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(54) **MULTI-MODE CONE BEAM CT RADIOTHERAPY SIMULATOR AND TREATMENT MACHINE WITH A FLAT PANEL IMAGER**

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See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,133,227 A 5/1964 Brown et al.
3,144,552 A 8/1964 Schonberg
3,193,717 A 7/1965 Nunan
4,149,247 A 4/1979 Pavkovich et al.
4,149,248 A 4/1979 Pavkovich
4,208,675 A 6/1980 Bajon et al.
4,209,706 A 6/1980 Nunan
4,521,808 A 6/1985 Ong et al.
4,593,967 A 6/1986 Haugen
4,675,731 A 6/1987 Takasu et al.
4,679,076 A 7/1987 Vikterlof et al.
4,726,046 A 2/1988 Nunan
4,741,621 A 5/1988 Taft et al.
4,825,393 A 4/1989 Nishiya
4,853,777 A 8/1989 Hupp
4,868,844 A 9/1989 Nunan
(Continued)

FOREIGN PATENT DOCUMENTS

DE 42 23 488 A1 1/1994
(Continued)

OTHER PUBLICATIONS

J. H. Siewerdsen and D. A. Jaffray, Med. Phys. 26, 2635-2647 (1999).*
(Continued)

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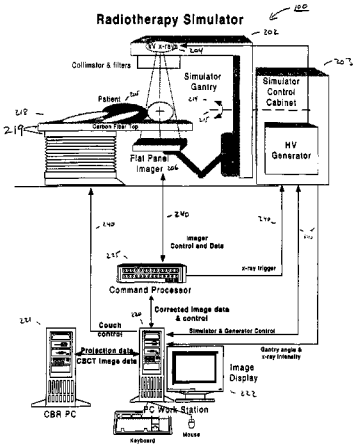
(57) **ABSTRACT**

A multi-mode cone beam computed tomography radiotherapy simulator and treatment machine is disclosed. The radiotherapy simulator and treatment machine both include a rotatable gantry on which is positioned a cone-beam radiation source and a flat panel imager. The flat panel imager captures x-ray image data to generate cone-beam CT volumetric images used to generate a therapy patient position setup and a treatment plan.

77 Claims, 4 Drawing Sheets



U.S. PATENT DOCUMENTS

5,014,292	A *	5/1991	Siczek et al.	378/196
5,027,818	A	7/1991	Bova et al.	
5,039,867	A	8/1991	Nishihara et al.	
5,080,100	A	1/1992	Trotel	
5,099,505	A	3/1992	Seppi et al.	
5,117,445	A	5/1992	Seppi et al.	
5,168,532	A	12/1992	Seppi et al.	
5,247,555	A	9/1993	Moore et al.	
5,262,649	A *	11/1993	Antonuk et al.	250/370.09
5,335,255	A	8/1994	Seppi et al.	
5,394,452	A	2/1995	Swerdloff et al.	
5,438,991	A	8/1995	Yu et al.	
5,471,516	A	11/1995	Nunan	
5,537,452	A	7/1996	Shepherd et al.	
5,661,773	A	8/1997	Swerdloff et al.	
5,692,507	A	12/1997	Seppi et al.	
5,751,781	A	5/1998	Brown et al.	
5,949,811	A *	9/1999	Baba et al.	378/108
5,956,382	A *	9/1999	Wiener-Avnear et al.	378/98.8
5,999,587	A *	12/1999	Ning et al.	378/4
6,031,888	A	2/2000	Ivan et al.	
6,041,097	A	3/2000	Roos et al.	
6,104,778	A	8/2000	Murad	
6,104,780	A	8/2000	Hanover et al.	
6,144,875	A	11/2000	Schweikard et al.	
6,222,901	B1	4/2001	Meulenbrugge et al.	
6,292,526	B1 *	9/2001	Patch	378/4
6,307,914	B1	10/2001	Kunieda et al.	
6,325,537	B1	12/2001	Watanabe	
6,325,758	B1	12/2001	Carol et al.	
6,370,421	B1	4/2002	Williams et al.	
6,381,302	B1	4/2002	Berestov	
6,385,286	B1	5/2002	Fitchard et al.	
6,429,578	B1	8/2002	Danielson et al.	
6,463,122	B1 *	10/2002	Moore	378/65
6,480,565	B1 *	11/2002	Ning	378/37
6,508,586	B2	1/2003	Oota	
6,590,953	B2	7/2003	Suzuki et al.	
6,661,870	B2	12/2003	Kapatoes et al.	
6,744,848	B2 *	6/2004	Stanton et al.	378/55
6,842,502	B2	1/2005	Jaffray et al.	
6,865,254	B2 *	3/2005	Nafstadius	378/65
6,888,919	B2 *	5/2005	Graf	378/65
6,914,959	B2	7/2005	Bailey et al.	
2001/0001807	A1	5/2001	Green	
2001/0008271	A1	7/2001	Ikeda et al.	
2003/0007601	A1 *	1/2003	Jaffray et al.	378/65

FOREIGN PATENT DOCUMENTS

DE	196 14 643	A1	10/1997
EP	0062941	B1	9/1984
EP	0205720	A1	12/1986
EP	0480035	B1	11/1994
FR	2 269 745		11/1975
FR	2 551 664		3/1985
GB	1328033		8/1973
JP	63294839		12/1988
JP	5057028		3/1993
WO	WO 85/03212	A1	8/1985
WO	WO 9014129		11/1990
WO	WO 9200567		1/1992
WO	WO 9220202		11/1992

OTHER PUBLICATIONS

J. H. Siewerdsen and D. A. Jaffray, Med. Phys. 26, 1624-1641 (1999).*

D. A. Jaffray et al., SPIE vol. 3659, 204-214 (1999).*

Ruola Ning et al., SPIE vol. 3659, 192-203 (1999).*

Ning et al., "Flat Panel Detector-Based Cone-Beam Volume CT Angiography Imaging: System Evaluation," IEEE Transactions on Medical Imaging, vol. 19, No. 9, Sep. 2000, 949-963.*

Ragan, "Correction for Distrotion in a Beam Outline Transfer Device in Radiotherapy CT-Based Simulation", Med. Phys. 20 (1), Jan./Feb. 1993, pp. 179-185.

Hara et al., "Radiotherapeutic System", 00480035/EP-B1, Citation from World Patent, 1994, 1 page.

"Advanced Workstation for Irregular Field Simulation and Image Matching", Copyright 1999, MDS Nordion, 7 pages.

Balter, James M. et al., "Daily Targeting of Intrahepatic Tumors for Radiotherapy," Int. J. Radiation Oncology Biol. Phys., vol. 52, No. 1 (2002), pp. 266-271.

Swindell, William et al., "Computed Tomography With a Linear Accelerator With Radiotherapy Applications," Med. Phys., vol. 10, No. 4, Jul./Aug. 1983; pp. 416-420.

Mosleh-Shirazi, Mohammad Amin et al., "A Cone-Beam Megavoltage CT Scanner for Treatment Verification in Conformal Radiotherapy," Radiotherapy and Oncology, vol. 48 (1998), pp. 319-328.

Midgley, S. et al., "A Feasibility Study for Megavoltage Cone Beam CT Using a Commercial EPID," Phys. Med. Biol., vol. 43 (1998), pp. 155-169.

Ruchala, K.J. et al., "Megavoltage CT on a Tomotherapy System," Phys. Med. Biol., vol. 44 (1999), pp. 2597-2621.

Nakagawa, Keiichi, M.D. et al., "Megavoltage CT-Assisted Sterotactic Radiosurgery for Thoracic Tumors: Original Research in the Treatment of Thoracic Neoplasms," Int. J. Radiation Onocology Biol. Phsy., vol. 48, No. 2, (2000), pp. 449-457.

Groh, B.A. et al., "A Performance Comparison of Flat-Panel Imager-Based MV and kV CT," Med. Phys., vol. 29, No. 6, Jun. 2002, pp. 967-975.

Uematsu, Minoru et al., "Daily Positioning Accuracy of Frameless Stereotactic Radiation Therapy With a Fusion of Computed Tomography and Linear Accelerator (FOCAL) Unit Evaluation of Z-Axis with a Z-Marker," Radiotherapy and Oncology, vol. 50, No. 3, Mar. 1999, pp. 337-339.

Uematsu, Minoru, M.D. et al., "A Dual Computed Tomography Linear Accelerator Unit for Stereotactic Radiation Therapy: A New Approach Without Cranially Fixated Stereotactic Frames," Int. J. Radiation Oncology Biol. Phys., vol. 35, No. 3 (1996), pp. 587-592.

Uematsu, Minoru, M.D. et al, "Intrafractional Tumor Position Stability During Computed Tomography (CT)-Guided Frameless Stereotactic Radiation Therapy for Lung or Liver Cancers With a Fusion of CT and Linear Accelerator (FOCAL) Unit," Int. J. Radiation Oncology Biol. Phys., vol. 48, No. 2 (2000), pp. 443-448.

Jaffray, David A., Ph.D. et al., "A Radiographic and Tomographic Imaging System Integrated Into a Medical Linear Accelerator for Localization of Bone and Soft-Tissue Targets," Int. J. Radiation Oncology Biol. Phys., vol. 45, No. 3 (1999), pp. 773-789.

Pisani, Laura, M.S. et al., "Setup Error in Radiotherapy: On-line Correction Using Electronic Kilovoltage and Megavoltage Radiographs," Int. J. Radiation Oncology Biol. Phys., vol. 47, No. 3 (2000), pp. 825-839.

Drake, D.G. et al, "Characterization of a Fluoroscopic Imaging System for kV and MV Radiography," Med. Phys., vol. 27, No. 5, May 2000, pp. 898-905.

Jaffray, D.A. and Siewerdsen, J.H., "Cone-Beam Computed Tomography with a Flat-Panel Imager: Initial Performance Characterization," Med. Phys., vol. 27, No. 6, Jun. 2000, 1311-1323.

Fahrig, R. and Holdsworth, D. W., "Three-Dimensional Computed Tomographic Reconstruction Using a C-Arm Mounted XRII: Image Based Correction of Gantry Motion Nonidealities," Med. Phys., vol. 27, No. 1, Jan. 2000, pp. 30-38.

Feldkamp, L.A. et al. "Practical Cone-Beam Algorithm," J. Opt. Soc. Am. A., vol. 1, No. 6, Jun. 1984; pp. 612-619.

Siewerdsen, Jeffery H. and Jaffray, David A., "Optimization of X-Ray Imaging Geometry (With Specific Application to Flat-Panel Cone-Beam Computed Tomography)," Med. Phys., vol. 27, No. 8, Aug. 2000, pp. 1903-1914.

Siewerdsen, Jeffery H. and Jaffray, David A., "Cone-Beam Computed Tomography With a Flat-Panel Imager: Magnitude and Effects of X-Ray Scatter," Med. Phys., vol. 28, No. 2, Feb. 2001, pp. 220-231.

Cho, Paul S. et al., "Cone-Beam CT for Radiotherapy Applications," Phys. Med. Biol., vol. 40 (1995), pp. 1863-1883.

Masahiro et al., "Patient Beam Positioning System Using CT Images", Phys. Med. Biol., 1982, vol. 27, No. 2, pp. 301-305, printed in Great Britain.

Midgley, S., et al., "A Feasibility Study for Megavoltage Cone Beam CT Using a Commercial EPID," Phys. Med. Biol. 43, United Kingdom, 1998, pp. 155-169.

Kudo et al., "Feasible cone beam scanning methods for exact reconstruction in three-dimensional tomography," J. Opt. Soc. Am. A; 7, 2169 (1990).
Rizo et al., "Comparison of two three-dimensional x-ray cone-beam-reconstruction with circular source trajectories," J. Opt. Soc. Am. A, 10, 1639 (1991).
Yan et al., "Derivation and analysis of a filtered backprojection algorithm for cone beam projection," IEEE Trans. Medical Imaging, 10, 462 (1991).
Andrew, JW, et al., "A video-based patient contour acquisition system for the design radiotherapy compensators," Abstract, Med Phys, May-Jun. 1989, vol. 16(3), pp. 425-430.
Brewsterfuauf, L, et al., "Automatic generation of beam apertures," Abstract, Medical Physics, 1993, vol. 20, pp. 1337, 1342.
Elliott, PJ, et al., "Interactive image segmentation for radiation treatment planning," Abstract, IBM Systems Journal, 1992, vol. 31, No. 4, pp. 620-634.
Gademann, G, et al., "Three-dimensional radiation planning. Studies on clinical integration," Abstract, Strahlenther Onkol, 1993, vol. 169(3), pp. 159-167.
Jaffray, DA, et al., "Cone-beam CT: applications in image-guided external beam radiotherapy and brachytherapy," Engineering in Medicine & Biology Society, Proceedings of the 22nd Annual International Conference of the IEEE, Jul. 2000, vol. 3, p. 2044.
Keys, D, "A CCTV-microcomputer biostereometric system for use in radiation therapy (topography, medical physics, tissue compensators)," Abstract, Energy Science and Technology, 1984, vol. 45-12B, pp. 3857.
Kuhn, MH, "AIM Project A2003: COmputer Vision in RAdiology (COVIRA)," Abstract, Computer Methods and Programs in Biomedicine, Oct. 1994, vol. 45, No. 1-2, pp. 17-31.
Kushima, T, et al., "New development of integrated CT simulation system for radiation therapy planning," Abstract, Kobe J Med Sci, Dec. 1993, vol. 39, No. 5-6, pp. 197-213.
Kutcher, GJ, et al., "Three dimensional radiation treatment planning," Abstract (1988), Dosimetry in radiotherapy. vol. 2. Proceedings of an international symposium held in Vienna, Austria, Aug.-Sep. 1987.
Mohan, R, et al., "Intersection of shaped radiation beams with arbitrary image sections," Abstract, Comput Methods Programs Biomed, Jun. 1987, vol. 24, pp. 161-168.
Ning, R, et al., "Image intensifier-based volume tomographic angiography imaging system: system evaluation," SPIE , Medical Imaging 1995, vol. 2432, pp. 280-290.
Redpath, AT, et al., "Use of a simulator and treatment planning computer as a CT scanner for radiotherapy planning," Abstract, Proceedings—Eighth International Conference on the Use of Computers in Radiation Therapy held in Toronto, Canada, 1984, pp. 281-287, IEEE, New York, New York.
Reynolds, RA, et al., "An algorithm for three-dimensional visualization of radiation therapy beams," Abstract, Med Phys, Jan.-Feb. 1988, vol. 15(1), pp. 24-28.
Jaffray, David A. et al., "Flat-Panel Cone-Beam Computed Tomography for Image-Guided Radiation Therapy", Int. J. Radiation Oncology Biol. Phys. vol. 53 No. 5 (2002), pp. 1337-1349.

* cited by examiner

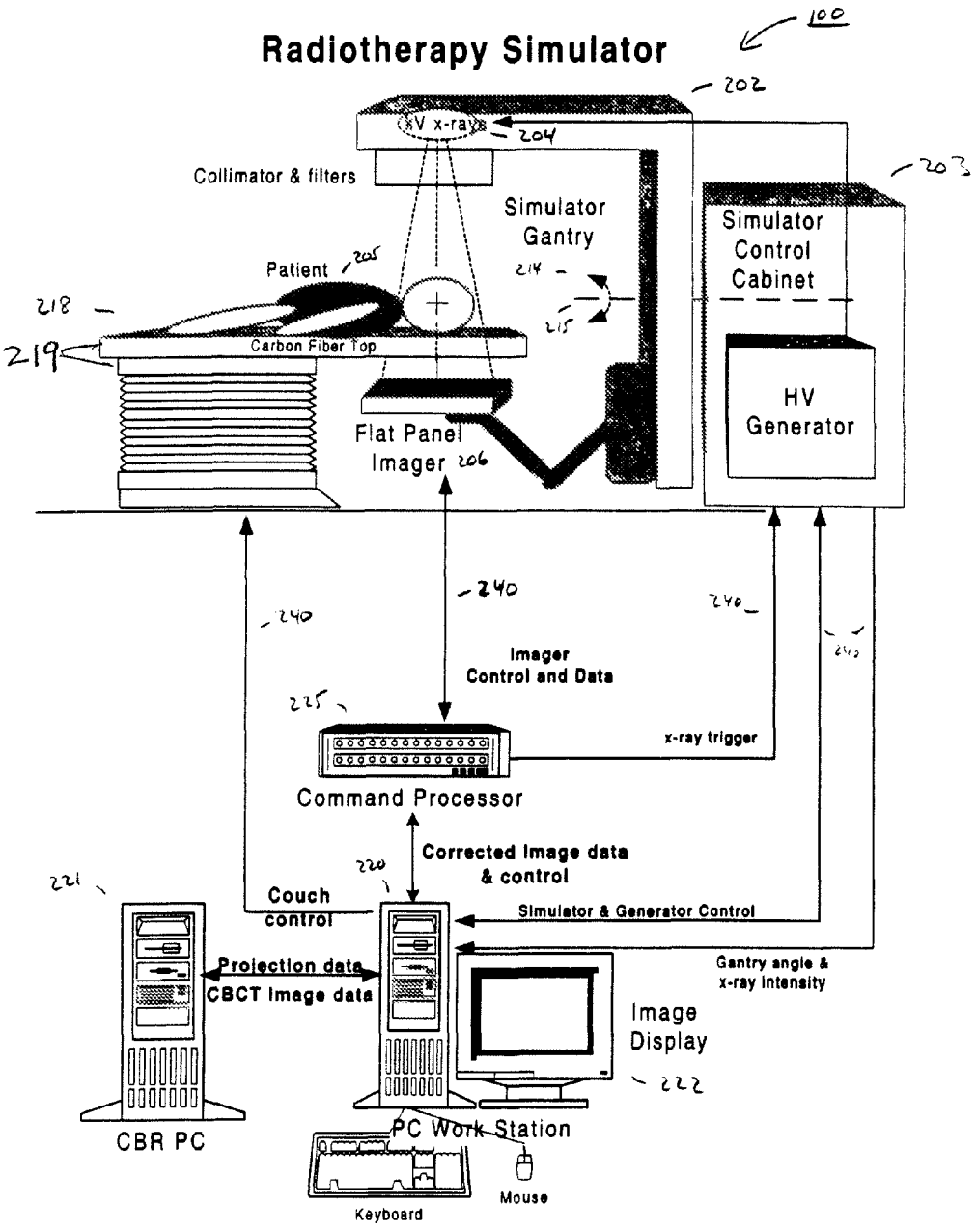


Figure 1- Simulator kV Cone Beam CT Diagram

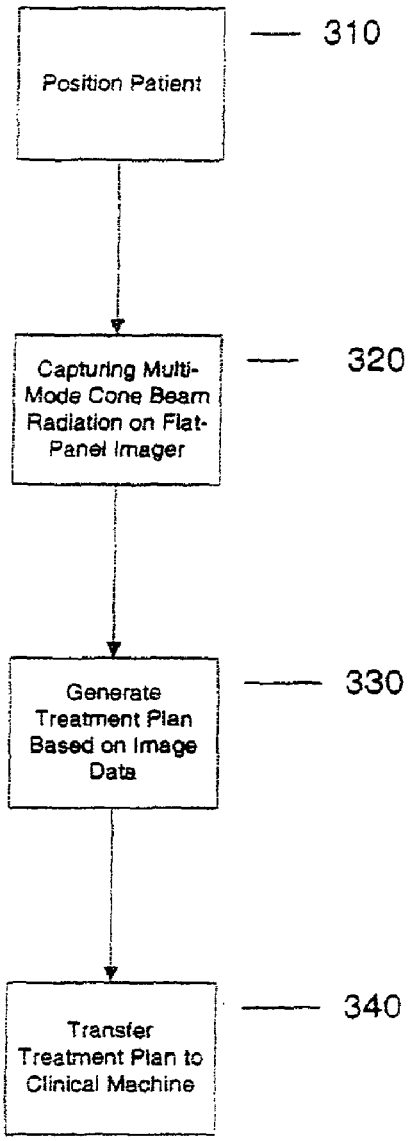

Position Patient
310
Capturing Multi-Mode Cone Beam Radiation on Flat-Panel Imager
320
Generate Treatment Plan Based on Image Data
330
Transfer Treatment Plan to Clinical Machine
340

Figure 2

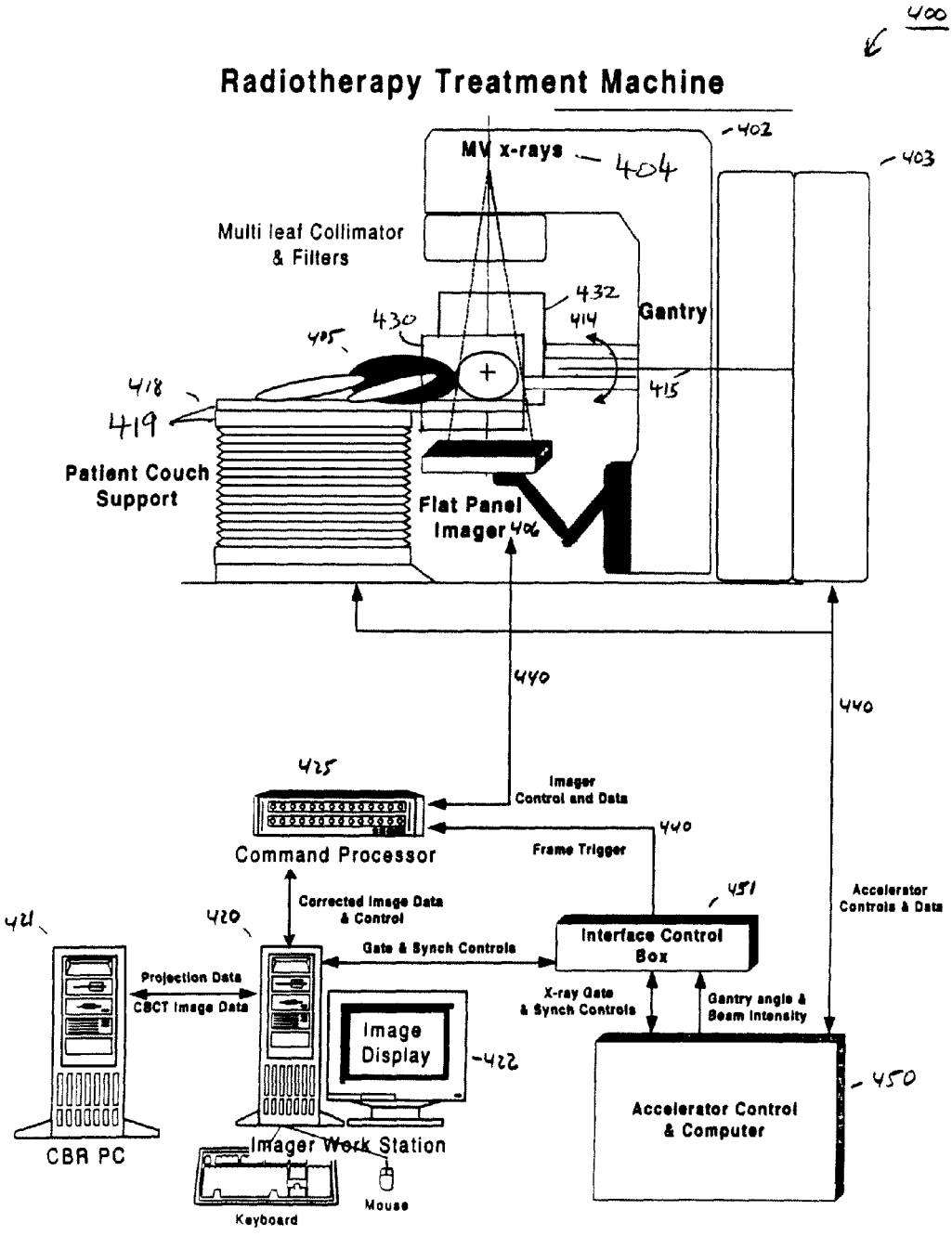
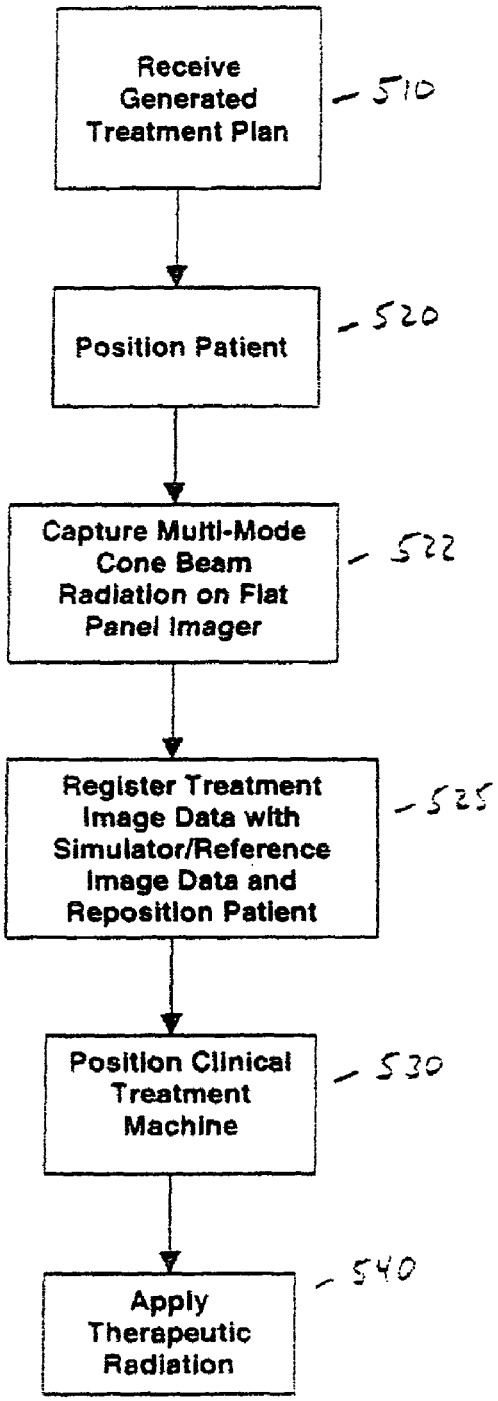


Figure 3- MV Cone Beam CT Diagram

Figure 4


Receive Generated Treatment Plan
510
Position Patient
520
Capture Multi-Mode Cone Beam Radiation on Flat Panel Imager
522
Register Treatment Image Data with Simulator/Reference Image Data and Reposition Patient
525
Position Clinical Treatment Machine
530
Apply Therapeutic Radiation
540

MULTI-MODE CONE BEAM CT RADIOTHERAPY SIMULATOR AND TREATMENT MACHINE WITH A FLAT PANEL IMAGER

TECHNICAL FIELD

The present invention pertains in general to therapeutic radiology. In particular, the invention involves imaging devices.

BACKGROUND

An objective of radiation therapy is to maximize the amount of radiation to a target volume (e.g., a cancerous tumor) and minimize the amount of radiation to healthy tissues and critical structures. The process of identifying the precise location of the target volume immediately prior to a dose of therapeutic radiation is key to the objective. Since each patient is treated over 30 to 40 fractionated sessions, then the time allowed for each session is relatively short, e.g. 10 to 15 minutes, so the process must be fast as well as accurate.

In the case of electronic portal imaging, megavolt therapeutic X-rays emerging from the patient can be used to generate images. However, this method of target location generates images of low contrast and quality, in addition to incidentally damaging healthy tissue. As a result, imaging with megavoltage (MV) radiation is used primarily for portal verification, that is, to confirm that the treatment volume is being radiated.

Radiotherapy simulator machines have been used to perform the pretreatment analysis of the target volume before a radiotherapy treatment machine applies the therapeutic radiation. However, traditional radiotherapy simulator machines use bulky image intensifier tube detectors to capture images of the treatment volume. These image intensifier tube detectors have the disadvantage of being very large relative to their imaging area. They also have image spatial distortions from their spherical shaped input surface and the orientation of the intensifier tube with the Earth's magnetic field.

SUMMARY OF AN EMBODIMENT OF THE INVENTION

A multi-mode cone beam computed tomography radiotherapy simulator and treatment machine is disclosed. The radiotherapy simulator and treatment machine both include a rotatable gantry on which is positioned a cone-beam radiation source and a flat panel imager. The flat panel imager captures x-ray image data to generate cone-beam CT volumetric images used to generate a therapy patient position setup and a treatment plan.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention is illustrated by way of example and not limitation in the figures of the accompanying drawings, in which like references indicate similar elements and in which:

FIG. **1** is an illustration of a side view of one embodiment of a simulation treatment machine;

FIG. **2** is an illustration of a process flow of one embodiment of a method for generating a treatment plan;

FIG. **3** is a side view of one embodiment of a clinical treatment machine; and

FIG. **4** illustrates a process flow of one embodiment of a method for implementing a treatment plan.

DETAILED DESCRIPTION

In the following description, for purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the present invention. It will be evident, however, to one skilled in the art that the present invention may be practiced without these specific details. In some instances, well-known structures and devices are shown in gross form rather than in detail in order to avoid obscuring the present invention. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention, and it is to be understood that other embodiments may be utilized and that logical, mechanical, electrical, and other changes may be made without departing from the scope of the present invention.

A clinical therapy simulation machine having a cone-beam computed tomograpy (CT) radiation source and a flat-panel imager is described. The clinical therapy simulation machine is capable of manipulating the flat-panel imager and the cone beam CT radiation source to generate x-ray images for determining patient setup/alignment and a clinical treatment plan to be implemented by a clinical treatment machine.

FIG. **1** is a side view of one embodiment of a simulation treatment machine **100**. The simulation treatment machine **100** includes a rotatable gantry **202** pivotably attached to a drive stand **203**. A cone-beam CT radiation source **204** and a flat panel imager **206** oppose each other and are coupled to the rotatable gantry **202**. In one embodiment, the cone-beam CT radiation source is a kilovoltage radiation source generally in the 50 to 150 kilovolt (kV) energy range, and for example at 125 kilovolts peak (kVp).

A treatment couch **218** is positioned adjacent to the gantry **202** to place the patient and the target volume within the range of operation for the radiation source **204** and the imager **206**. The couch **218** may be connected to the therapy simulator rotatable gantry via a communications network and is capable of translating in multiple planes plus angulation **219** for positioning and re-positioning the patient **205** and therefore the target volume.

The gantry **202** can rotate **214** about an isocenterline **215** to place the radiation source **204** and imager **206** at any position 360 degrees around the target volume, for example, to generate CT scan image data. As will be described, cone-beam CT image data can be used to generate a three-dimensional representation of the patient anatomy and the target volume. The image data may further be used to generate a treatment plan to tailor a dose of therapeutic radiation to the target volume.

FIG. **2** is a process diagram of one embodiment of a method for generating a treatment plan. At block **310**, a patient is placed on the treatment couch **218** and the couch **218** positioned relative to the simulation machine **100**. At block **320**, the gantry **202** rotates around the patient **205** while the radiation from the cone-beam CT radiation source **204** impinges the flat-panel imager **206**. The gantry **202** rotates and collects image data until a computer can calculate a representation of the patient and the target volume. For example, software in a computer may take the image data to generate cone-beam CT volumetric image data for generation of a treatment plan. At block **330**, a treatment plan may be generated from the collected image data. The treatment plan may then be transferred, at block **340**, to a clinical treatment machine to provide instructions to the clinical treatment machine, for example, to position a therapeutic radiation source to apply a radiation dose to a target volume, and to minimize dose to health tissue and critical structures.

In one embodiment the flat panel imager **206** is a real-time digital x-ray imager incorporating a large-area amorphous silicon sensor array with a high-sensitivity cesium iodide (CsI) scintillator. The flat panel imager may include a receptor module that incorporates the amorphous silicon sensor array, which accepts incoming X-ray photons and converts them to a digital video signal. The X-ray to light conversion may be provided by a thin or thick columnar CsI:Tl (cesium iodide: thalium doped) scintillator The scintillator may be vacuum deposited in a thin (e.g. 0.6 mm) layer or include individual CsI crystals (e.g., being approximately 9 mm thick with an approximate 0.38 mm×0.38 mm pixel pitch) supported in a housing with an aluminum window (e.g., approximately 1 mm thick). The top of the thin CsI scintillator may be coated with a reflective powder/epoxy mixture. Five sides of each thick crystal may be coated with a reflecting powder/epoxy mixture. The sixth side may be in contact with and face the flat-panel sensor. Alternatively, the scintillator components may have other dimensions.

The receptor module may also include a power supply module (e.g., 24 VDC power), interconnecting cables (e.g., fiber optic control and data cables), and drive and readout circuits followed by digital data conversion and transmission capabilities well known to those of ordinary skill in the art.

It should be appreciated that the flat panel imager may be a two-dimensional large flat panel imager that can operate, for example, at 15 to 30 frames per second (fps) over a wide range of dose. In this way, fluoroscopic, radiographic and cone-beam CT imaging can all be achieved with the same flat panel system. Typically, 300-900 projections may be collected during a single rotation of the gantry depending on the image resolution and dose requirements. Fewer projections allow for a faster collection of cone-beam CT image data (e.g., in 20 to 40 seconds depending on gantry speed limits), thereby, allowing for lower dose cone-beam CT images with less patient motion artifacts. Alternatively, the images may operate at other frame rates.

In one embodiment, the flat panel imager has a landscape orientation, an active area of 39.7×29.8 cm^2 with 194 micron pixel pitch, and a pixel count of 2048×1536 pixels. It can operate at a frame rate of 7.5 fps in full resolution mode and at a frame rate of 30 fps in 2×2 binned mode—where the pixel count is reduced to 1024×768 $pixels^2$. For example, the flat panel imager may be an amorphous silicon (a-Si) imager available from Varian Medical Systems of Palo Alto, Calif., under the tradename PaxScan™ 4030A. The PaxScan™ 4030A detectors are each 40 cm×30 cm. The detectors may be coupled to signal processing circuitry comprising a preamplifier stage with dynamically controllable signal gain, as described in U.S. Pat. No. 6,486,808, filed on Oct. 16, 2001, assigned to the assignee of the present invention and incorporated by reference, herein, to improve contrast resolution and dynamic range.

The readout electronics may also be located out of the path of the primary cone-beam CT radiation source **204**. The flat panel imager **206** may also employ a split data-line where the top half of the array and the bottom half of the array are read out simultaneously. This allows the imager **206** to read out more rapidly and reduces the parasitic capacitance of the data-lines, which in turn reduces the noise gain of the readout charge amplifiers. It should be appreciated that only half of the frame time is used to read out the pixels. During the rest of the frame time, the sensor can be irradiated without generating any interference patterns due to the pulsing of the cone-beam CT radiation source **204**. In addition, it should also be appreciated the control system of the flat panel imager **206** allows an external synchronization signal (from the computer **220**) to initiate the readout of a frame. This allows the user to externally control when the imager will acquire an image.

In one embodiment, a command processor module **225** manages the receptor module, processes the digital video, and provides interfaces to other components of the simulator **100**. The command processor module **225** may include a microcontroller-based, single board computer running a real-time operating system with acquisition, control, and interface software. Also, included in the command processor may be a high-speed digital video interface card, a dedicated image processor card to perform real-time image corrections, a system interface card, and a parallel output to transmit image data to an external image processor and display. Scan-converted digital and analog video may also be provided.

The captured cone-beam CT image projection data may be delivered and stored to a computer **220**. As shown in FIG. **1**, the computer **220** connects to the simulator **100** and the command processor **225** via communications network **240**. The computer **220** may control the synchronized movement of the simulator **100** including the rotatable gantry **202**, the cone-beam CT radiation source **204**, imager **206**, and the treatment couch **218**. Specifically, the computer **220** may be used by an oncologist to display image projection data on a monitor **222**, control the intensity of the cone-beam CT radiation source **204**, and control the gantry angle.

The cone-beam CT image projection data may also be transferred to a cone-beam CT reconstruction computer **221** that includes software designed to achieve rapid cone-beam CT image generation. The computer **221** can merge or reconstruct the image data into a three-dimensional representation of the patient and target volume. In one embodiment, cone-beam CT reconstruction software may allow for full-cone and partial-cone input data that can produce cone-beam CT images (e.g., approximately 26 to 48 cm diameter) at a specific source-to-imager distance (e.g., 140-150 cm). In addition, in this way, the clinical simulator machine **100** and cone-beam reconstruction software may also allow for large diameter (e.g., approximately 48 cm) axial image volumes.

In one embodiment, the cone-beam CT reconstruction software may transform the image projection data into volumetric CT image data. The volumetric CT image data may include full-fan and/or partial cone image data to reconstruct head size (e.g. 26 cm diameter×17 cm length) and body size (e.g. 48 cm diameter×15 cm length) volumes. For example, the partial-cone method may be used to obtain body size scans when the flat panel imager is not long enough to image the full body in each projection. If the 15 or 17 cm axial section is not wide enough and therefore does not cover sufficient anatomical volume, then multiple scans can be performed. For example, in the two scan case, the patient may be moved axially by 15 or 17 cm couch movements between scans and the reconstructed image volumes may then be merged to provide a 30 to 34 cm axial view.

In one embodiment, prior to reconstruction, the image projection data is preprocessed to account for x-ray beam and detector properties and the system electronic and geometric properties. The algorithm and its implementation is similar to that used in single slice computer tomography in reconstruction of fan beam data obtained with a one-dimensional detector. For partial cone beam reconstruction, the partial cone image projection data is extended to full cone beam image data and then reconstructed using a full cone beam reconstruction algorithm well known to those of ordinarily skill in the art, such as, for example, the Feldkamp cone beam reconstruction technique. It should be understood that the extension of the partial cone beam image data is performed using

techniques similar to those used for the extension of partial fan data in well known single slice fan beam computer tomography.

In one embodiment, using the shape and distance data determined from the generated dimensional representation, the target volume may be automatically identified by the computer system **221** and/or by the inspection of an oncologist. The identified target volume may be applied to a radiotherapy planning computer system **220**, which creates a treatment plan to be implemented by a clinical treatment machine. The visualization of the data along arbitrary planes, e.g. sagital, coronal, axial, beams eye view, etc., can be displayed to assist the oncologist. To further enhance the visualization, averaging of volume image data perpendicular to the plane of view, i.e. rectangular voxels may be used.

FIG. **3** is a side view of one embodiment of a clinical treatment machine **400** that may implement the treatment plan generated by the simulator **100** and treatment planning computer **220**. The clinical treatment machine **400** includes a rotatable gantry **402** pivotably attached to a drive stand **403**. A cone-beam CT radiation source **404** and a flat panel imager **406** oppose each other and are coupled to the rotatable gantry **402**. In one embodiment, the cone-beam CT radiation source **404** is a megavoltage (MV) radiation source generally in the 4 to 25 MV energy range, for example, at 6 MV.

A treatment couch **418** is positioned adjacent to the gantry **402** to place the patient and the target volume within the range of operation for the radiation source **404** and the imager **406**. The couch **418** can be capable of translating in multiple planes plus angulation **419** for positioning and re-positioning the patient **405** and therefore the target volume.

The gantry **402** can rotate **414** about an isocenterline **415** to place the cone-beam CT radiation source **404** and imager **406** at any position 360 degrees around the target volume. The resulting megavoltage cone-beam CT image data can then be used to tailor a dose of therapeutic radiation based on at least the generated pre-defined treatment plan.

FIG. **4** is a process diagram of one embodiment of a method for implementing a treatment plan. At block **510**, an accelerator control computer **450** is provided with the treatment plan generated from the clinical simulator machine **100** for a specific patient. For example, the treatment plan may provide initial targeting information about the target volume. At block **520**, a patient is placed on the treatment couch **418** and the couch **418** is positioned relative to the clinical treatment machine **400**. At block **522**, multi-mode cone beam radiation from the radiation source **404** is captured by the imager **406** to generate images of the target volume. At block **525**, the captured image data can be compared/registered with the simulator or other reference images to determine the patient repositioning required, if any, before treatment. Image data can also be taken without repositioning to determine the random and systematic errors in treatment position, if any. At block **530**, the gantry **402** is rotated around the patient **405** to a treatment position based on the generated treatment plan. At block **540**, a therapeutic radiation dose is applied to the target volume from the cone-beam CT radiation source **404** based on the generated treatment plan. The cone-beam CT radiation source **404** also impinges the flat-panel imager **406** with radiation. In this way, the flat panel imager **406** may provide verification that the target volume is properly targeted. The process **500** may be repeated until the treatment session is complete.

The flat panel imager **406** is similar to the flat panel imager **206** including the corresponding interconnects with a command processor module **425**, a computer **420**, a monitor **422**, and a cone-beam reconstruction computer **421**, corresponding with the command processor module **225**, the computer **220**, monitor **222**, and the cone-beam reconstruction computer **221**, as described above. However, in one embodiment, the flat panel imager **406** may have its electronics unfolded from beneath the imager **406** and the input screen coating may be thicker (e.g., 9 mm vs. 0.6 mm). An example of a flat panel imager that may be used in the present invention is described in U.S. patent Ser. No. 10/013,199, filed on Nov. 2, 2001, now U.S. Pat. 6,800,898 B1 assigned to the assignee of the present invention and incorporated herein by reference.

The imager **406** may also interface with an accelerator interface control box **451**. The accelerator interface control box **451** interfaces with an accelerator control computer **450** to provide synchronization and gated control between the imager **406** and the cone-beam CT radiation source **404** during treatment based on the generated treatment plan. As shown in FIG. **3**, box **451**, processor **425**, and computer **450** connect to simulator **400** via communications network **440**. This allows single or multiple beam pulse images that are not affected by accelerator noise during readout.

In one embodiment, the accelerator interface control box **451** includes a timing interface. The timing interface coordinates acquisition by the flat panel imager **406** and pulsing of the cone-beam CT radiation source **404**. With this interface, as little as one radiation pulse (0.028 cGy at the isocenter) can be used to form projection images.

In one embodiment, the timing interface includes a National Instruments PCI 6602 data acquisition card from National Instruments Corporation of Austin, Tex. USA, that contains hardware and firmware for counting and timing pulses; computer software that provides control logic; and a user interface for the interface system. Alternatively, other cards may also be used.

A master clock signal is derived from a sync signal of the cone-beam CT radiation source **404**, which may operate at 360 pulses/s (6 MV) or 180 pulses/s (15-18 MV), according to one embodiment. Using a counter on the National Instruments PCI **6602** card, the sync signal is divided down to produce a master clock, and hence are timed relative to the production of cone-beam CT radiation pulses from the cone-beam CT radiation source **404**.

The master clock may be used to generate two control pulses, one that gates the cone-beam CT radiation source **404** on and off and the other that triggers the flat panel imager **406**. In one embodiment, the frequency of these pulses is user selectable, and may be any value below 30 pulses/sec. The relative timing of the two pulses may also be user selectable. When the flat panel imager **406** is triggered there is a period, while the image is being read out (half a frame time) during which no beam from the cone-beam CT radiation source **404** is desired. A user can enter the appropriate delay that will prevent irradiation during the frame readout period of the imager. The length of the gate pulse of the cone-beam CT radiation source **404** is also user selectable. By adjusting the width of the gate pulse, the user can control the number of beam pulses emitted by the cone-beam CT radiation source **404** during each gate pulse.

It should be appreciated that the MV cone-beam CT flat panel imager **406** has a high quantum efficient 9 mm thick CsI:Tl screen (e.g., approximately 10% efficient at 6 MV), which preserves spatial resolution and minimizes dose to the patient by at least a factor of 5 over a standard 1 mm thin copper plate and less than 1 mm GOS (gadolinium oxysulfide) screens used in standard flat panel and screen-camera portal imaging. Therefore, images with as low as one 6 MV accelerator beam pulse (e.g., 0.028 cGy) per frame may be collected. In addition, a low patient dose of 8 to 16 cGy per

cone-beam CT data set may be yielded for 300 to 600 CT image frames or projections per data set. The lower dose of the MV cone-beam CT radiation allows for more frequent use on each patient during the typical 30 to 37 fractionated treatment sessions. Moreover, reduced spatial resolution on the MV cone-beam CT scans can be afforded for faster processing time using the cone-beam reconstruction software on the CBR computer **421** to achieve rapid image generation.

It should be appreciated that a separate kV cone-beam CT radiation source (optional and shown as source **430**) and another opposing flat panel imager (as described above on the simulator, optional and shown as imager **432**) may also be coupled to the gantry **404** to perform a diagnostic cone-beam CT scan. For example, the kV cone-beam CT radiation source and opposing flat panel imager may be coupled to the treatment machine gantry **404** at an off axis of e.g. forty-five or ninety degrees from the MV cone-beam radiation source **404** and opposing imager **406**. As before, software in the computers **420** and/or **421** may generate the three-dimensional representation of the patient anatomy and target volume from the cone-beam CT image data provided by the kV radiation source. The clinical treatment machine **400** may use the kV cone-beam CT image data to make any necessary adjustments to the treatment plan based on identified movement of the target volume or to determine the amount of patient repositioning required by the treatment couch **418** or collimator movements. In this way, the kV cone-beam CT radiation source and flat panel imager share a common axis of rotation with the MV cone-beam CT radiation source **404** and provide additional information for aligning the patient to the generated simulation treatment plan.

It should also be appreciated that in this way, either the clinical simulator machine **100** and/or the clinical treatment machine **400** diagnostic cone-beam CT image data can be used as a reference for applying the MV radiation beams.

It should also be understood that it is not necessary for the therapeutic radiation to be applied from the exact position(s) where any of the previously generated CT images were taken since the computer software can provide virtual two-dimensional representations for any desired radial location in-between the images.

It should be understood that although the clinical treatment machine **400** has been described as having a cone-beam radiation source, in alternative embodiments beam shaping, along with intensity modulation, may also be implemented based on the generated treatment plan by directing a therapeutic beam through a dynamic multileaf collimator. The multileaf collimator may include a series of stacked metal shims having a center of shim pairs where each shim of the pairs may be individually moved to create a shaped opening capable of shaping the therapeutic beam. To be effective, the radiation field should be large enough to radiate the entire tumor while at the same time minimize radiating healthy tissue. The collimator may be dynamic in that the shims can rapidly move to reshape the beam, which results in blocking the therapeutic beam from striking certain areas of the target volume based on the treatment plan. Such dynamic shaping may result in different areas of the tumor receiving different amounts of radiation over the time that a radiation dose is applied.

It should be appreciated that more or fewer processes may be incorporated into the methods illustrated in FIGS. **2** and **4** without departing from the scope of the invention and that no particular order is implied by the arrangement of blocks shown and described herein. It further will be appreciated that the method described in conjunction with FIGS. **2** and **4** may be embodied in machine-executable instructions (e.g. software). The instructions can be used to cause a general-purpose or special-purpose processor that is programmed with the instructions to perform the operations described. Alternatively, the operations might be performed by specific hardware components that contain hardwired logic for performing the operations, or by any combination of programmed computer components and custom hardware components. The methods may be provided as a computer program product that may include a machine-readable medium having stored thereon instructions that may be used to program a computer (or other electronic devices) to perform the methods. For the purposes of this specification, the terms "machine-readable medium" shall be taken to include any medium that is capable of storing or encoding a sequence of instructions for execution by the machine and that cause the machine to perform any one of the methodologies of the present invention. The term "machine-readable medium" shall accordingly be taken to included, but not be limited to, solid-state memories, optical and magnetic disks, and carrier wave signals. Furthermore, it is common in the art to speak of software, in one form or another (e.g., program, procedure, process, application, module, logic . . .), as taking an action or causing a result. Such expressions are merely a shorthand way of saying that execution of the software by a computer causes the processor of the computer to perform an action or produce a result.

It should be appreciated that a clinical simulation machine having a cone-beam radiation source and flat-panel imagers, as described, allows for identification of a target volume via fluoroscopic, radiographic, and cone-beam CT imaging. In this way, the generation of the treatment plan via the clinical simulation machine prior to the application of therapeutic radiation, increases the accuracy of treating the tumor target. Furthermore, embodiments of the invention as described above may capture images while the gantry is continuously rotating versus traditional systems that stop and shoot every, approximately, four degrees around the patient, thereby further lessening the time for completion.

It should also be appreciated that the cone-beam volumetric reconstruction software can utilize image projection data at non-uniformly spaced gantry angles. Thus the data collection does not require a precise gantry speed of rotation. There is a normalizing detector at the radiation source, which is used to correct for system output variations. In one embodiment, the support arms for the images **206** and **406** are sufficiently precise in mechanical stability during gantry rotation that no compensating spatial corrections are required.

Although the present invention has been described with reference to specific exemplary embodiments, it will be evident that various modifications and changes may be made to these embodiments without departing from the broader scope of the invention as set forth in the claims. Accordingly, the specification and drawings are to be regarded in an illustrative rather than a restrictive sense.

What is claimed is:

1. An apparatus, comprising:

a radiation treatment system capable of implementing a treatment plan, the system comprising:

a frame;

a rotatable gantry coupled to the frame;

a high-energy radiation source coupled to the rotatable gantry to radiate a patient with therapeutic radiation;

a cone-beam radiation source coupled to the rotatable gantry to radiate the patient;

a flat-panel imager coupled to the rotatable gantry, wherein the flat-panel imager is operable to capture image projection data of the patient from the cone-

beam radiation source to generate cone-beam computed tomography (CT) volumetric image data of the patient; and

a computing unit, coupled to the rotatable gantry via a communications network, to store the image projection data captured by the flat-panel imager.

2. The apparatus of claim **1**, wherein the flat-panel imager is capable of fluoroscopic imaging, radiographic imaging, and cone-beam CT imaging.

3. The apparatus of claim **1**, wherein the computing unit generates a treatment plan based on the image projection data.

4. The apparatus of claim **1**, wherein the computing unit generates a three-dimensional image of a target volume based on the captured image projection data.

5. The apparatus of claim **1**, wherein the cone-beam CT radiation source is a kilovoltage radiation source and the high-energy radiation source is a megavoltage radiation source.

6. The apparatus of claim **1**, wherein the rotatable gantry is capable of 360 degree rotation.

7. The apparatus of claim **1**, wherein the high-energy source comprises a megavoltage radiation source to radiate a target volume with radiation.

8. The apparatus of claim **1**, wherein the frame comprises a drive stand pivotably coupled to the rotatable gantry at a pivotable attachment at which the gantry pivots about an isocenter.

9. The apparatus of claim **1**, wherein the cone-beam source and high-energy radiation source are different from one another, and the cone-beam source comprises a KV source and wherein the high-energy radiation source comprises a MV source coupled to the rotatable gantry to radiate a patient with therapeutic radiation.

10. The apparatus of claim **1**, wherein the rotatable gantry is coupled to the frame at a rotational axis of the gantry; wherein the cone-beam radiation source is a cone-beam imaging source coupled to a first end of a first arm, the first arm having a second end coupled to the gantry; wherein the flat-panel imager is coupled to a first end of a second arm, the second arm having a second end coupled to the gantry; and wherein the high-energy radiation source comprises a high-energy cone-beam source.

11. An apparatus, comprising:

a radiation treatment system capable of implementing a treatment plan, the system comprising:

a frame;

a rotatable gantry coupled to the frame;

a high-energy radiation source coupled to the rotatable gantry to radiate a patient with therapeutic radiation;

a cone-beam radiation source coupled to the rotatable gantry to radiate the patient; and

a flat-panel imager coupled to the rotatable gantry, wherein the flat-panel imager is operable to capture image projection data of the patient from the cone-beam radiation source to generate cone-beam computed tomography (CT) volumetric image data of the patient, wherein the flat-panel imager includes an amorphous silicon sensor array, and wherein the flat-panel imager includes a cesium iodide scintillator for kilovoltage imaging.

12. The apparatus of claim **11**, wherein the scintillator includes cesium iodide crystals coated with a reflective powder and epoxy mixture in a large matrix for megavoltage imaging.

13. An apparatus, comprising:

a radiation treatment system capable of implementing a treatment plan, the system comprising:

a frame;

a rotatable gantry coupled to the frame;

a high-energy radiation source coupled to the rotatable gantry to radiate a patient with therapeutic radiation;

a cone-beam radiation source coupled to the rotatable gantry to radiate the patient; and

a flat-panel imager coupled to the rotatable gantry, wherein the flat-panel imager is operable to capture image projection data of the patient from the cone-beam radiation source to generate cone-beam computed tomography (CT) volumetric image data of the patient, wherein the flat-panel imager is capable of generating image projection data at 15 to 30 frames per second.

14. An apparatus, comprising:

a radiation treatment system capable of implementing a treatment plan, the system comprising:

a frame;

a rotatable gantry coupled to the frame;

a high-energy radiation source coupled to the rotatable gantry to radiate a patient with therapeutic radiation;

a cone-beam radiation source coupled to the rotatable gantry to radiate the patient;

a flat-panel imager coupled to the rotatable gantry, wherein the flat-panel imager is operable to capture image projection data of the patient from the cone-beam radiation source to generate cone-beam computed tomography (CT) volumetric image data of the patient; and

a translatable treatment couch coupled to the rotatable gantry via a communications network.

15. The apparatus of claim **14**, wherein the translatable treatment couch is capable of movement in three planes plus angulation.

16. An apparatus, comprising:

a radiation treatment system capable of implementing a treatment plan, the system comprising:

a frame;

a rotatable gantry coupled to the frame;

a high-energy radiation source coupled to the rotatable gantry to radiate a patient with therapeutic radiation;

a cone-beam radiation source coupled to the rotatable gantry to radiate the patient;

a flat-panel imager coupled to the rotatable gantry, wherein the flat-panel imager is operable to capture image projection data of the patient from the cone-beam radiation source to generate cone-beam computed tomography (CT) volumetric image data of the patient, wherein the a flat-panel imager is a flat-panel KV imager; and

a flat-panel MV portal imager coupled to the rotatable gantry, wherein the MV imager is operable to capture image projection data of the patient produced by the high-energy MV radiation source.

17. A method to perform a clinical treatment, comprising:

rotating a gantry pivotably coupled at a pivot point to a frame of a clinical radiation treatment machine capable of implementing a treatment plan;

irradiating a patient with a radiation source;

using the clinical radiation treatment machine to capture image projection data from a flat-panel imager for generating cone-beam computed tomography (CT) volumetric image data; and

modifying a treatment plan for the clinical treatment machine based on the cone-beam volumetric image data.

18. The method of claim 17, further comprising:
generating a treatment plan for the clinical treatment machine based on the cone-beam volumetric image data; and
transferring the treatment plan to the clinical treatment machine, wherein the clinical treatment machine implements the treatment plan.

19. The method of claim 17, wherein the radiation source is a cone-beam computed tomography radiation source, and wherein the image projection data is generated from a flat-panel imager capturing radiation from the cone-beam computed tomography radiation source passing through a target volume.

20. The method of claim 19, wherein the radiation source is a kilovoltage radiation source.

21. The method of claim 17, wherein the image projection data is fluoroscopic image projection data.

22. The method of claim 17, further comprising:
generating a treatment plan for the clinical treatment machine based on the cone-beam volumetric image data; and
using the treatment plan to instruct the clinical treatment machine to at least adjust a therapeutic radiation source into position to align a treatment volume with the therapeutic radiation.

23. The method of claim 17, further comprising:
generating a treatment plan for the clinical treatment machine based on the cone-beam volumetric image data.

24. The method of claim 17, further comprising:
positioning a patient based on the cone-beam volumetric image data.

25. The method of claim 17, wherein the clinical radiation treatment machine comprises a drive stand pivotably coupled to the rotatable gantry at a pivotable attachment at which the gantry pivots about an isocenter.

26. A method to perform a clinical treatment, comprising:
rotating a gantry pivotably coupled at a pivot point to a frame of a clinical radiation treatment machine capable of implementing a treatment plan;
irradiating a patient with a radiation source; and
capturing image projection data from a flat-panel imager using the clinical radiation treatment machine, the image projection data for generating cone-beam computed tomography (CT) volumetric image data, wherein capturing comprises capturing the image projection data at a frame rate in the range of 15-30 frames per second.

27. A method to perform a clinical treatment, comprising:
rotating a gantry pivotably coupled at a pivot point to a frame of a clinical radiation treatment machine capable of implementing a treatment plan;
irradiating a patient with a radiation source;
using the clinical radiation treatment machine to capture image projection data from a flat-panel imager for generating cone-beam computed tomography (CT) volumetric image data, wherein the radiation source is a cone-beam computed tomography radiation source, wherein the image projection data is generated from a flat-panel imager capturing radiation from the cone-beam computed tomography radiation source passing through a target volume;
deriving a master clock signal from a synchronization signal of the radiation source;
using the master clock signal to generate a first control pulse to gate the radiation source on and off and a second control pulse to trigger reading of an image from the imager; and
selecting a timing of the first control pulse as compared to the second control pulse to read out the image while the radiation source is off.

28. A method to perform a clinical treatment, comprising:
rotating a gantry pivotably coupled at a pivot point to a frame of a clinical radiation treatment machine capable of implementing a treatment plan;
irradiating a patient with a radiation source;
using the clinical radiation treatment machine to capture image projection data from a flat-panel imager for generating cone-beam computed tomography (CT) volumetric image data, wherein the radiation source is a cone-beam computed tomography radiation source, wherein the image projection data is generated from a tlat-panel imager capturing radiation from the cone-beam computed tomography radiation source passing through a target volume;
continuously rotating the radiation source about the target volume while capturing image projection data; and
one of capturing image projection data at non-uniformly spaced angles with respect to the rotation, and changing the speed of rotation of the gantry during a rotation.

29. A method to perform a clinical treatment, comprising:
rotating a gantry pivotably coupled at a pivot point to a frame of a clinical radiation treatment machine capable of implementing a treatment plan;
irradiating a patient with a radiation source;
using the clinical radiation treatment machine to capture image projection data from a flat-panel imager for generating cone-beam computed tomography (CT) volumetric image data, wherein the radiation source is a cone-beam computed tomography radiation source, wherein the image projection data is generated from a flat-panel imager capturing radiation from the cone-beam computed tomography radiation source passing through a target volume; and
continuously rotating the radiation source about the target volume while capturing image projection data.

30. An apparatus, comprising:
one of a radiation simulation system comprising logic configured to determine a patient position relative to a high-energy radiation treatment beam and a radiation treatment system comprising logic configured to implement a treatment plan for a high-energy radiation treatment, the logic comprising at least one of hardwired logic and a programmable computer component, the system comprising:
a frame;
a rotatable gantry pivotably coupled to the frame at a pivot point;
means for applying a cone-beam computed tomography (CT) radiation beam coupled to the rotatable gantry; and
means for capturing image projection data with a flat-panel imager, coupled to the rotatable gantry, to generate cone-beam computed tomography (CT) volumetric image data of a patient's anatomy.

31. The apparatus of claim 30, wherein the means for capturing includes an amorphous silicon sensor array.

32. The apparatus of claim 31, wherein the means for capturing includes a cesium iodide scintillator for kilovoltage imaging.

33. The apparatus of claim 32, wherein the scintillator includes cesium iodide crystals coated with a reflective powder and epoxy mixture in a large matrix.

34. The apparatus of claim 30, wherein the means for capturing is capable of fluoroscopic imaging, radiographic imaging, and cone-beam CT imaging.

35. The apparatus of claim 30, wherein the means for capturing captures the image data at 15 to 30 frames per second.

36. The apparatus of claim 30, further comprising:

means for storing the captured image projection data is coupled to the rotatable gantry via a communications network.

37. The apparatus of claim 30, further comprising:

means for generating a treatment plan based on the image projection data coupled to the means for capturing via a communications network.

38. The apparatus of claim 37, wherein the means for generating generates a three-dimensional age of a target volume based on the captured image projection data.

39. The apparatus of claim 30, wherein the means for applying includes a kilovoltage radiation source.

40. The apparatus of claim 30, further comprising a translatable treatment couch coupled to the rotatable gantry via a communications network.

41. The apparatus of claim 40, wherein the translatable treatment couch is capable of movement in three planes plus angulation.

42. The apparatus of claim 30, wherein the rotatable gantry is capable of 360-degree rotation.

43. The apparatus of claim 30, further comprising:

means for generating a treatment plan for a clinical treatment machine based on the cone-beam volumetric image data; and

means for treating a patient according to the treatment plan including providing synchronization and gate control between the imager and the radiation beam during treatment.

44. The apparatus of claim 43, wherein treating includes means for coordinating acquisition by the flat panel imager and pulsing by the radiation source.

45. The apparatus of claim 30. wherein the radiation simulation system comprises logic configured to determine a patient position relative to a high-energy radiation treatment beam of a treatment machine to be simulated by the simulation system, the logic comprising at least one of hardwired logic and a programmable computer component; and wherein the radiation treatment system includes a high-energy radiation treatment beam source.

46. A machine-readable medium selected from the group consisting of solid-state memories, optical disks, and magnetic disks; the machine-readable medium having instructions to cause a machine to perform a method to perform a clinical treatment, the method comprising:

rotating a gantry pivotably coupled at a pivot point to a frame of a clinical radiation treatment machine capable of implementing a treatment plan;

irradiating a patient with a radiation source; and

instructing the clinical radiation treatment machine to capture image projection data from a flat-panel imager for generating cone-beam computed tomography (CT) volumetric image data.

47. The machine-readable medium of claim 46, further comprising:

generating a treatment plan for the clinical treatment machine based on the cone-beam volumetric image data; and

transferring the treatment plan to the clinical treatment machine, wherein the clinical treatment machine implements the treatment plan.

48. The machine-readable medium of claim 46, wherein capturing comprises capturing the image projection data at a frame rate in the range of 15-30 frames per second.

49. The machine-readable medium of claim 46, further comprising:

generating a treatment plan for the clinical treatment machine based on the cone-beam volumetric image data; and

using the treatment plan to instruct the clinical treatment machine to at least adjust a therapeutic radiation source into position to align the treatment volume with the therapeutic radiation.

50. The machine-readable medium of claim 46, wherein instructing further comprises instructing the clinical radiation treatment machine to capture partial cone image data to reconstruct one of a head size and a body size.

51. The machine-readable medium of claim 46, further comprising instructing a megavoltage radiation source to radiate a target volume with radiation.

52. The machine-readable medium of claim 46, wherein the clinical radiation treatment machine comprises a drive stand pivotably coupled to the rotatable gantry at a pivotable attachment at which the gantry pivots about an isocenter.

53. An apparatus, comprising:

a clinical radiation treatment system capable of implementing a treatment plan, the system comprising:

a frame;

a rotatable gantry coupled to the frame;

a high-energy radiation source coupled to the rotatable gantry to radiate a patient with therapeutic radiation;

a cone-beam radiation source coupled to the rotatable gantry to radiate the patient; and

a flat-panel imager coupled to the rotatable gantry, wherein the flat-panel imager captures fluoroscopic or cone-beam CT imaging image projection data of the patient from the cone-beam radiation source to generate fluoroscopic or cone-beam computed tomography (CT) volumetric image data of the patient.

54. The apparatus of claim 53, wherein the flat-panel imager includes an amorphous silicon sensor array capable of fluoroscopic imaging, radiographic imaging, and cone-beam CT imaging.

55. The apparatus of claim 54, wherein the cone-beam CT radiation source is a kilovoltage radiation source, and the flat-panel imager includes a cesium iodide scintillator for kilovoltage imaging.

56. The apparatus of claim 55, wherein the scintillator includes cesium iodide crystals coated with a reflective powder and epoxy mixture in a large matrix for megavoltage imaging.

57. The apparatus of claim 53, further comprising:

a treatment plan for the clinical treatment machine based on the cone-beam volumetric image data; and

a computing unit, coupled to the rotatable gantry via a communications network, to store the image projection data captured by the flat-panel imager, wherein the computing unit generates the treatment plan based on the image projection data.

58. The apparatus of claim 57, wherein the computing unit generates a three-dimensional image of a target volume based on the captured image projection data.

59. The apparatus of claim 58, wherein the high-energy radiation source comprises:

a megavoltage radiation source coupled to the rotatable gantry to radiate the volume with radiation, wherein the megavoltage radiation source comprises a source of between 4 and 25 mega-volts of radiation.

60. The apparatus of claim 53, further comprising a translatable treatment couch coupled to the rotatable gantry via a

communications network, wherein the translatable treatment couch is capable of movement in three planes plus angulation.

61. The apparatus of claim **53**, wherein the rotatable gantry is capable of 360 degree rotation and the imager is capable of capturing image projection data while continuously rotating about a target volume.

62. The apparatus of claim **53**, wherein the cone-beam source and high-energy radiation source are different from one another, and the cone-beam source comprises a KV source and wherein the high-energy radiation source comprises a MV source coupled to the rotatable gantry to radiate a patient with therapeutic radiation.

63. An apparatus, comprising:

a radiation treatment simulation system comprising logic configured to determine a patient position relative to a high-energy radiation treatment beam, the logic comprising at least one of hardwired logic and a programmable computer component, the system comprising:

a frame;

a rotatable gantry pivotably coupled to the frame at a pivot point;

a cone-beam imaging radiation source coupled to the rotatable gantry to radiate a patient; and

a flat-panel imager coupled to the rotatable gantry, wherein the flat-panel imager is operable to capture image projection data of the patient to generate cone-beam computed tomography (CT) volumetric image data of the patient.

64. The apparatus of claim **63**, wherein the flat-panel imager includes an amorphous silicon sensor array and a cesium iodide scintillator, and wherein the imager is capable of fluoroscopic imaging, radiographic imaging, and cone-beam CT imaging.

65. The apparatus of claim **64**, wherein the imager captures fluoroscopic or cone-beam CT imaging kilovoltage image projection data to generate fluoroscopic or cone-beam computed tomography (CT) volumetric image data

66. The apparatus of claim **63**, further comprising:

a computing unit, coupled to the rotatable gantry via a communications network, to store the image projection data captured by the flat-panel imager and to generate a three-dimensional image of a target volume based on the captured image projection data.

67. The apparatus of claim **63**, wherein the rotatable gantry is capable of 360 degree rotation and the imager is capable of capturing image projection data while continuously rotating about a target volume.

68. A method to perform a clinical treatment simulation, comprising:

rotating a gantry pivotably coupled at a pivot point to a frame of a clinical treatment simulator machine comprising logic configured to implement a treatment plan for a high-energy radiation treatment beam, the logic comprising at least one of hardwired logic and a programmable computer component;

irradiating a patient with a radiation source; and

using the clinical treatment simulator machine to capture image projection data from a flat-panel imager for generating cone-beam computed tomography (CT) volumetric image data.

69. The method of claim **68**, further comprising:

generating a treatment plan for a clinical treatment machine based on the cone-beam volumetric image data;

transferring the treatment plan to the clinical treatment machine, wherein the clinical treatment machine implements the treatment plan; and

using the treatment plan to instruct the clinical treatment machine to at least adjust a therapeutic radiation source into position to align a treatment volume with the therapeutic radiation.

70. The method of claim **68**, wherein the image projection data is generated from the flat-panel imager capturing radiation from a cone-beam computed tomography radiation source passing through a target volume.

71. The method of claim **70**, further comprising:

continuously rotating the radiation source about the target volume while capturing image projection data.

72. The method of claim **68**, wherein rotating further comprises pivoting the gantry about an isocenter using a drive stand pivotably coupled to the rotatable gantry by a pivotable attachment.

73. The method of claim **68**, further comprising:

using the flat-panel imager to capture fluoroscopic, radiographic, and cone-beam CT imaging image projection data to generate fluoroscopic, radiographic, and cone-beam computed tomography (CT) volumetric image data.

74. A method to perform a clinical treatment simulation, comprising:

rotating a gantry pivotably coupled at a pivot point to a frame of a clinical simulator machine comprising logic configured to determine a patient position relative to a high-energy radiation treatment beam, the logic comprising at least one of hardwired logic and a programmable computer component;

irradiating a patient with a radiation source; and

using the clinical simulator machine to capture fluoroscopic or cone-beam CT imaging image projection data from a flat-panel imager for generating fluoroscopic or cone-beam computed tomography (CT) volumetric image data.

75. The method of claim **74**, further comprising:

generating a treatment plan for a clinical treatment machine based on the cone-beam volumetric image data;

transferring the treatment plan to the clinical treatment machine, wherein the clinical treatment machine implements the treatment plan; and

using the treatment plan to instruct the clinical treatment machine to at least adjust a therapeutic radiation source into position to align a treatment volume with the therapeutic radiation.

76. The method of claim **74**, wherein rotating further comprises pivoting the gantry about an isocenter using a drive stand pivotably coupled to the rotatable gantry by a pivotable attachment.

77. The method of claim **74**, further comprising:

using the flat-panel imager to capture fluoroscopic, radiographic, and cone-beam CT imaging image projection data to generate fluoroscopic, radiographic, and cone-beam computed tomography (CT) volumetric image data.

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