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(19) **United States**(12) **Patent Application Publication**
GU et al.(10) **Pub. No.: US 2022/0249874 A1**(43) **Pub. Date: Aug. 11, 2022**(54) **A COMPACT DOSIMETRIC DATA
COLLECTION PLATFORM FOR A BREAST
CANCER STEREOTACTIC RADIOTHERAPY
SYSTEM****Related U.S. Application Data**

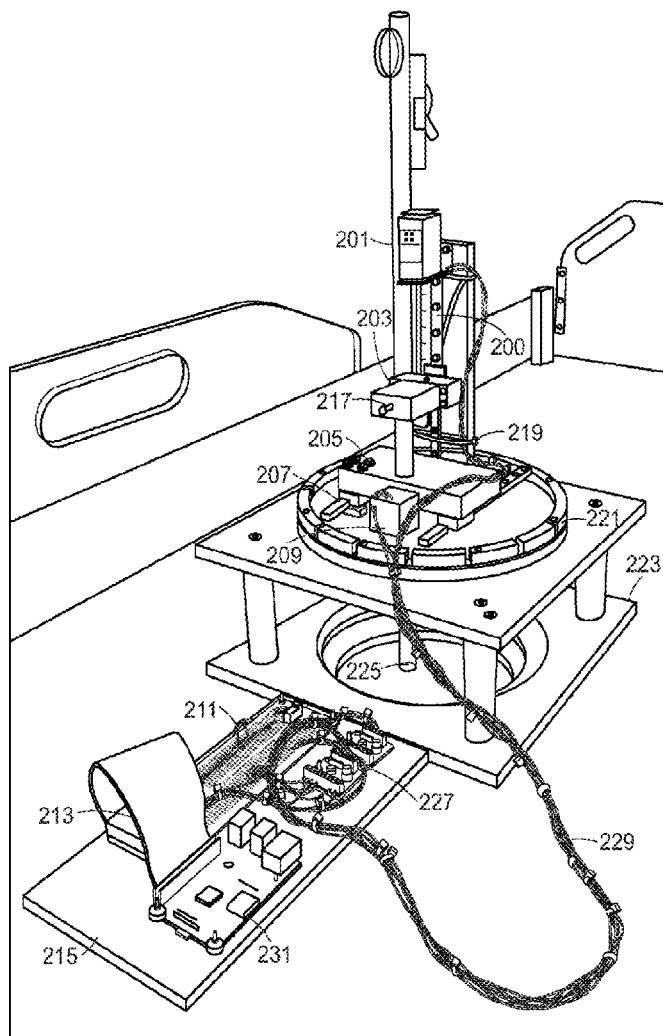
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THE UNIVERSITY OF TEXAS
SYSTEM**, Austin, TX (US)(57) **ABSTRACT**

The present disclosures describes a remotely controlled stereotactic radiotherapy system. The system may include a gamma-ray irradiation system for radioablation of a target region of human tissue, the system having an irradiating unit configured to produce a radiation field, and a processor remote from the gamma-ray irradiation system configured to control the dosage and position of the radiation field applied to the target region.

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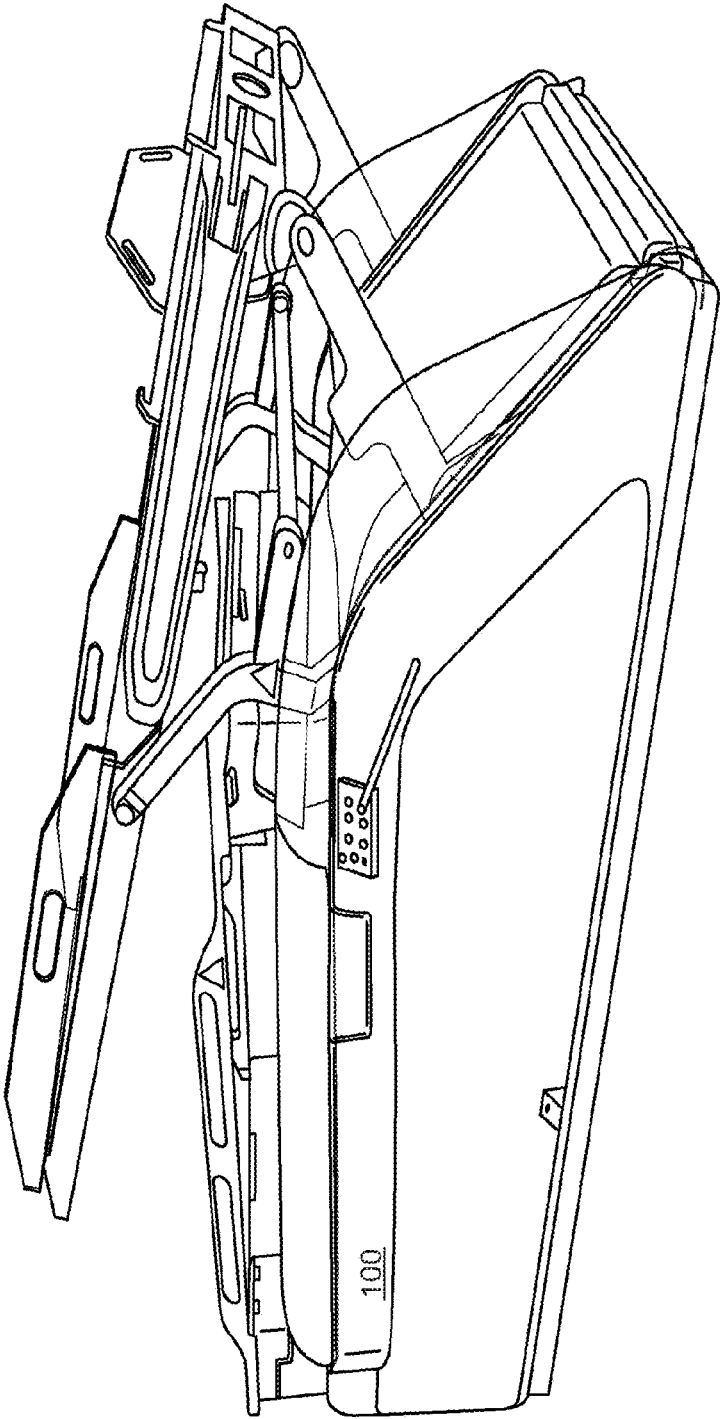


FIG. 1

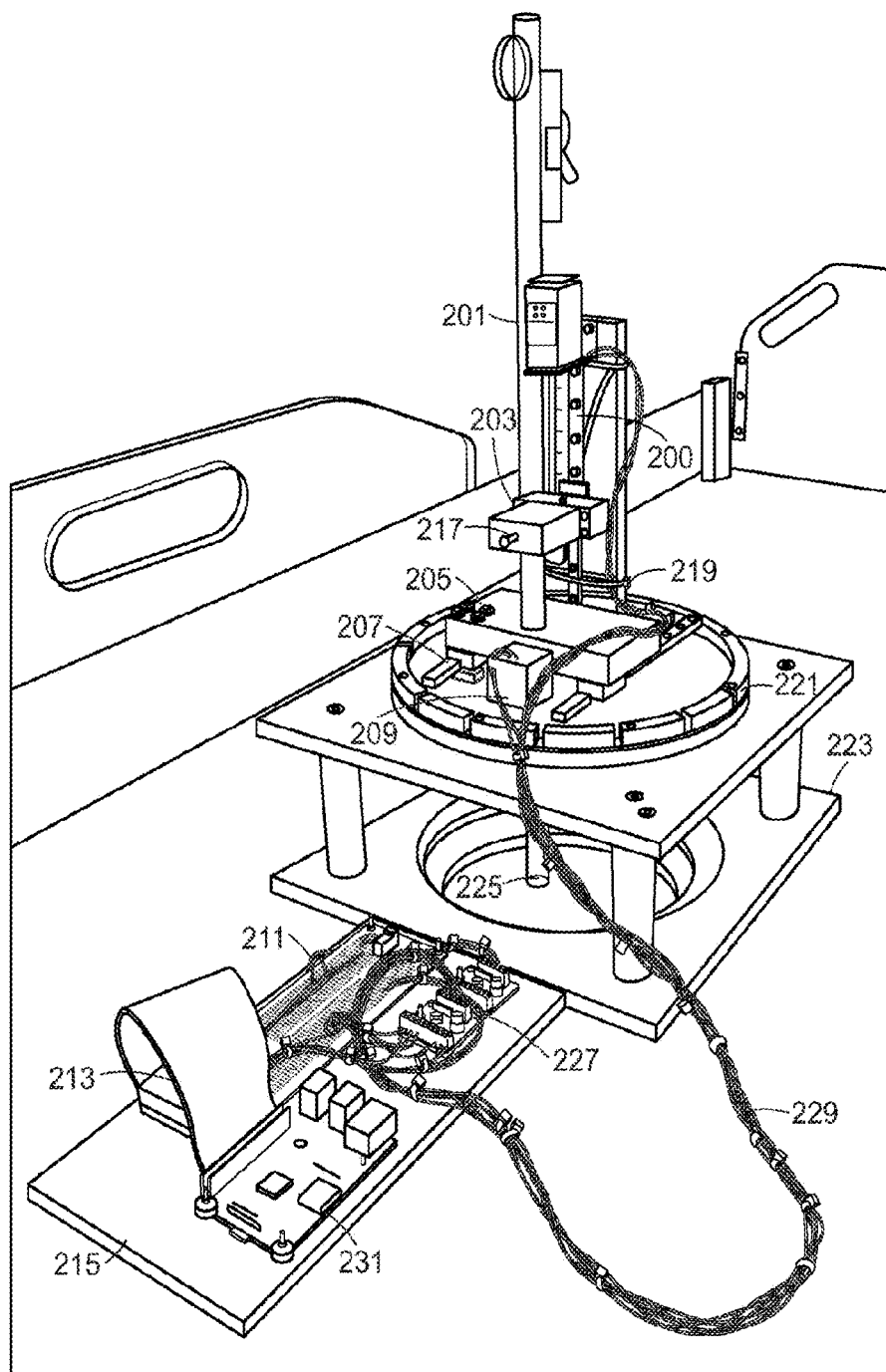


FIG. 2A

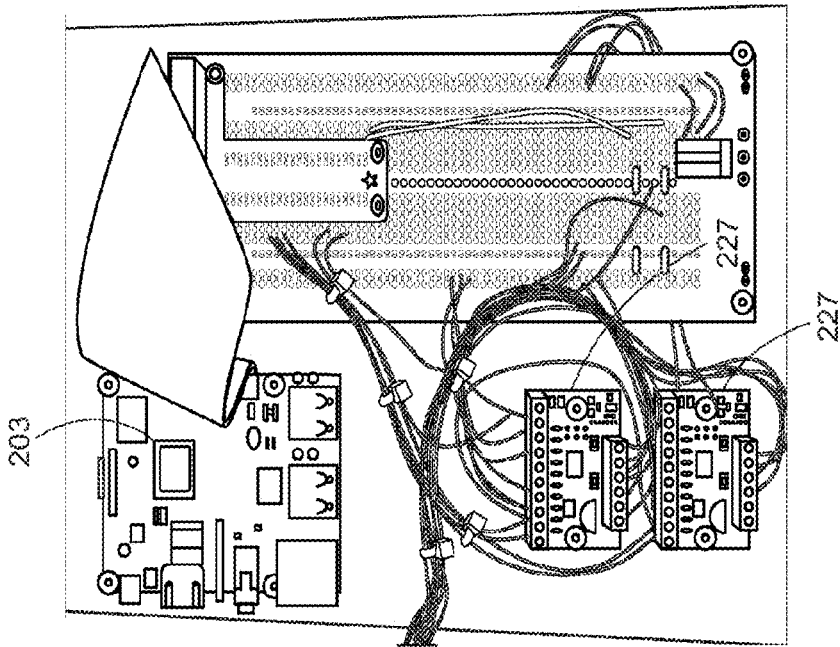


FIG. 2C

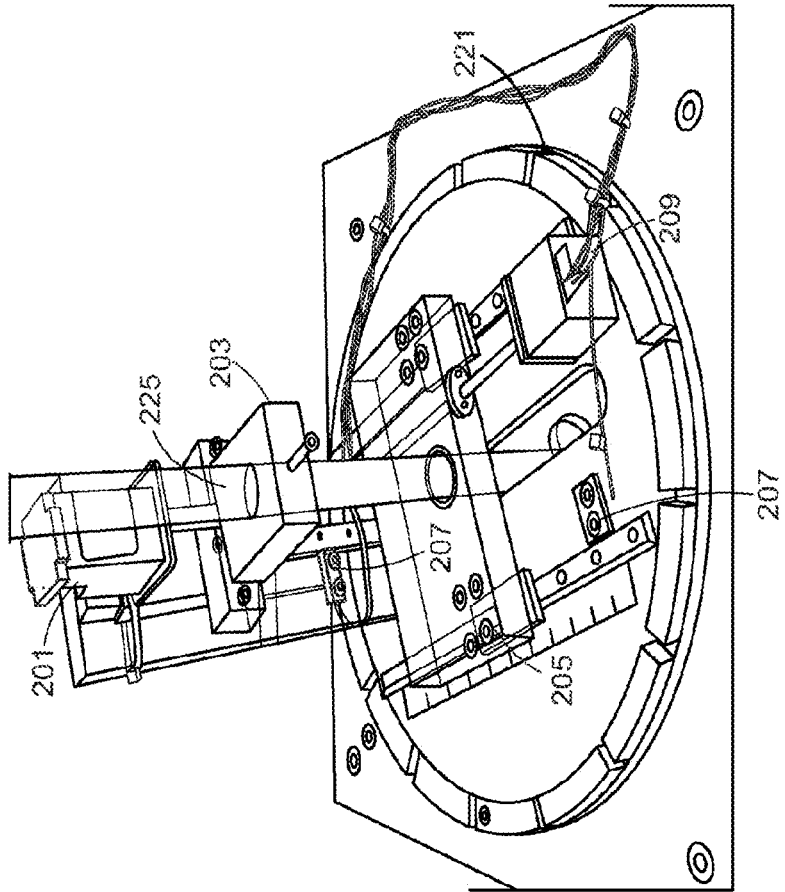


FIG. 2B

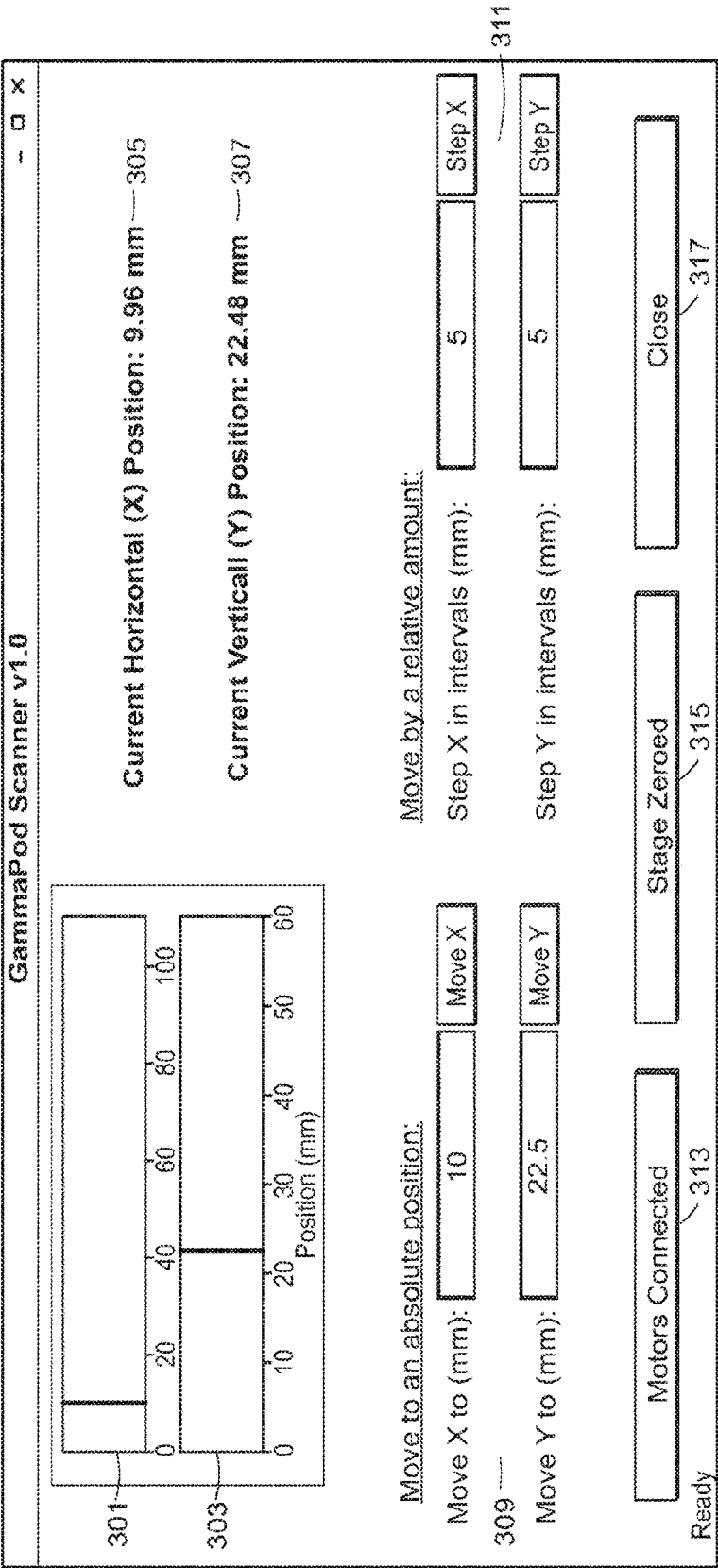


FIG. 3

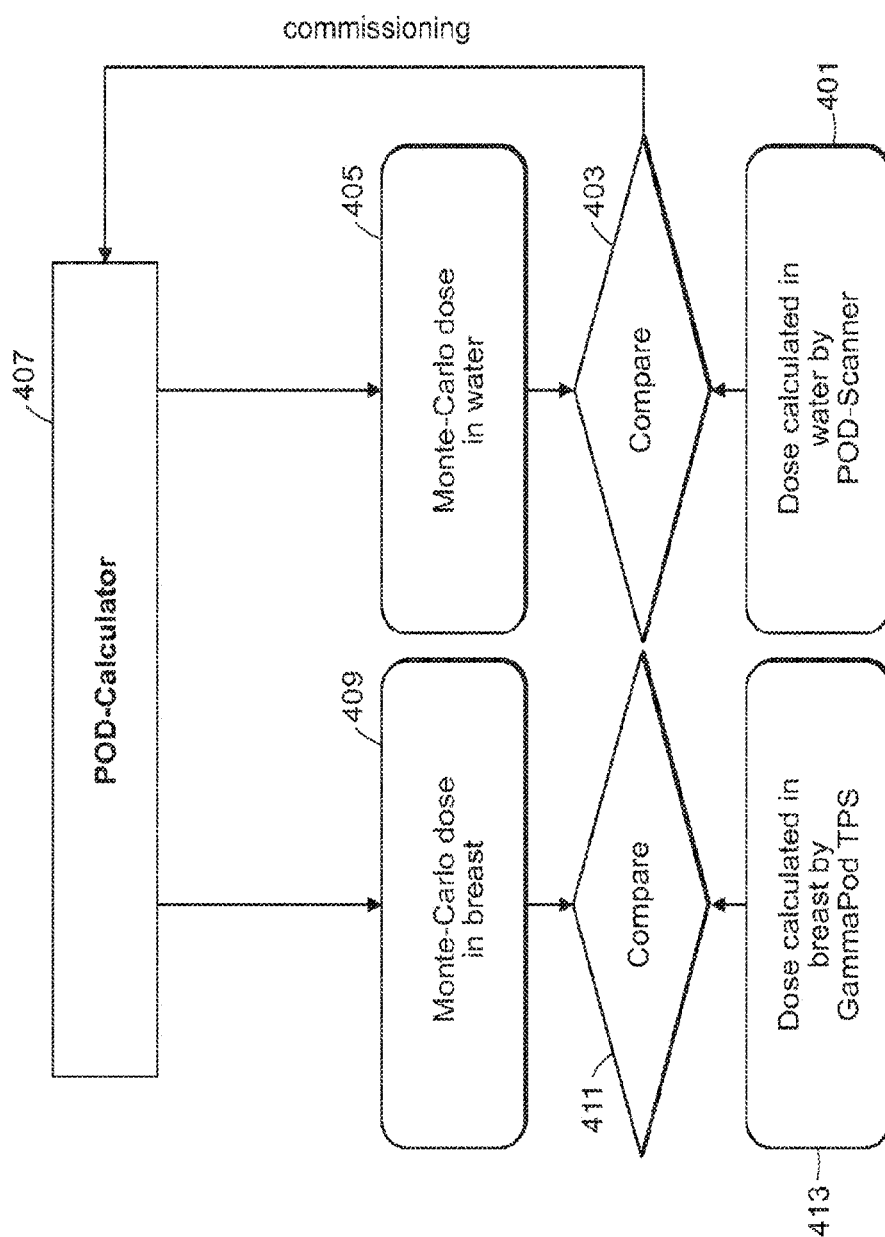


FIG. 4

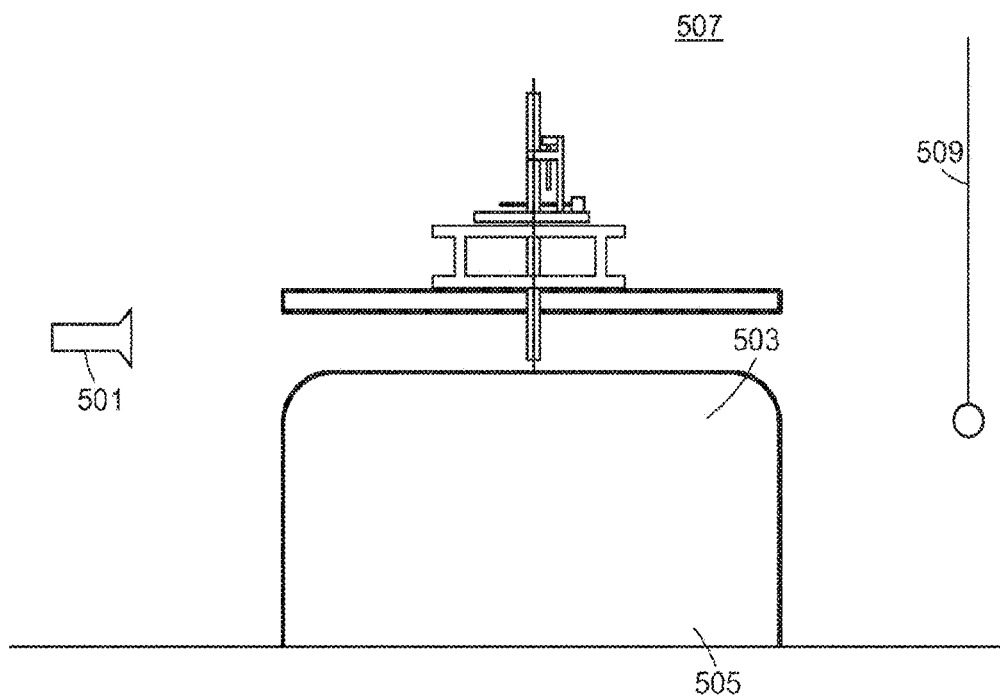


FIG. 5A

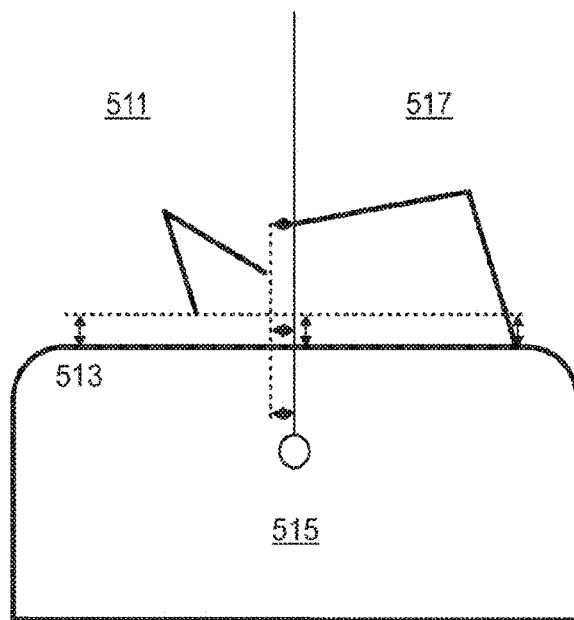


FIG. 5B

A COMPACT DOSIMETRIC DATA COLLECTION PLATFORM FOR A BREAST CANCER STEREOTACTIC RADIOTHERAPY SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority from U.S. Provisional Application Ser. No. 62/873,501, filed Jul. 12, 2019, and U.S. Provisional Application Ser. No. 62/873,515, filed Jul. 12, 2019, which are hereby incorporated by reference in their entireties. The present disclosure is also related to the PCT application entitled “Independent Stereotactic Radiotherapy Dose Calculation and Treatment Plan Verification,” filed concurrently herewith, and incorporated by reference in its entirety.

TECHNICAL FIELD

[0002] The present disclosure is directed to a stereotactic radiotherapy system.

BACKGROUND

[0003] A stereotactic radiotherapy system is configured to apply ionizing radiation to a targeted location, such as a cancerous tumor located in the breast tissue or brain.

[0004] Examples of a stereotactic radiotherapy system include a GammaPod™ and a GammaKnife™, as described in Yu et al, “Gammapod-A New Device Dedicated for Stereotactic Radiotherapy of Breast Cancer”, Med Phys. 40(5) (May 2013), the contents of which is hereby incorporated by reference.

[0005] In stereotactic radiotherapy sessions one or more radiation sources may be distributed over a range of angles and used to apply a focused dose of radiation at a target area. A stereotactic radiotherapy system may be configured to include components that rotate continuously, creating thousands of beam angles that combine with one another to create an intense focal spot to apply radiotherapy. This method allows the surrounding healthy tissue to be spared.

[0006] For example, in the GammaPod™ 25-36 radiation sources of Cobalt-60 are distributed over a range of latitudinal angles in a hemispherical structure to form multiple Gamma-ray beams aiming at the same isocenter or target location. The entire GammaPod™ structure is configured to rotate during treatment, creating multiple non-overlapping conical arcs to achieve highly focused dose distribution. In conventional systems, dosimetric data collection in connection with a stereotactic radiotherapy system is manually conducted. In particular, for each data point collection, a radiation worker or physicist enters the radiation treatment vault and manually positions the chamber. In order for the radiation worker or physicist to safely enter the radiation treatment vault, the stereotactic radiotherapy system must be placed in an idle position (e.g., jaw and source of the stereotactic radiotherapy system fully closed), which creates extensive delays in the ability to collect dosimetric data. For example, conventional systems for acquisition of beam data may require several weeks to acquire beam data.

[0007] Further, there remains a need to provide mechanisms for quality control of stereotactic radiotherapy systems, including for the verification of treatment plans. For example, the unique mechanical design and treatment planning system (TPS) of the GammaPod™ system poses chal-

lenges associated with system commissioning and the continued determination of quality assurance (QA) metrics.

SUMMARY

[0008] Embodiments in accordance with the present disclosure provide a remotely controlled stereotactic radiotherapy system where data collection may also be conducted and controlled remotely, from outside of the treatment vault. The remote control of the ion-chamber position of the stereotactic radiotherapy system allows for the more accurate positioning of the ion-chamber, a reduction in time needed for data collection (e.g. reduction in radiation profile scan time from hours to minutes), and reduces the risk of radiation exposure to a radiation worker. Further, the use of an automated, remote control system may also eliminate human induced chamber positioning error.

[0009] In some embodiments, a system includes a gamma-ray irradiation system for radioablation of a target region of human tissue having an irradiating unit configured to produce a radiation field, and a processor remote from the gamma-ray irradiation system configured to control the dosage and position of the radiation field applied to the target region.

[0010] In some embodiments, the disclosed system includes an automatic ion-chamber positioning system that is driven by two translational stepper motors for anterior-posterior, longitudinal and lateral beam scanning. The stepper motors may be controlled by a microcomputer through a graphical user interface. The graphical user interface may be remotely accessed by a user computing system. The disclosed system may be used for system commissioning and dose verification.

[0011] In some embodiments, a compact beam scanner system includes a gamma-ray irradiation system for radioablation of a target region of human tissue having an irradiating unit configured to produce a radiation field, and a compact beam scanner configured to determine beam data for the gamma-ray irradiation system, and wherein a processor of the compact beam scanner controls the operation of the gamma-ray irradiation system.

[0012] Optionally, the compact beam system may also include a user computing device with a graphical user interface, where the graphical user interface is configured to receive user input for positioning and display current positional data, and the user computing device controls the operation of the compact beam scanner. Further, in some embodiments, the user computing device may be positioned in a room remote from a treatment room including the compact beam scanner. The compact beam scanner may include a vertical positioning platform configured to translate the gamma-ray irradiation system along a vertical axis, a horizontal positioning platform configured to translate the gamma-ray irradiation system along a horizontal axis, and a rotational platform having a base. In such an embodiment, the vertical positioning platform and horizontal positioning platform may be positioned on top of the rotational platform and the connected to the base of the rotational platform via a rotational bearing. Optionally, at least one of the vertical positioning platform, horizontal positioning platform, and rotational platform comprises at least one of polyethylene, metal, stainless steel, aluminum and molded plastic. Optionally, the position of at least one of the vertical positioning

platform, horizontal positioning platform and rotational platform is driven by a stepper motor controlled by the user computing device.

[0013] In some embodiments, a method for commissioning a stereotactic radiotherapy device may include the steps of engaging a compact beam scanner with a stereotactic radiotherapy device, initializing one or more platforms of the compact beam scanner, determining a radiation center by coarsely scanning a target area, and obtaining beam data from the radiation center by finely scanning the target area. The method may also include the steps of determining a baseline for quality assurance metrics by performing a plurality of fine scans of the target area, and averaging the plurality of fine scans. Optionally, the beam data may be determined for at least one of the x, y, or z axis of the stereotactic radiotherapy device. Optionally, the operation of the compact beam scanner may be driven by user input into a graphical user interface on a user computing device positioned outside of a treatment room including the compact beam scanner. In some embodiments, engaging a compact beam scanner with the stereotactic radiotherapy device includes the steps of aligning the compact beam scanner to the stereotactic radiotherapy device using an alignment jig and placing an ion chamber of the stereotactic radiotherapy device within a holder of the compact beam scanner. In some embodiments, initializing the one or more platforms of the compact beam scanner includes initializing one or more stepper motors configured to control the position of a horizontal platform and a vertical platform of the compact beam scanner, where the horizontal platform is positioned to the middle and the vertical platform is positioned to its limit, and lowering the holder of the compact beam scanner to a water surface. Optionally, coarsely scanning a target area has a resolution between about 3 to 5 mm. Optionally, finely scanning a target area has a resolution at about 1 mm. Additionally, optionally, finely scanning a target area further may include starting an electrometer integration charge for a time period between about 30 to 60 seconds, resetting the electrometer, and moving to a new collection point in the target area using the stepper motors.

[0014] In some embodiments, a compact beam scanner includes a vertical positioning platform configured to translate a gamma-ray irradiation system along a vertical axis, where the gamma-ray irradiation system is configured to radioablate a target region of human tissue and includes an irradiating unit configured to produce a radiation field, a horizontal positioning platform configured to translate the gamma-ray irradiation system along a horizontal axis, and a rotational platform comprising a base, wherein the vertical positioning platform and horizontal positioning platform are positioned on top of the rotational platform and the connected to the base of the rotational platform via a rotational bearing.

[0015] Optionally, the compact beam scanner may include at least one stepper motor configured to control the position of at least one of the vertical positioning platform, horizontal positioning platform and rotational platform. The compact beam scanner may also include a processor configured to control the at least one stepper motor, and the processor may be configured to receive instructions from a graphical user interface displayed on a user computing device. The compact beam scanner may also include an alignment jig configured to align the compact beam scanner to gamma-ray irradiation system. The compact beam scanner may also

include a holder configured to receive an ion chamber of the gamma-ray irradiation system.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] For a more complete understanding of the present invention and for further features and advantages, reference is now made to the following description, taken in conjunction with the accompanying drawings, in which:

[0017] FIG. 1 illustrates a stereotactic radiotherapy system in accordance with some embodiments of the present disclosure.

[0018] FIG. 2A illustrates a prototype for a stereotactic radiotherapy system in accordance with some embodiments of the present disclosure.

[0019] FIG. 2B illustrates a component of the prototype for a stereotactic radiotherapy system illustrated in FIG. 2A in accordance with some embodiments of the present disclosure.

[0020] FIG. 2C illustrates a second component of the prototype for a stereotactic radiotherapy system illustrated in FIG. 2A in accordance with some embodiments of the present disclosure.

[0021] FIG. 3 illustrates a graphical user interface for a stereotactic radiotherapy system in accordance with some embodiments of the present disclosure.

[0022] FIG. 4 illustrates a graphical user interface for a stereotactic radiotherapy system in accordance with an embodiment of the present disclosure.

[0023] FIG. 5A illustrates an experimental setup for a stereotactic radiotherapy system in accordance with some embodiments of the present disclosure.

[0024] FIG. 5B illustrates an experimental setup for a stereotactic radiotherapy system in accordance with some embodiments of the present disclosure.

DETAILED DESCRIPTION

[0025] Disclosed herein are embodiments of a remotely controlled stereotactic radiotherapy system that can be used for system commissioning and dose verification. Embodiments of the present disclosure include an automatic ion-chamber positioning system driven by two translational stepper motors for anterior-posterior, longitudinal and lateral beam scanning. The stepper motors may be controlled by a microcomputer through a graphical user interface, which can be remotely accessed by a user computing device (i.e., laptop, tablet, cell phone, desktop) via a communication network (i.e., wireless connection, Ethernet connection, etc.).

[0026] FIG. 1 illustrates a stereotactic radiotherapy system, and in particular, a GammaPod™ system 100. As illustrated in FIG. 1, a patient lies in a prone position, and radiation may be applied to a target area (e.g., breast tissue). Main components of the depicted stereotactic radiotherapy system include a top shielding door, the shielding body, radiation source carrier, collimator, and patient support system, as described in Yu et al., "Gammapod-A New Device Dedicated for Stereotactic Radiotherapy of Breast Cancer", Med Phys. 40(5) (May 2013), the contents of which is hereby incorporated by reference.

[0027] Stereotactic radiotherapy systems are designed to achieve high quality breast cancer radiotherapy treatments by delivery of highly-tumoricidal doses in a short treatment course (one to five fractions), while reducing radiation

damages to surrounding normal tissues. To ensure the accurate and precise dose delivery by the stereotactic radiotherapy system, it is imperative to design and follow comprehensive, rigorous protocols for initial system commissioning and routine periodic quality assurance (QA).

[0028] Commissioning is a key step prior to the clinical release of radiation delivery systems. During commissioning relevant machine and radiation beam parameters are characterized and collected to build and verify dose calculation models. Optionally, the calculation models may be used in connection with the treatment planning system (TPS) of the stereotactic radiotherapy system.

[0029] Commissioning simultaneously establishes the baseline parameters for periodic QA. QA is routinely performed to detect potential machine deviations from the commissioned standards. A comprehensive QA program includes machine mechanical/safety checks, dosimetric measurements, and patient-specific treatment plan verifications through independent dose calculations or in-phantom dose measurements.

[0030] The unique design of stereotactic radiotherapy systems such as the GammaPod™ system, and the unique features of the related treatment planning system, GammaPod™ TPS, render the relevant commissioning and QA of the GammaPod™ system less straightforward and more challenging than that for conventional teletherapy systems.

[0031] Distinct from conventional medical linear accelerators, the current GammaPod™ system comprises 25 Cobalt-60 sources encased in a rotating, dual-layer, hemispherical collimator/source carrier bowl and a 3-dimensional motion-enabled couch. The outer shell of the dual-layer bowl serves as a source carrier hosting 25 non-overlapping Cobalt-60 sources. The inner shell of the bowl is made of blocks and holes featuring collimators with two cone sizes: 15 mm and 25 mm. The relative angular offset between the collimator and carrier shells determines the status of radiation off, 15 mm cone open, or 25 mm cone open. The source carrier and the collimator shells rotate in synchrony so that all 25 sources revolve around the isocenter to create crossfire radiation beams. The treatment couch is configured to hover above the collimator assembly. During treatment delivery, a patient is configured to lie in a prone position on the treatment couch, with the targeted breast vacuumed within a stereotactic breast cup, and anchored through the couch via a locking mechanism. The targeted breast is inserted into the collimator/carrier bowl.

[0032] The couch then moves continuously along three axes, which translates the targeted breast within the dual-layer bowl system, for dose painting to achieve highly-conformal radiation treatment. The diameter of the hemispherical bowl is limited in design, considering a trade-off between factors including the Cobalt-60 source strength, the dose rate at isocenter, and the treatment range. For example, the diameter of the GammaPod™ bowl may take into consideration factors such as source strength, dose rate, and treatment range. More specifically, the bowl may include more shielding if the radiation source is of greater strength in order to attenuate the radiation when not in the largest cone. Further, the greater the distance between the outer diameter and radiation center, the longer the treatment will take, due in part to the dose rate falling off in accordance with the inverse square law (by a factor of the radius of the bowl squared). Further, the diameter may also take into account the fact that the smaller the diameter, the smaller the

size of the breast area that can be placed into the bowl, and the range that the breast can be moved in the bowl is impacted, thus changing the treatment range per patient section.

[0033] As a result of the unique design of stereotactic radiotherapy systems such as the GammaPod™ system, commercially-available water tank systems which are used for commissioning are too large and cannot fit into this limited space to scan beam profiles during commissioning. To address this problem, film dosimetry is used in conventional applications for profile measurements. However, due to the inherent uncertainties of film dosimetry, the profiles measured with films may not be sufficiently accurate to establish and/or evaluate a dose calculation model. Accordingly, there was a need to design a robust and efficient dose profile measurement system that can be used for the commissioning of non-conventional stereotactic radiotherapy devices, such as GammaPod™.

[0034] Further, in conventional stereotactic radiotherapy devices, data collection from the devices may not be configured to be controlled from outside of the treatment vault. For example, due to the nature of how GammaPod™ functions and the design of the treatment vault, to collect a second data point at an additional location in space through manual means involves retracting the measurement device from machine radiation center, closing the cobalt shielding, opening the vault dose, moving the data collection device and then doing the reverse (closing vault, opening shielding, lowering the data collection equipment to machine radiation center). As such, the process for obtaining beam data per data point takes a prolonged time 5-10 mins in conventional systems. Disclosed herein are systems and methods that allow for robotically moving the data collection point in space, which subsequently leads to obtaining beam data in shorter time periods than in conventional systems. For example, a compact beam scanner built in accordance with the disclosed embodiments may be positioned outside of a room containing the ion chamber (data collection device), and controlled robotically with the compact beam scanner. Accordingly, the time between data collection points may be reduced from several minutes to 1-10 seconds (depending on the distance between measurements).

[0035] Discussed herein is a dedicated, compact beam profile scanner, optionally referred to as POD-Scanner, that is capable of automatic, accurate and efficient GammaPod™ beam scanning and dosimetric measurements, for use in commissioning, and quality assurance (QA).

[0036] FIG. 2A illustrates a prototype for a stereotactic radiotherapy system 200, and more particularly a compact beam profile scanner, in accordance with some embodiments of the present disclosure. In some embodiments, the compact beam profile scanner of FIG. 2A may be used in connection with a GammaPod™ device. Further, in FIG. 2A the prototype for the compact beam profile scanner used in connection with a stereotactic radiotherapy system is illustrated as being positioned on a GammaPod™ couch with ancillary electronics.

[0037] FIG. 2A provides a robotic dosimetry system including a compact beam profile scanner (i.e., The POD-Scanner), that is configured to facilitate beam data acquisition and plan dosage measurement of a stereotactic radiotherapy device such as GammaPod™. In some embodiments, the disclosed robotic dosimetry system may enable remote, automatic navigation and positioning of

radiation detectors (ion chamber, for instance), without the necessity to manually adjust the detector position point-by-point in the vault. It reduces the potential errors associated with manual radiation detector positioning. It also substantially reduces the beam scanning time. Because in conventional systems, the manual, point-by-point beam scanning requires the radiation to be turned on and off, and the vault door to be opened and closed for each measurement point, conventional systems suffer from long beam scanning times.

[0038] By contrast, using the robotic dosimetry system disclosed herein, a profile can be continuously acquired outside the vault with minimal interruptions. The disclosed systems include a hardware component, which locks onto the GammaPod™ couch to navigate the radiation detector within the hemispherical collimator/source carrier bowl, and a software component that can remotely control the motion of the radiation detector via a wireless connection.

[0039] As illustrated in FIG. 2A, the compact beam profile scanner (i.e., The POD-Scanner) may include a gamma-ray irradiation system **200** that is configured to radioablate a target region of human tissue. The gamma-ray irradiation system **200** may include a vertical stepper **201** configured to control the vertical positioning of a vertical positioning platform **203**. The gamma-ray irradiation system **200** may also include a horizontal positioning platform **205** driven by a horizontal stepper **209**. The gamma-ray irradiation system **200** may also include a positioning switch **207**. Accordingly, the device may be configured to translate in horizontal and vertical directions. Further, in some embodiments, the gamma-ray irradiation system **200** may be rotated (either manually or automatically). For example, an angular step ring **221** may be configured to rotate at 22.5 degree angle per step.

[0040] The stage may be configured to be positioned above the irradiation source (e.g., Cobalt-60). For example, as depicted, the ion chamber positioning tube **225** may be positioned below the support platform **223** and stage. The ion chamber tube may be held by a tension screw **217**. In some embodiments, cabling may be secured to the assembly by a zip tie **219** or similar element.

[0041] As illustrated, the ion-chamber of the stereotactic radiotherapy system **200** may be attached to the chamber positioning tube **225** and the chamber positioning tube is attached to step motors **201**, **209** on the motion stage. In some embodiments, each step motor controls one direction of motion (e.g., horizontal, vertical).

[0042] In other embodiments, the vertical positioning platform **203** and the horizontal positioning platform **205** are positioned on top of a rotational platform. Accordingly, the system may operate under cylindrical coordinates. In such an embodiment, the positioning system including the horizontal positioning platform **205** and vertical positioning platform **203** may be connected to a base via a rotation bearing, which makes the rotational platform. In some embodiments, the rotational bearing may be between about 200 and 300 mm in size, and optionally, 250 mm.

[0043] The base may be composed of two polyethylene plates with a 200 mm opening to host the rotational bearing. Optionally, each of the polyethylene plates may be between about 1 and 2 cm in thickness, and optionally, 2 cm-thick. The two polyethylene plates may be connected by four polyethylene pillars. In some embodiments, the pillars may have a radius between about 1 and 2 cm, and optionally 2 cm-radius each. Although polyethylene plates and pillars are

described, it is envisioned that metal, stainless steel or aluminum components having smaller radius and thickness may be used. Alternatively, molded plastic may be used.

[0044] Translations of the positioning system are enabled through two stepper motors one for vertical positioning and the other for horizontal positioning. Both stepper motors may allow a fine motion resolution. For example, the stepper motors may allow a fine motion resolution of 0.0254 mm per step. The horizontal positioning may have a travel range of 110 mm, enabled by two linear rail bearings. Similarly, the vertical positioning may have a travel range of 60 mm, enabled by one linear rail bearing. Greater vertical positioning travel ranges such as 100 mm, 120 mm, etc. are envisioned.

[0045] The radiation detector may be held inside a plastic tube, which is attached to the positioning system via a tension screw. This tube may be adopted from water tank, made of acrylic and used for holding reference chamber in conventional LINAC beam scanning. The tube may be in cylindrical shape. For example, in some embodiments the tube may have a diameter of 15.0 mm and length 500.0 mm and wall thickness of 2.2 mm. Additionally, a 3D printed attachment may be manufactured to reproducibly center the chamber in the acrylic tube.

[0046] Through the vertical motor, the radiation detector moves anterior-posteriorly in the patient coordinate (y axis of the GammaPod™ coordinate). Depending on the angle of the rotational platform, the radiation detector also moves either longitudinally (z axis of the GammaPod™ coordinate) or laterally (x axis of the GammaPod™ coordinate) in the patient coordinate, or along directions in between, when driven by the horizontal motor. In some embodiments, the system manually rotates the rotational platform to adjust the horizontal scan direction, with an angular step size of 22.5°.

[0047] The gamma-ray irradiation system **200** may be communicatively coupled to a processor unit **211** including a circuit board. The processor unit **211** may also include a connection ribbon **213**, and be positioned along a 3D printed base **215**. The processor unit **211** may also include one or more stepper drive boards **227** configured to control the operation of the vertical stepper **201** and/or the horizontal stepper **209**. The processor unit **221** may include a micro-processor **231** such as a RaspberryPi.

[0048] In some embodiments, the gamma-ray irradiation system **200** may be communicatively coupled to the processor unit **211** via a wired connection including electrical and/or logical cables **229**, or wirelessly.

[0049] In some embodiments, the gamma-ray irradiation system **200** may include an irradiating unit configured to produce a radiation field. Further, the processing unit **211** may be remote from the gamma-ray irradiation system **200** and configured to control the dosage and position of the radiation field applied to the target region (e.g., breast tissue, brain tissue).

[0050] In some embodiments, the processor unit **221** may be remotely coupled to a user computing device (not shown). The user computing device may include a graphical user interface that is configured to receive input from a user (e.g., technician, radiologist, physician, scientist). The ion-chamber position may be controlled by the motion stage, which is in turn controlled by a software program on the RaspberryPi. The RaspberryPi may be remotely accessed from outside of the radiation vault.

[0051] FIG. 2B illustrates the radiation detector positioning system of FIG. 2A, with sub-components labeled. For example, illustrated is a perspective view of the vertical stepper 201, ion chamber positioning tube 225, vertical positioning platform 203, horizontal positioning platform 205, positioning switches 207, horizontal stepper 209, and angular step ring 221. In the depicted embodiment, the angular step ring may be configured to rotate 22.5 degrees per step.

[0052] FIG. 2C illustrates the electronics that drive the motion of the positioning system. Illustrated is a microprocessor 231, and stepper drive boards 227. The compact beam profile scanner system may be controlled through a microprocessor 231. The microprocessor 231 may be connected to a user computing device such as a laptop that is configured to wirelessly to drive the motion of the compact beam profile scanner (i.e., POD-Scanner). Each stepper motor of the compact beam profile scanner may be controlled using a micro-stepping driver chip (e.g., A4983 by Allegro Micro-Systems, Worcester, Mass.) which is further configured to coordinate motion through an operation frequency of 1 kHz.

[0053] FIG. 3 illustrates a graphical user interface for a stereotactic radiotherapy system in accordance with an embodiment of the present disclosure. As illustrated, the graphical user interface (GUI) may provide a depiction 301 of the horizontal position of the ion chamber in relation to the possible horizontal position values. Similarly, the graphical user interface may provide a depiction 303 of the vertical position of the ion chamber in relation to the possible vertical position values. The absolute horizontal ion chamber position 305 and vertical ion chamber position 307 may also be depicted. A user may be able to enter in the coordinates (including vertical and horizontal positions) that they would like the ion chamber to move to 309. Alternatively, the user may elect to command the ion chamber to move or step by a relative amount 311. The graphical user interface may also include command functions such as those for connecting the steppers/motors depicted in FIGS. 2A-2C to a microprocessor 313. Other commands include the ability to reset or zero the motors and/or stage position 315. Further, the graphical user interface may include an option 317 to allow a user to exit the application and/or power down.

[0054] As illustrated, in some embodiments, the graphical user interface of FIG. 3 may include a Python-based graphical user interface (GUI). The graphical user interface may be configured to show the current absolute location of the radiation detector and the corresponding allowable motion range. The user can use the graphical user interface to enter values to drive absolute positioning or relative motion of the radiation detector. The bottom row of buttons can energize and zero (initial positioning) the stepper motors as well as power down the system. Initial positioning of the stepper motors is accomplished using positioning limit switches.

[0055] In some embodiments, the compact beam scanner may be used for commissioning a stereotactic radiotherapy device. For example, the compact beam scanner may be used to commission a GammaPod™. The compact beam scanner may be placed close to a radiation center of the radiotherapy device using an alignment jig. The ion chamber may be placed within the holder of the compact beam scanner. A computer may be connected, and the stepper motors may be initialized to a zero position. In some embodiments, the horizontal platform may be moved to the

middle, and the vertical platform may be raised to its limit. The holder may then be lowered to the water surface. The ion chamber may then be connected, and a user may be able to exit the vault.

[0056] The user (outside of the treatment vault) may then zero the ion chamber to account for the background radiation signal. Next, the user may select a cone and set the GammaPod™ to an active state. A coarse scan may be performed in the vertical direction. The coarse scan may span 3-5 mm. At the mid plane of the vertical scan, the scan may be repeated for the two horizontal directions. Using the three mid plans, the radiation center may be determined.

[0057] Starting from the radiation center, fine scans to obtain beam data may be performed. For example, fine scans (1 mm or less) may be performed along a plane. For a given point, the electrometer integration charge (30-60 seconds) may be started, the electrometer may then be reset and the moved to a new collection point using the stepper motors. This process may be repeated along collection points in a plane. The process may also be repeated for additional planes (x, y, or z planes).

[0058] In some embodiments, the compact beam scanner may be used to develop a baseline for quality assurance determinations. In particular, the radiation center may be verified by using coarse scans along the x, y, or z planes in accordance with the techniques described above. Additionally, fine resolution scans may be conducted starting at the radiation center and individually scanning along the x, y, or z directions. Fine resolutions scans may be on the order of 1 mm. Each scan may be repeated several times and then averaged to determine a baseline for quality assurance determinations.

EXPERIMENTAL DATA

Experiment #1: Dosimetry Experiments

[0059] In some embodiments, the systems and methods described herein related to the compact beam profile scanner (the POD-scanner) were integrated into a two-part system (POD-Scanner and POD-Calculator), that provides dedicated dosimetry system for accurate and efficient commissioning and QA of GammaPod™ including beam profile scanning and TPS validation. In-water beam profiles were automatically acquired by the POD-Scanner, and subsequently fed into the POD-Calculator to commission the phase space file. After commissioning, the POD-Calculator can switch the calculation medium from water to breast tissue. As a result, beam profiles in the breast medium were used to commission and evaluate the GammaPod™ TPS in accordance with the schematic depicted in FIG. 4.

[0060] As illustrated in FIG. 4, doses were measured in water by the compact beam profile scanner or POD-Scanner 401 were compared 403 by a dose calculated by monte-carlo methods 405 and used for the commissioning of a calculator or dosimetry system 407. Similarly, a monte-carlo dose for breast tissue 409 calculated by the calculator or dosimetry system 407 is compared 411 to a dose for breast tissue provided by the GammaPod™ Treatment Planning System 413.

[0061] As illustrated in FIG. 4, in addition to the beam profile comparison, the POD-Calculator or dosimetry system 407 and the compact beam profile scanner or POD scanner were integrated to conduct end-to-end tests. Each end-to-end test was featured with CT image acquisition,

image exporting/importing, stereotactic system coordinates registration, target contouring, treatment planning, secondary dosimetry check and plan-specific QA. Since the GammaPod™ system provides 26 breast cups for treatment, each with a different size, the end-to-end tests were conducted on these 26 water-filled breast cup phantoms. In-water dose measurements via the POD-Scanner 401 were compared 403 with in-water dose calculations via the POD-Calculator 405 and compared the corresponding in-breast dose calculations via the POD-Calculator 409 with the in-breast dose calculations via the GammaPod™ TPS 413.

[0062] In total, 56 different treatment plans were generated to verify the GammaPod™ TPS and the commissioned POD-Calculator dose engine. The planning target volumes (PTVs) of these 56 end-to-end testing plans ranged from 1.91 cc to 63.18 cc and placed randomly inside breast cups. The prescribed dose ranged from 4 Gy to 25 Gy in 1 fraction and dose distribution were normalized to 95% of PTV covered by 100% of the prescription dose. Considering the quick dose fall-off of a GammaPod™ plan and distal critical structures (e.g. heart and lung), in these 56 plans, dose constraints were not imposed. Thus, these plans were desired for dosimetry measurement and comparison rather than plan quality evaluation.

Experiment #2: Mechanical Evaluation of Compact Beam Scanner

[0063] As illustrated in FIGS. 5A-5B, the compact beam scanner (i.e., POD-Scanner) was evaluated for horizontal and vertical straightness as well as positioning accuracy and reproducibility. Depicted is a light source 501, ion chamber 503 and GammaPod™ 505, a compact beam scanner 507 positioned above the GammaPod™ 505, and a plumb line 509. Also shown is the ion chamber shadow path 511, GammaPod™ shielding door shadow 513, plumb line shadow 515, and distance measurements made along the path 517.

[0064] As illustrated in FIGS. 5A-5B, horizontal and vertical straightness were validated by measuring the light field projection 501 of the device against the GammaPod™ 505 shielding door surface (zero horizontal inclination verified with a spirit level prior to measurement) and a plumb line 509, respectively. In particular, the angular variation over the range of travel was calculated by measuring the distance 517 from the GammaPod™ shielding door surface shadow 513 and the plumb line shadow 515.

[0065] The angular variation was found to be less than 0.1° for each axis over the range of motion. Positioning accuracy and reproducibility of the system was validated using a caliper to be better than 0.1 mm.

[0066] The compact beam scanner, and related dosimetry system provides a dedicated tool for highly-focused stereotactic breast radiation therapy, which could potentially help to increase the therapeutic ratio by escalating dose to the tumor and reducing dose to surrounding healthy tissues. The single- and hypo-fractionated treatment regimens could also potentially improve patient convenience and reduce the medical cost. The disclosed system and methods may be used for GammaPod™ commissioning and patient-specific QAs.

[0067] The compact beam scanner allows automatic radiation detector navigation from outside the vault and avoids interruptions to beam profile and point dose acquisitions. Using such a system substantially reduces the beam profile

acquisition time (e.g., less than two days) as compared to greater than one month (as is required by the GammaPod™ device). The mechanical evaluations of the POD-Scanner system yielded excellent motion straightness, accuracy and reproducibility.

[0068] The disclosed system allows manual rotation to change the profile acquisition direction within the x-z plane. Although it results in minimal interruptions to our acquisition flow, a fully-automatic implementation may help to further improve the efficiency of data acquisition and reduce the chance of human errors. Accordingly, a third rotational motor to allow such automatic rotations is envisioned.

[0069] The disclosed compact beam scanner and dosimetry system (i.e., the POD-DOSI system) meets the challenge of GammaPod™ commissioning and QA, to improve the efficiency, accuracy and safety for commissioning and routine clinical treatments. The developments can potentially be used at other centers, to coordinate streamlined and homogeneous commissioning and QA practices, allowing more efforts to be geared towards evaluating and exploring the potential of the new breast-dedicated radiotherapy device in cancer treatment.

[0070] In some embodiments, the systems and methods described herein may be used to validate a treatment plan. A treatment plan may include user-defined targets and dose prescriptions as well as dynamic paths between user-defined targets.

[0071] In some embodiments, the described systems may be used to determine the radiation focal spot and calibrate for the absolute dose. Radiation focus spot may be determined by scanning radiation dose profiles. For example, a first horizontal direction may be scanned first to find the maximal dose position along the horizontal. Then from the found maximal position, a second vertical direction may be scanned to find the maximal dose position along the second vertical direction. Finally, the first horizontal direction may be re-scanned to verify the maximal position.

[0072] The described systems and methods may be used in collecting dosimetric data. Dosimetric data may include dose profiles along defined lines. A dose profile may be formed by the measured dose (or charge collected at a designated time period) at points along the line. The measured dose profile may be used to adjust or calibrate the dose calculation model parameters in a treatment planning system, such that the treatment planning system dose matches the modified system.

[0073] In conventional systems, treatment plans for stereotactic radiotherapy may be verified by measuring dose profiles in water. However, some stereotactic radiotherapy systems, such as the GammaPod™ system are not configured to be used with water. Accordingly, in some embodiments for verifying a treatment plan, a breast cup may be modified to hold water. Thus, a dose may be measured in water, thereby providing a secondary verification and/or calibration mechanism.

[0074] While the present disclosure has been shown and described in accordance with practical and preferred embodiments thereof, it is recognized that departures may be made within the spirit and scope of the present disclosure which, therefore, should not be limited except as set forth in the following claims as interpreted under the doctrine of equivalents.

We claim:

1. A system for radioablating a target region of human tissue comprising:

a gamma-ray irradiation device comprising an irradiating unit configured to produce a radiation field to radioablate the target region; and

a compact beam scanner in communication with the gamma-ray irradiation device, the compact beam scanner comprising a processor for:

controlling the operation of the gamma-ray irradiation device and

determining beam data for the gamma-ray irradiation device, wherein the beam data comprises positional geometry for the gamma-ray radiation emitted from the irradiating unit.

2. The system of claim 1, wherein the compact beam scanner comprises a user computing device with a graphical user interface, wherein the graphical user interface is configured to receive user input for positioning and display current positional data, and the user computing device controls the operation of the compact beam scanner.

3. The system of claim 2, wherein the user computing device is positioned in a room remote from a treatment room including the compact beam scanner.

4. The system of claim 2, wherein the compact beam scanner comprises:

a vertical positioning platform configured to translate the gamma-ray irradiation device along a vertical axis;

a horizontal positioning platform configured to translate the gamma-ray irradiation device along a horizontal axis; and

a rotational platform comprising a base, wherein the vertical positioning platform and horizontal positioning platform are positioned on top of the rotational platform and the connected to the base of the rotational platform via a rotational bearing.

5. The system of claim 4, wherein at least one of the vertical positioning platform, horizontal positioning platform, and rotational platform comprises at least one of polyethylene, metal, stainless steel, aluminum and molded plastic.

6. The system of claim 4, wherein the position of at least one of the vertical positioning platform, horizontal positioning platform and rotational platform is driven by a stepper motor controlled by the user computing device.

7. A method for radioablating a target region of human tissue comprising:

engaging an ion chamber of a stereotactic radiotherapy device within a holder of a compact beam scanner;

initializing one or more platforms of the compact beam scanner;

determining a radiation center by scanning a target area at a first resolution; and

obtaining beam data from the radiation center by scanning the target area at a second resolution, wherein the second resolution is finer than the first resolution.

8. The method of claim 7, comprising:

determining a baseline for quality assurance metrics by performing a plurality of fine scans of the target area based on the beam data; and

averaging the plurality of fine scans.

9. The method of claim 7, wherein the beam data is determined for at least one of the x, y, or z axis of the stereotactic radiotherapy device.

10. The method of claim 7, wherein

operation of the compact beam scanner is driven by user input into a graphical user interface on a user computing device positioned outside of a treatment room including the compact beam scanner.

11. The method of claim 7 wherein engaging a compact beam scanner with the stereotactic radiotherapy device comprises:

aligning the compact beam scanner to the stereotactic radiotherapy device using an alignment jig.

12. The method of claim 11 wherein initializing one or more platforms of the compact beam scanner comprises:

initializing one or more stepper motors configured to control the position of a horizontal platform and a vertical platform of the compact beam scanner, wherein the horizontal platform is positioned to the middle and the vertical platform is positioned to its limit; and

lowering the holder of the compact beam scanner to a water surface.

13. The method of claim 11, wherein the first resolution is between about 3 to 5 mm.

14. The method of claim 11, wherein the second resolution is between about 0.5 to 2.5 mm.

15. The method of claim 11, wherein finely scanning a target area comprises:

starting an electrometer integration charge for a time period between about 30 to 60 seconds;

resetting the electrometer; and

moving to a new collection point in the target area using the stepper motors.

16. A compact beam scanner comprising:

a processor for controlling the operation of a gamma-ray irradiation device and determining beam data for the gamma-ray irradiation device, wherein the gamma-ray irradiation device is configured to radioablate a target region of human tissue and includes an irradiating unit configured to produce a radiation field;

a vertical positioning platform configured to translate a gamma-ray irradiation device along a vertical axis;

a horizontal positioning platform configured to translate the gamma-ray irradiation device along a horizontal axis;

a rotational platform comprising a base, wherein the vertical positioning platform and horizontal positioning platform are positioned on top of the rotational platform and the connected to the base of the rotational platform via a rotational bearing; and

a stepper motor configured to control the position of at least one of the vertical positioning platform, horizontal positioning platform and rotational platform, wherein the processor is configured to control the at least one stepper motor.

17. The compact beam scanner of claim 16, wherein the processor is configured to receive instructions from a graphical user interface displayed on a user computing device.

18. The compact beam scanner of claim 17, wherein the user computing device is remote from the compact beam scanner.

19. The compact beam scanner of claim 16, comprising an alignment jig configured to align the compact beam scanner to gamma-ray irradiation device.

20. The compact beam scanner of claim **16**, comprising a holder configured to receive an ion chamber of the gamma-ray irradiation device.

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