Towards 3D web-based simulation and training systems for radiation oncology

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Abstract. Radiation therapy is an effective cancer treatment solution, involving complex machinery and careful planning. Physicians find difficulty in visualizing the relative three-dimensional positions of linac (linear accelerator) components. We propose a graphical simulator for linacs that will improve the planning process, saving time and resources in generating the optimal treatment plan, and serve as a learning tool. Embedding patient-specific data (CT scans) in the interactive simulator advances the radiation therapy planning process by early detection of collision cases.

Keywords: X3D; web-based simulation; 3D modeling; radiation therapy

1. Introduction

The complexity of interaction between the hardware components of external beam radiation therapy (EBRT) machinery, such as linacs (linear accelerators), makes it difficult for radiation oncology students and trainees to visualize spatial beam orientations during the treatment planning process. The lack of collision detection (CD) tools at the planning stage burdens the planner with the challenge of creating a collision-free treatment plan.

2. Purpose

This work focuses on the development and assessment of a graphical simulator for linacs that will aid in the planning process and could serve as a learning tool. The simulator offers a web-based interface that can be used in the planning process to visualize the behavior of the linac components and detect collision scenarios. All the components of the simulator are designed in accordance with the actual hardware motion and angle conventions and can be controlled individually using a mouse or typing in specific values, allowing the user to explore a host of gantry-table-collimator combinations in 3D. Beam-table intersections can also be easily detected by simulating the radiation beam as a prism of light projected at the isocenter and collimated to match the beam geometry.

Analytical methods of CD for linac-based radiation surgery have been proposed as a means to improve the EBRT planning process [1-4]. Some of these methods, even though accurate, are based on the hardware numeric rotational and translational values disregarding patient-specific as well as detailed hardware-specific geometry. Previous research and development concerning graphical simulations of linac systems have the following limitations:

(1) Setups and additional software and hardware components are sophisticated and require additional expertise and setup;

(2) The simulations involve only generic patient body representations [5] and not accurate hardware 3D models; hence, collisions with patients are not accurately modeled or predicted;

(3) The simulators are standalone applications and cannot be deployed over the web for potential collaboration with remote experts during treatment planning.

One of the most accurate representations of the patient and hardware is under development of the researchers at the Hull university [6]; however, the implementation is proprietary to CMS™ and cannot be deployed freely over the web. Our efforts are directed towards a distributed web-based simulator that will allow easy access from a web browser to the virtual room and will improve the actual planning process of the EBRT by providing a high-resolution model of all treatment components, including patient-specific geometry.

3. Implementation

3.1 Methods

With the advent of the X3D [7] standard and its extended functionality, the Internet-Based systems for simulation gained momentum. X3D is being developed by the Web3D Consortium (originally the VRML Consortium) as a more mature and refined standard. The simulator implementation takes advantage of X3D, and in the development process we employ several software tools for 3D modeling. Fig. 1 illustrates a snapshot of the virtual room (denoted 3D Radiation Therapy Treatment — 3DRTT) which models the real environment.

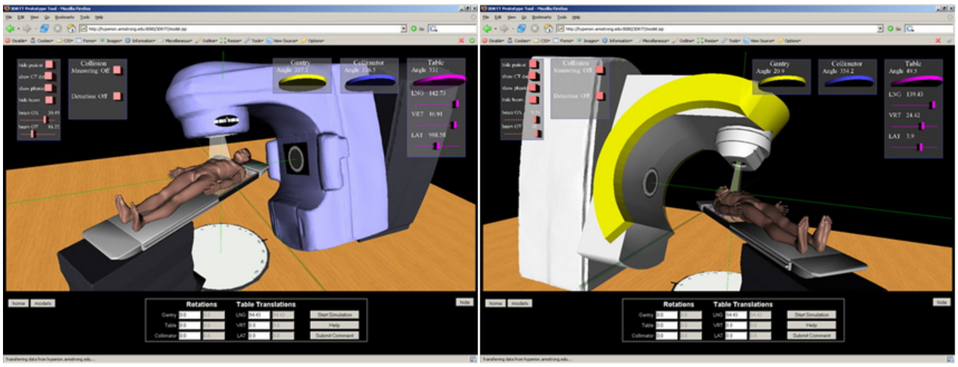

Fig. 1. Graphical simulators for Varian™ 23iX (left), and Varian™ 600N (right).

3.2 Graphical User Interface

The simulator provides an intuitive floating graphical user interface (GUI) for controlling the angles and locations of the machine's parts (Fig. 1). The GUI is designed in the form of multiple semitransparent windows holding various volumetric controls. Segregating the controls into the semantically logical groups improves overall intuitiveness. Specifically, the scrolls manage rotations; slides are responsible for translations; and buttons switch between different simulation modes. The GUI components can be easily rearranged to avoid occlusions of important objects.

The measuring mode allows users to measure the exact distance between any two points in the virtual space. Such measurements are useful for simulation assessment purposes and in collision scenarios, when spatial misinterpretation is possible.

The CD mode activates an automatic collision warning system to guard for the user's potential misinterpretation of the visual collision scenario. The CD system is based on bounding primitives, and the algorithm has been optimized to work in a web-based environment. The CD accounts for collisions between the gantry and the table. The system brings any small clearance case to the therapist's attention. The measuring tool can be used to obtain accurate measurements following a collision warning.

Finally, there is an additional menu that allows the user to visualize on the table 3D patient data, Digital Imaging and Communication in Medicine Radiation Therapy (DICOM RT) CT data scans, and phantom device (Fig. 2), used by therapists for testing purposes. The user can also enable the beam projected by the collimator and control the size of the beam spot, changing the X and Y dimensions with special sliders.

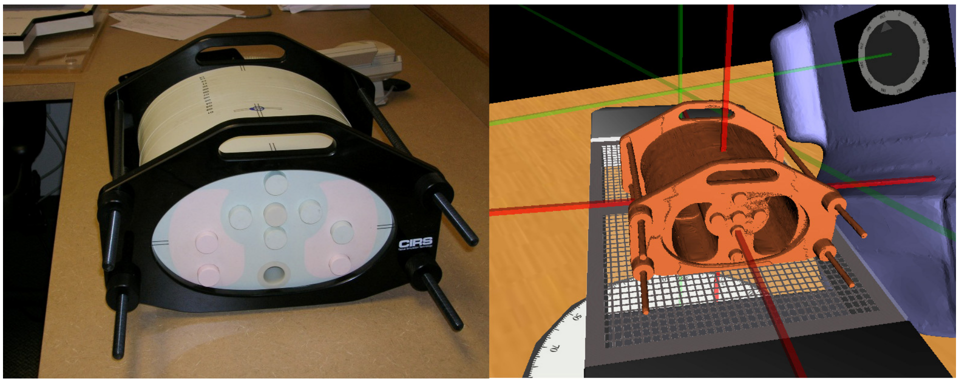

Fig. 2. The phantom device: physical (left) and modeled (right).

3.3 Polygonal Models Acquisition and Processing

Laser scanners from Faro™ Technologies and Minolta™ were employed to collect point clouds from several viewpoints. Once the point clouds are collected, they are merged into one cloud based on a set of specially designated markers. We filter the noise and wrap the valid points into a polygonal model. Due to the inaccuracies of the laser scanner (approx. 3mm), we smooth the 3D objects, obtaining better consistency with the real equipment. To improve the rendering process, we decimate the model by removing redundant polygons in flat areas while securing the regularity of the regions with sophisticated geometry. The polygonal model is exported into an X3D object and employed as a part of the virtual scene. Considering the geometrical complexity and the high-polygonal resolution of the model, we have to optimize it such that adequate frame rates (25 FPS or more) are obtained on machines with less rendering power. To further improve the rendering speed and reduce the file size, we make use of textures, simulating the geometry of complex areas. Special processing might be needed in some cases. For instance, the table contains a special glass-like component. Because this glass-like material does not attenuate the beam in reality, we tune the transparency of the detail's surface to resemble the glass and combine it with a translucent cellular texture laid underneath, as illustrated in Fig. 2 (right).

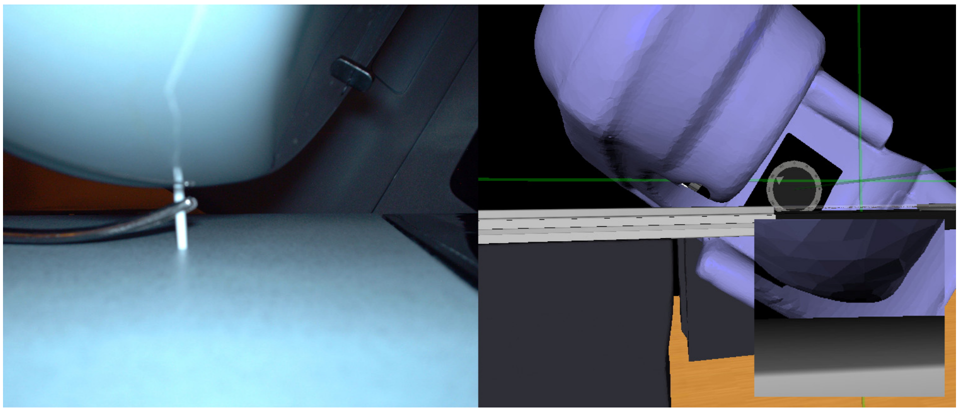

Fig. 3. Visual collision validation: the real linac (left), and the simulator (right).

3.4 Patient 3D model generation from CT scans

An important issue we address in this work is inclusion of real patient data in the simulation. We have to efficiently convert a set of CT scans of a patient to the polygonal model of the patient's body. The set of CT scans used is stored using DICOM RT standard [8]. As opposed to other types of image files, the DICOM RT file standard contains slice resolution, slice spacing, and pixel size which all are useful parameters in producing a realistic polygonal model of a patient. We process the CT scans using the Visualization Toolkit (VTK) [9]. We apply the Marching Cubes algorithm with a value that selects the isosurface of the patient's skin. Then the model can be embedded in the simulator.

4. Results

We have deployed a prototype of the system on a secure website (http://hyperion.armstrong.edu:8080/3DRTT) in 2005 and in the first phase allowed medical personnel from M. D. Anderson Cancer Center, Orlando, to remotely access the simulator. Since then, several other medical groups and institutions have expressed interest in the simulator; so, we have provided them with access and a feedback mechanism to improve the simulator. To objectively test collision scenarios, we asked a radiation therapy technician and a therapist to simulate a plan that contains collisions among the system components (illustrated in Fig. 3). The simulator provides an accurate representation of the linac (specifically the Varian™ 23iX linac) that can predict any collision scenarios with one and a half centimeter accuracy.

5. Conclusion

We have presented a system for EBRT treatment simulation that can be also used as a remote teaching tool for distance learning. The ability to precisely detect/predict a possible collision between all linac components for a given patient eliminates the need for backup plans and saves planning time. In addition, it enables the planner to explore differing and unconventional gantry-table-collimator combinations for treatment that may give rise to better quality plans.

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