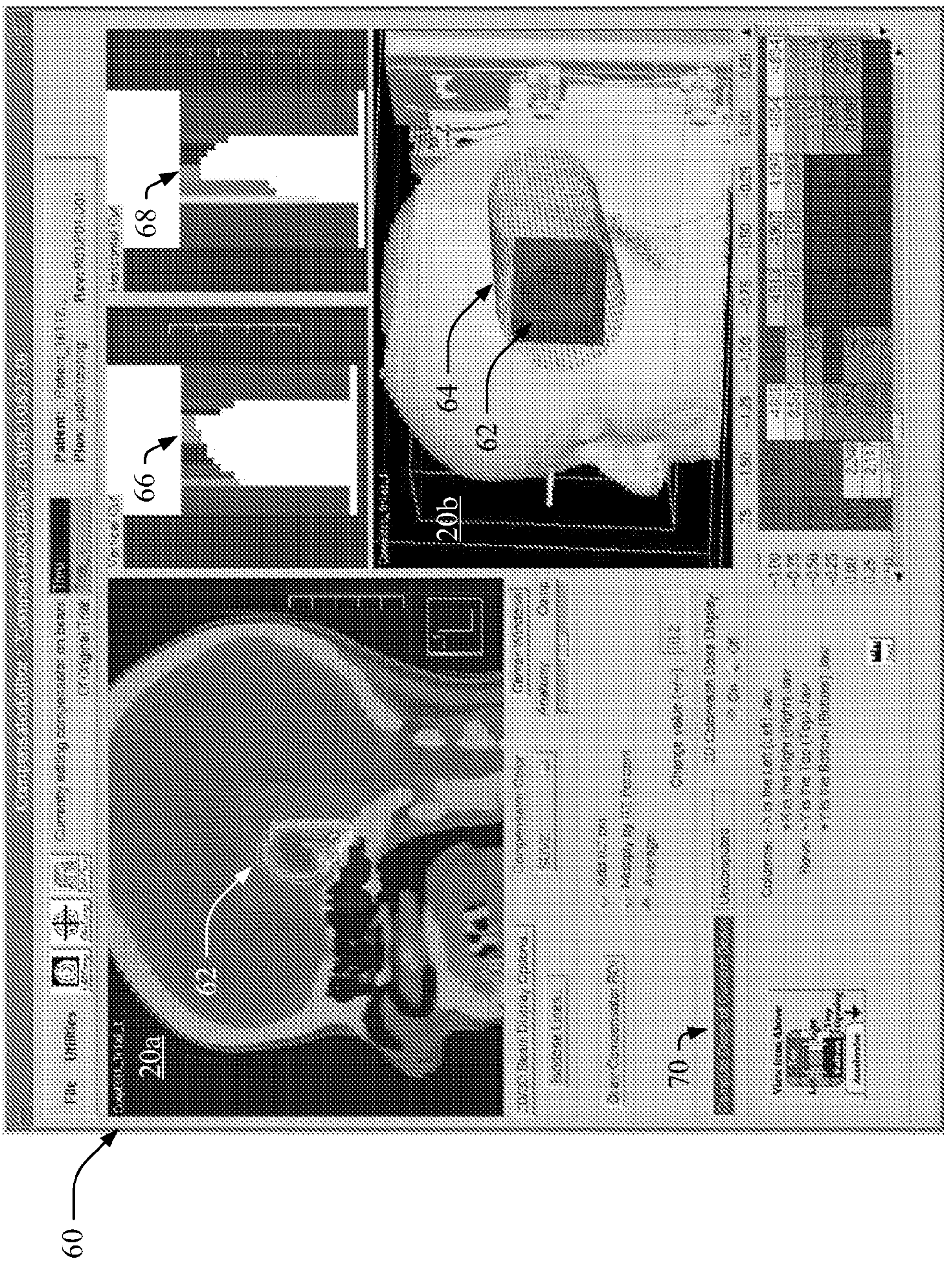


FIG. 2

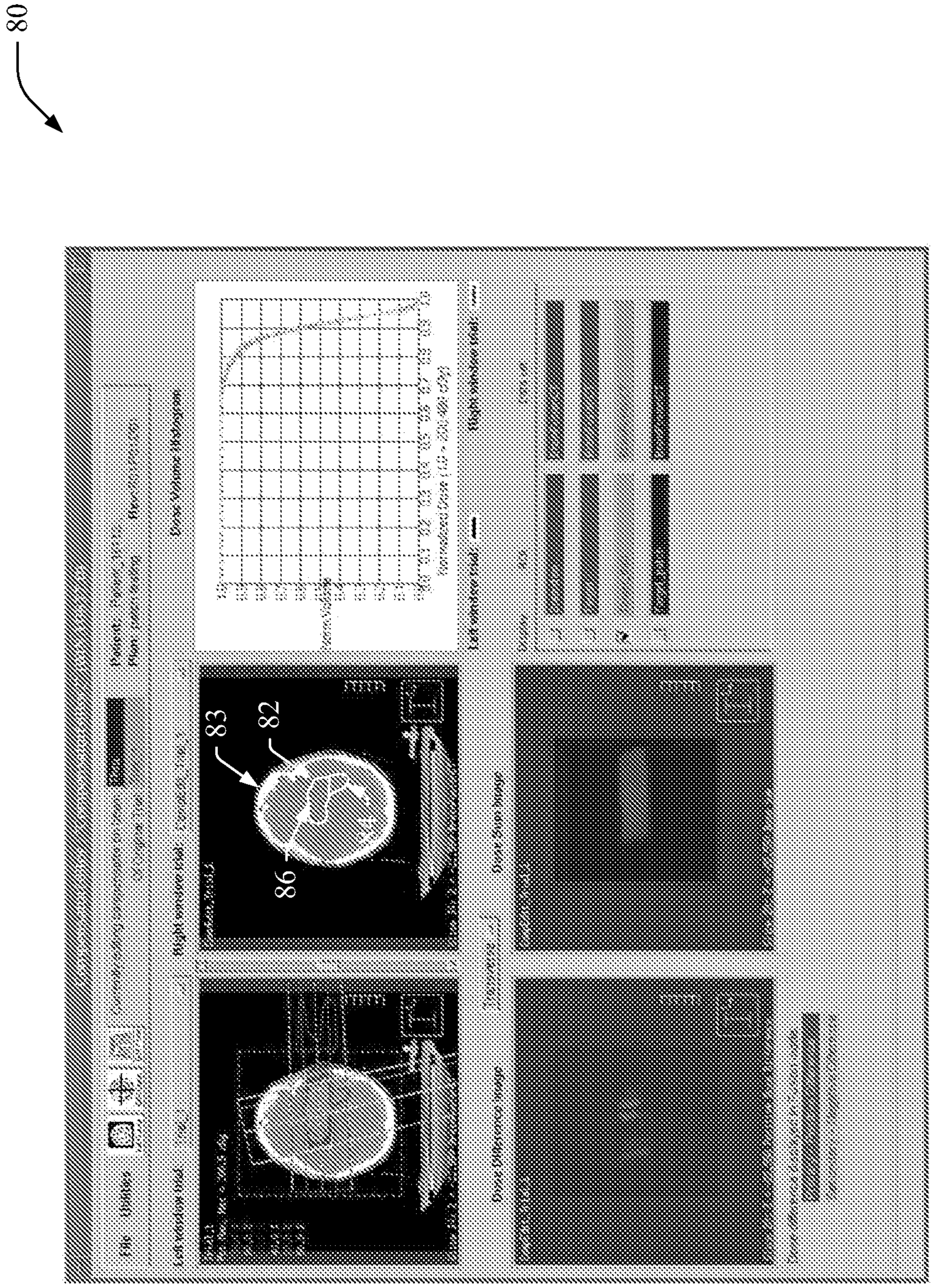


FIG. 3

100

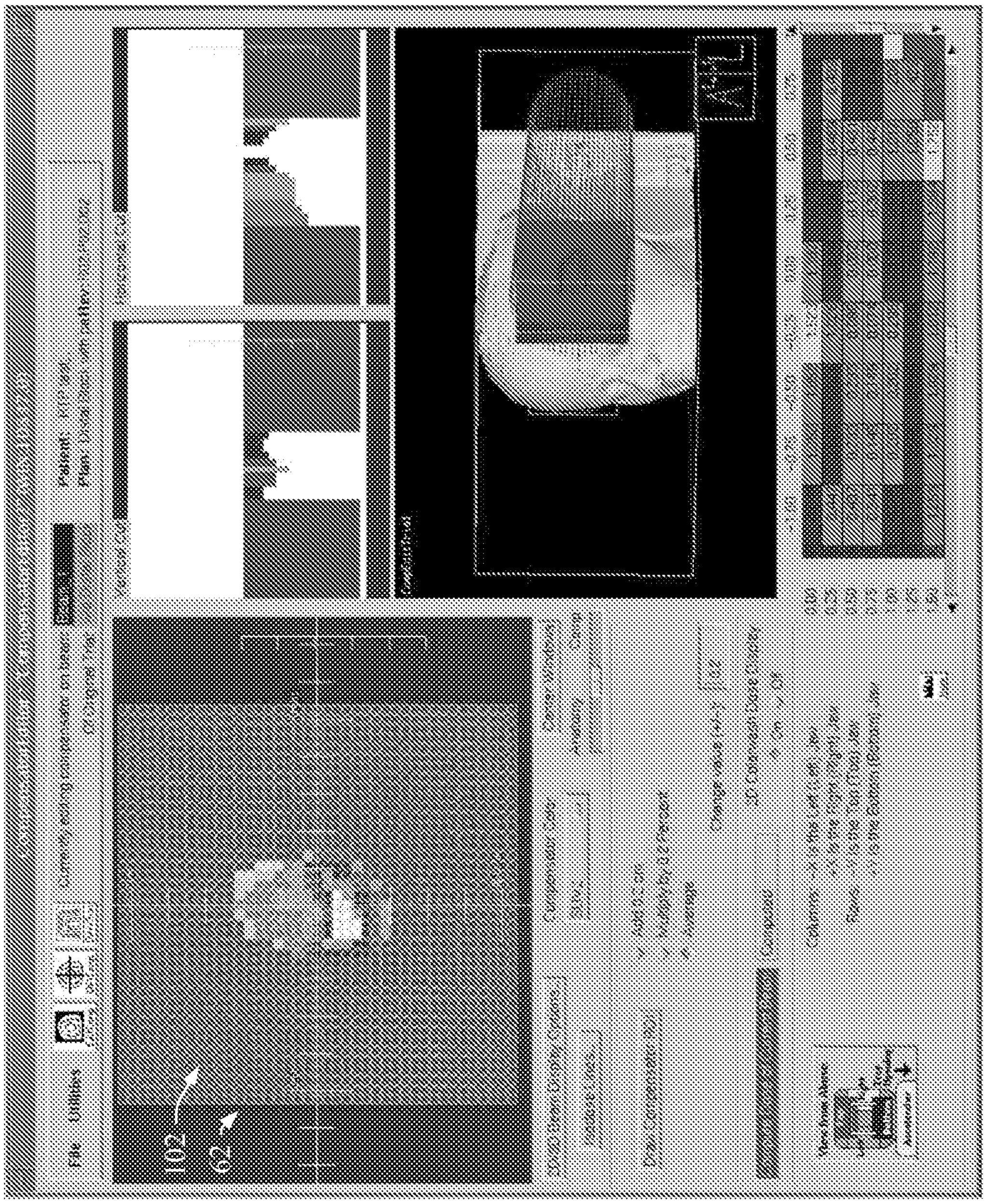


FIG. 4

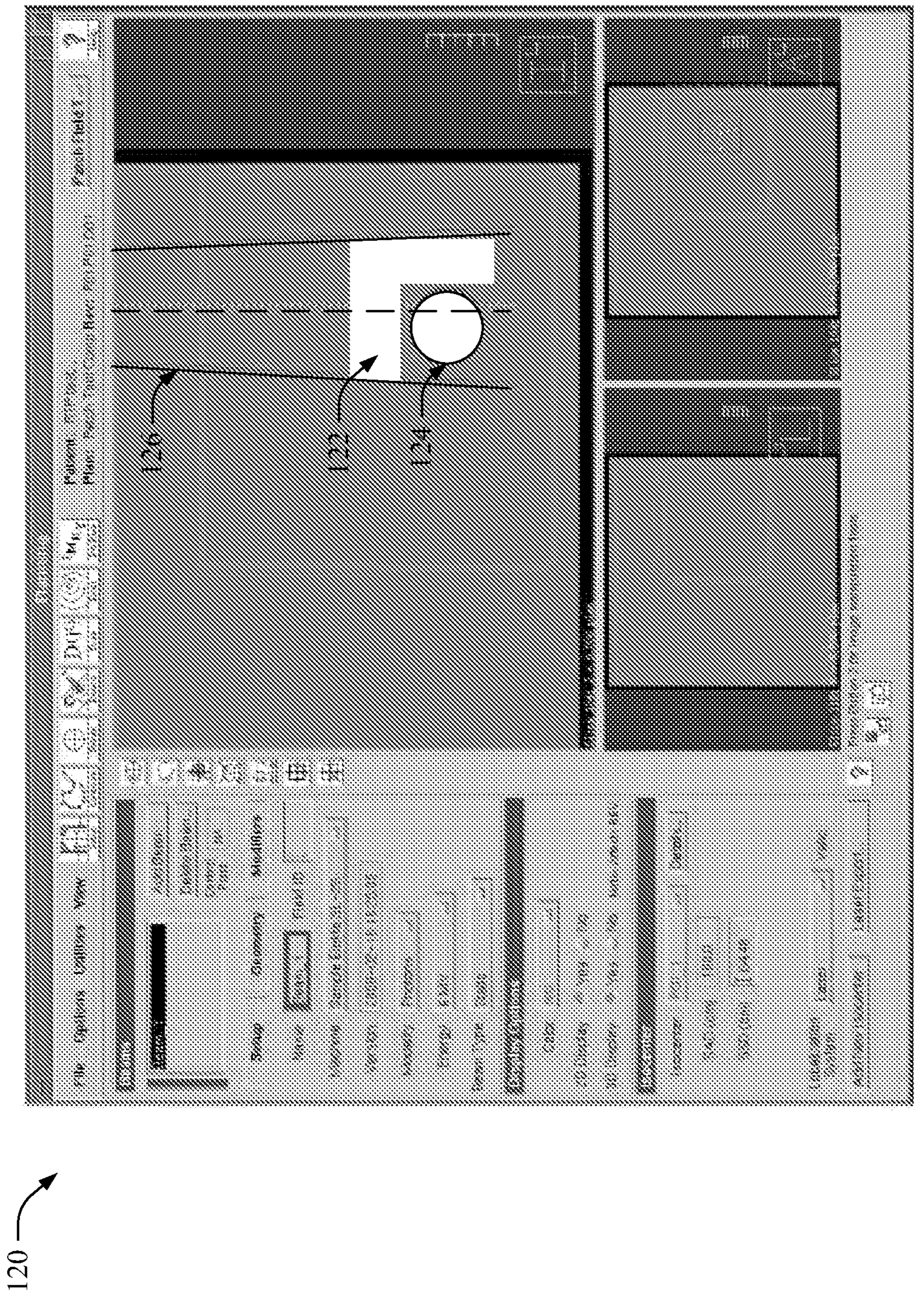


FIG. 5

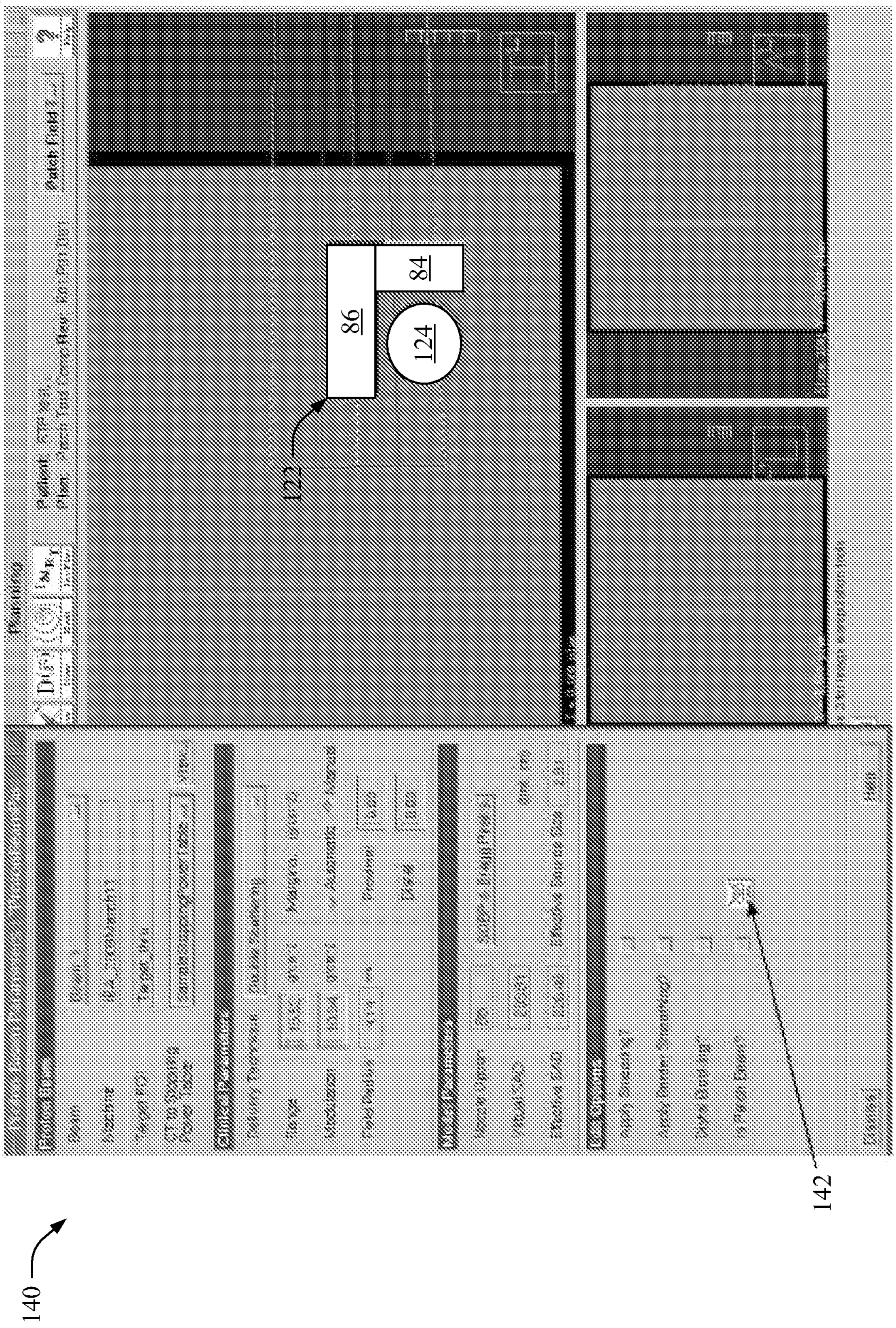
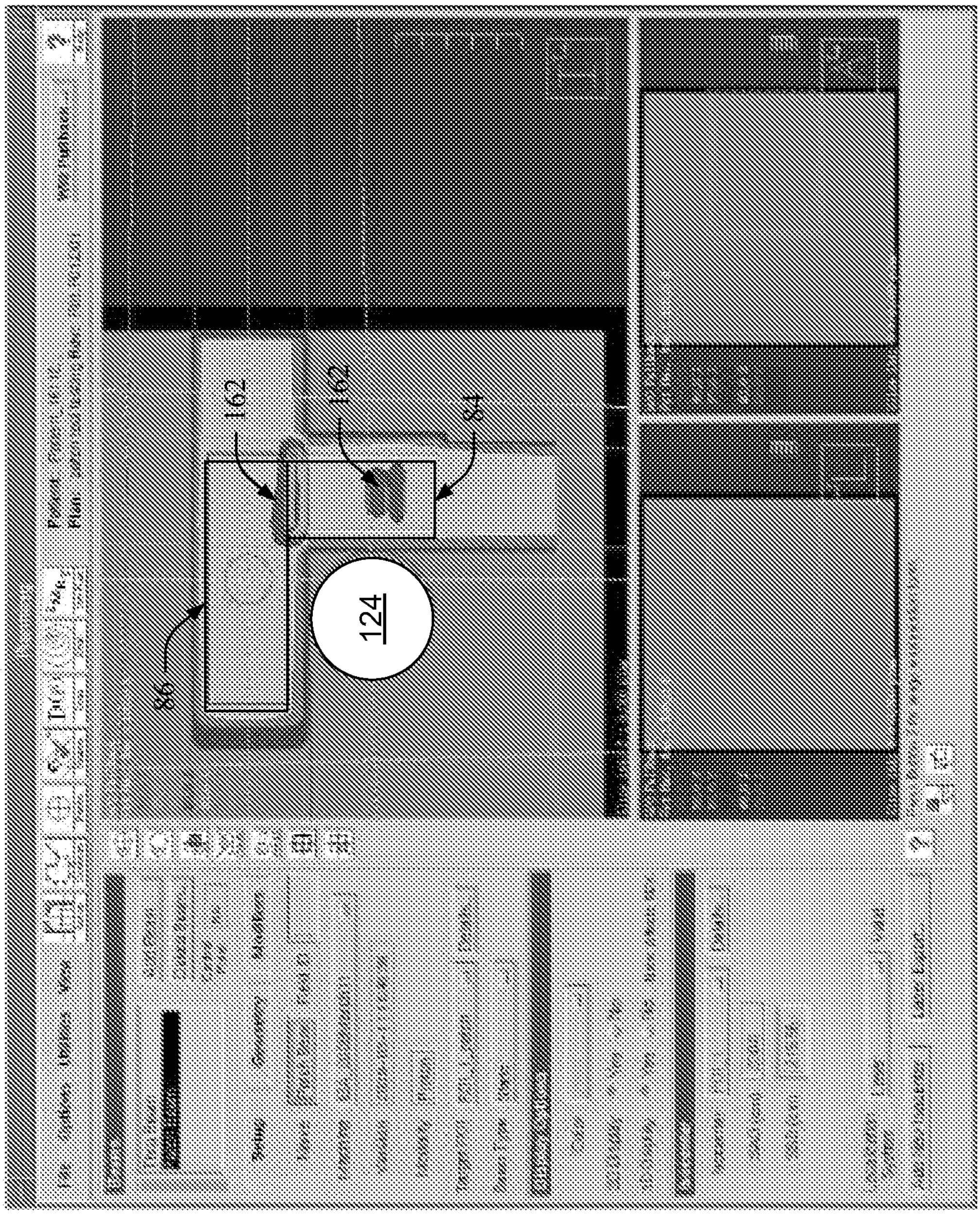


FIG. 6



160

FIG. 7

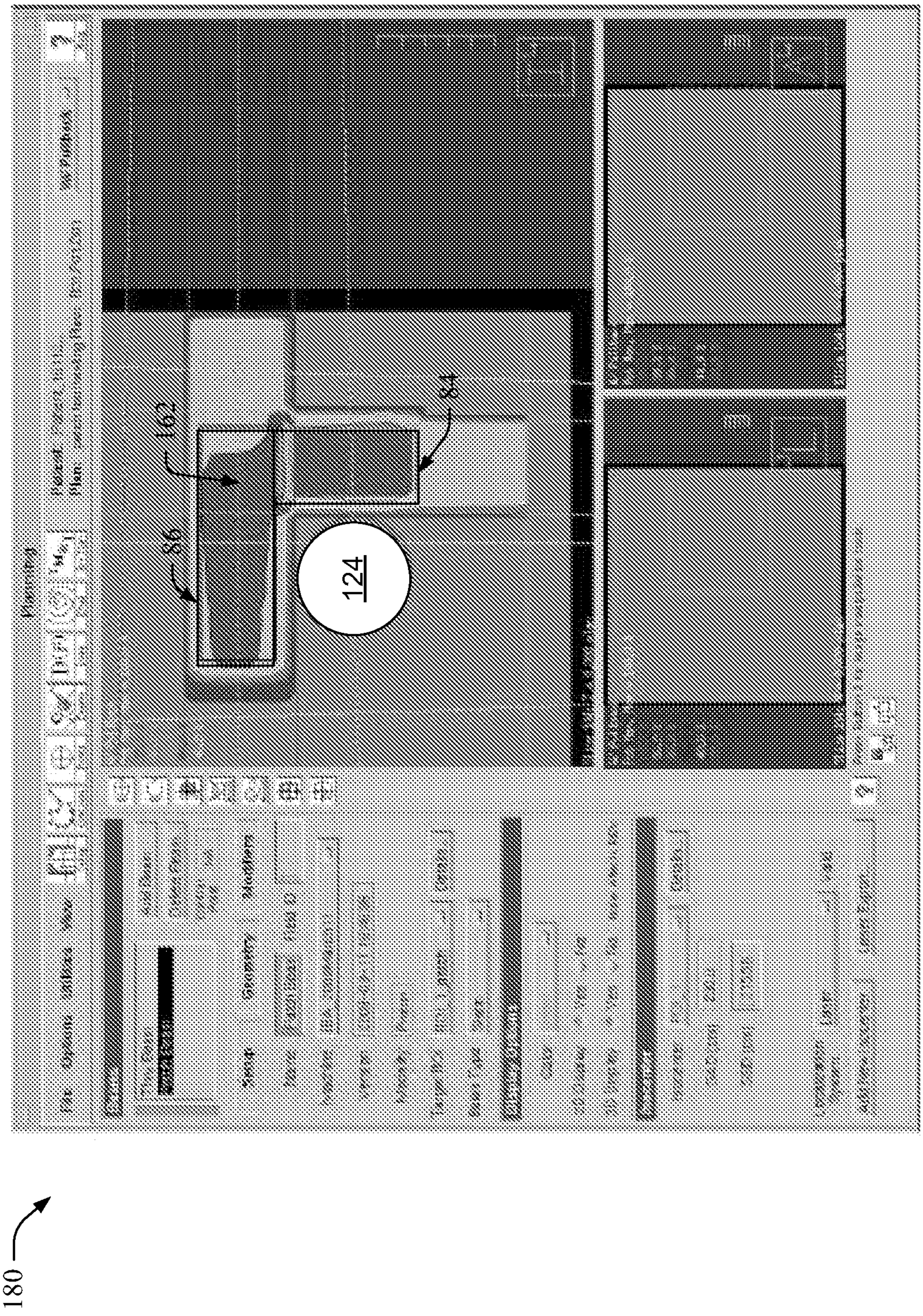


FIG. 8

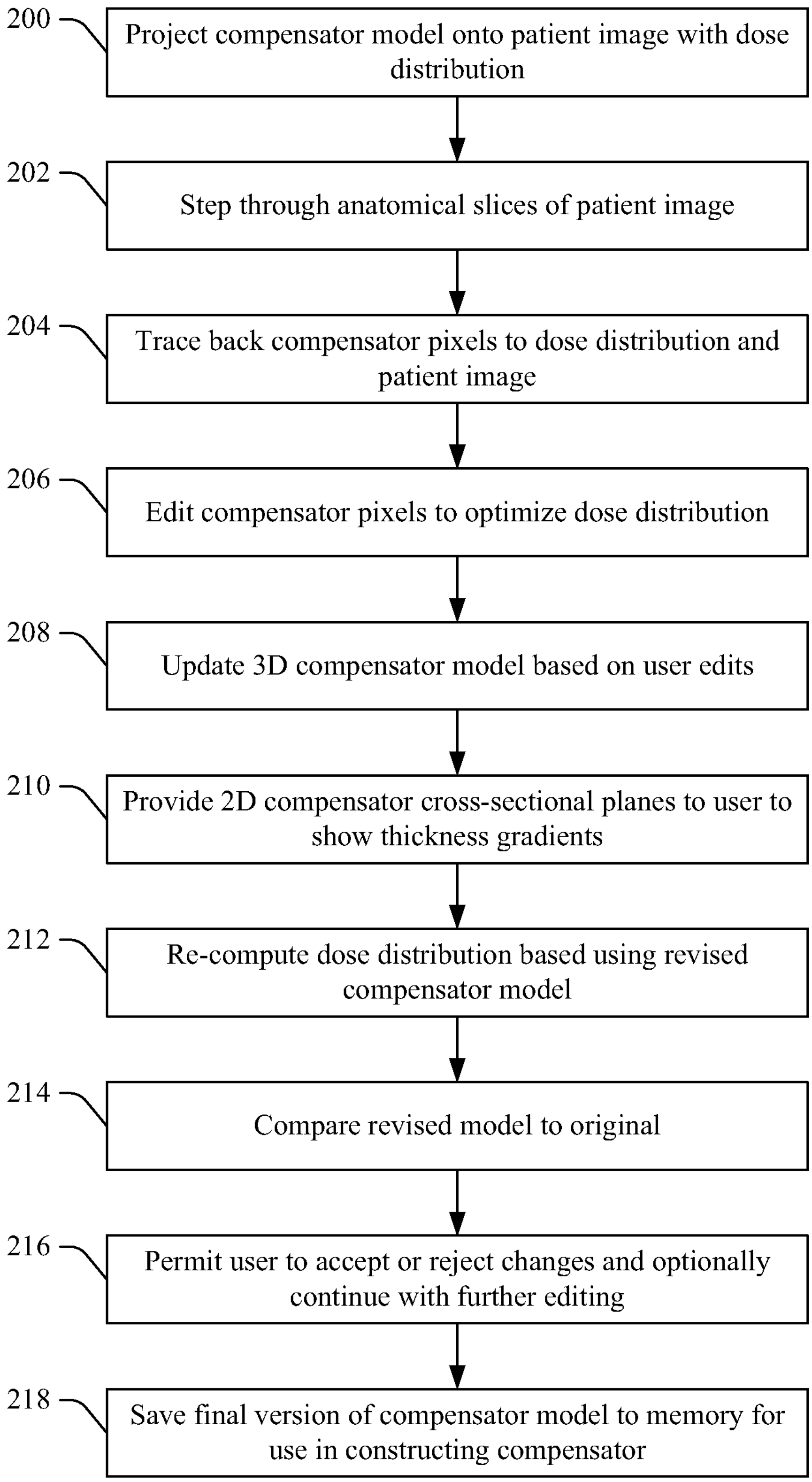

200
Project compensator model onto patient image with dose distribution
202
Step through anatomical slices of patient image
204
Trace back compensator pixels to dose distribution and patient image
206
Edit compensator pixels to optimize dose distribution
208
Update 3D compensator model based on user edits
210
Provide 2D compensator cross-sectional planes to user to show thickness gradients
212
Re-compute dose distribution based using revised compensator model
214
Compare revised model to original
216
Permit user to accept or reject changes and optionally continue with further editing
218
Save final version of compensator model to memory for use in constructing compensator

FIG. 9

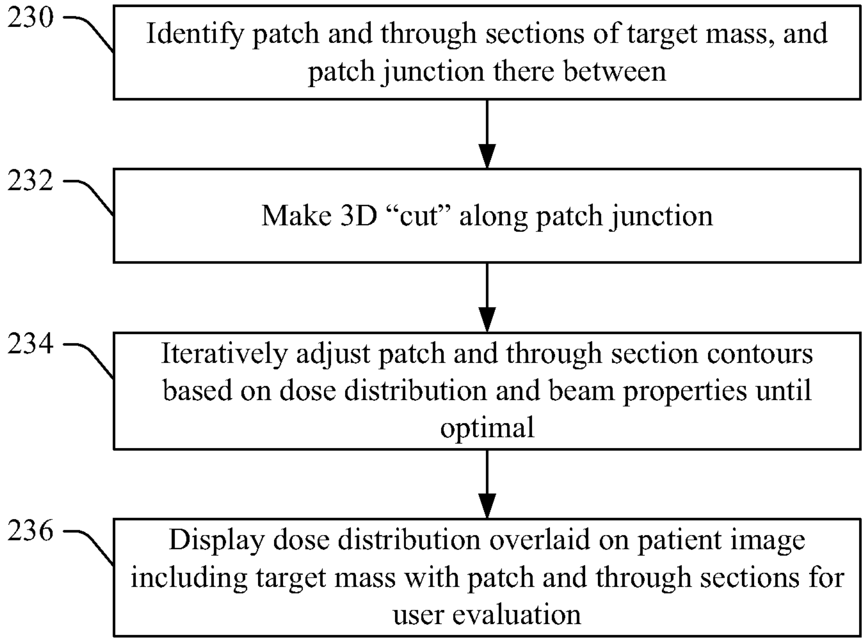

230
Identify patch and through sections of target mass, and patch junction there between
232
Make 3D "cut" along patch junction
234
Iteratively adjust patch and through section contours based on dose distribution and beam properties until optimal
236
Display dose distribution overlaid on patient image including target mass with patch and through sections for user evaluation

FIG. 10

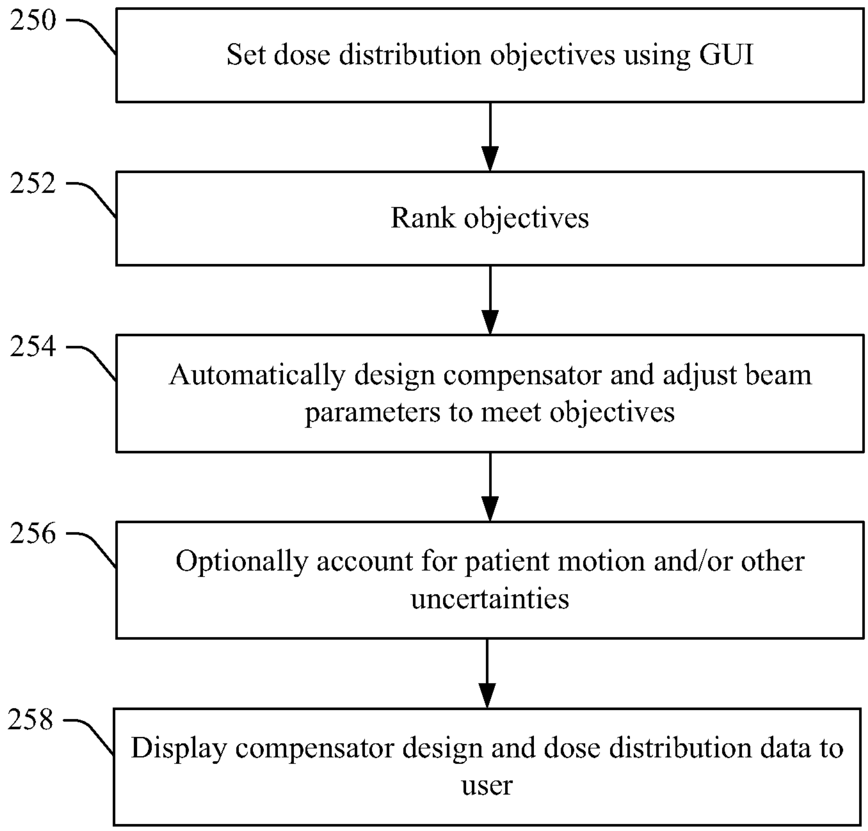

250
Set dose distribution objectives using GUI
252
Rank objectives
254
Automatically design compensator and adjust beam parameters to meet objectives
256
Optionally account for patient motion and/or other uncertainties
258
Display compensator design and dose distribution data to user

FIG. 11

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2010/053156

A. CLASSIFICATION OF SUBJECT MATTER
INV. G06F19/00 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)
G06F A61N

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)

EPO-Internal, WPI Data, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GOODBAND J H ET AL: "A mixture of experts committee machine to design compensators for intensity modulated radiation therapy" PATTERN RECOGNITION, ELSEVIER, GB LNKD- DOI:10.1016/J.PATCOG.2006.03.018, vol. 39, no. 9, 1 September 2006 (2006-09-01), pages 1704-1714, XP025226809 ISSN: 0031-3203 [retrieved on 2006-09-01] abstract page 1705, left-hand column, paragraph 3 - page 1706, right-hand column, paragraph 1 page 1711, right-hand column, paragraph 1 - page 1713, left-hand column, paragraph 1 figures 1,3 ----- -/--	1-17

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

[ ] See patent family 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
8 November 2010	25/01/2011

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, Fax: (+31-70) 340-3016	Hilbig, Matthias

Form PCT/ISA/210 (second sheet) (April 2005)

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	PETTI P L: "New compensator design options for charged-particle radiotherapy" PHYSICS IN MEDICINE AND BIOLOGY IOP PUBLISHING UK, vol. 42, no. 7, July 1997 (1997-07), pages 1289-1300, XP002608556 ISSN: 0031-9155 abstract page 1289, paragraph 1 - page 1293, last paragraph page 1299, paragraph 2 - last paragraph figures 1,2	1-17
X	WILKS R J ET AL: "The use of a compensator library to reduce dose inhomogeneity in tangential radiotherapy of the breast" RADIOTHERAPY AND ONCOLOGY ELSEVIER IRELAND, vol. 62, no. 2, February 2002 (2002-02), pages 147-157, XP002608557 ISSN: 0167-8140 abstract page 148, left-hand column, paragraph 2 - page 152, left-hand column, paragraph 1 page 153, right-hand column, paragraph 1 - page 154, left-hand column, last paragraph figure 1	1-17
X	JURKOVIC ET AL: "An alternative approach to compensators design for photon beams used in radiotherapy" NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH, SECTION - A:ACCELERATORS, SPECTROMETERS, DETECTORS AND ASSOCIATED EQUIPMENT, ELSEVIER, AMSTERDAM, NL LNKD- DOI:10.1016/J.NIMA.2007.05.222, vol. 580, no. 1, 29 August 2007 (2007-08-29), pages 530-533, XP022218399 ISSN: 0168-9002 abstract page 530, left-hand column, paragraph 1 - page 532, left-hand column, paragraph 2 figures 1,2	1-17
X	KANEMATSU N ET AL: "Tumour shapes and fully automated range compensation for heavy charged particle radiotherapy" PHYSICS IN MEDICINE AND BIOLOGY IOP PUBLISHING UK, vol. 49, no. 2, 21 January 2004 (2004-01-21), pages N1-N5, XP002608558 ISSN: 0031-9155 the whole document	1-17

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB2010/053156

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-17

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-17

   System and method that facilitate optimizing a computer-generated 3D compensator model for use in radiotherapy treatment planning.

   ---

2. claims: 18-20

   Method of optimizing radiation dose distribution for an irregularly-shaped target mass in a patient while mitigating radiation dose to a nearby organ.
