

Web-based 3D Planning Tool for Radiation Therapy Treatment

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Abstract

One of the biggest concerns in external treatment planning is the collision avoidance of the treatment Linear Accelerator (LINAC®) components such as gantry (G), table (T), collimator (C), and any other auxiliary components such as fixation devices etc, with the patient. Some external treatment plans require complex components of the above GTC combinations.

We are presenting a preliminary design and implementation of a 3D-graphical tool for the detection of potential gantry-collimator-couch collisions in external treatment planning. The graphical tool uses the Virtual Reality Modeling Language (VRML) to model the exact geometry of any treatment machine by reading its manufacturer's CAD design files. Unlike other anti-collision methods developed so far in the literature, our tool would be able to model the details of the treatment linac and add-on devices for patient-specific setups. Hence, the tool will create patient-specific realistic collision map for any external treatment scenario. The tool can be used as a stand-alone program or embedded in the Eclipse treatment planning system.

Keywords: collision avoidance, treatment planning, VRML, Web 3D simulation.

1. Introduction

The field of radiation therapy is currently going through a revolution of image-guided therapy that heavily relies on the manipulation of 3D patient-related imaging information to determine the best course of treatment. In addition, external treatment planning is getting exceedingly complex as more components to the treatment unit are being added to assess in delivering precise treatments. Some of these components include, but are not limited to, Kilo-Volt (KV) imaging devices such as the Varian's Trilogy system (Varian Medical Systems, located in Palo

Alto, CA), head and neck fixation devices. In addition, some of the specialized linear accelerators (LINAC®) such as Novalis Brainlab™, have a non-conventional rounded collimator. Those components give rise to additional difficulty to the planner, since s/he will have to incorporate all of these components in the treatment plans.

The principle of operation for such devices is fairly simple. Based upon the patient's tumor location, the hardware components change position and orientation while delivering pre-planned radiation doses to the tumor while minimizing the healthy tissue exposure. System components may collide with the patient and/or external objects in the treatment room; external objects may block the beam. However, sometimes the planner will generate a seemingly optimal plan, only to result in a collision when a "dry run" is executed on the LINAC. This is a serious problem as it results in a delay to patient treatment since the plan has to be revised to account for these unforeseen collisions. Additional time and resources must be invested to adjust or to create an alternative treatment plan. Figure 1 illustrates the general flow of external radiation therapy.

There is crucial planning information that the planner currently lacks to produce an optimal plan. Such information includes but is not limited to (1) the extent of patient external contours (i.e., skin) with respect to the LINAC modules and tumor location with respect to LINAC's isocenter (center of rotation). (2) Precise modeling of the LINAC components is not readily available. Hence, occasionally treatment plans may not be executable due to unpredictable collision which could have been avoidable if all 3D patient specific and machine specific geometrical data were available. The availability of an exact patient-LINAC geometrical visualization could potentially create a host of new non-conventional and treatable Gantry-Table-Collimator angles combinations.

In this paper we are presenting the design, implementation and new open research problems for a web-based 3D planning tool that facilitates the radiotherapy treatment planning. The graphical simulation represents patient specific treatment data as well as a simulation of the treatment machine dynamics using the Virtual Reality Modeling Language (VRML).

By visualizing a graphical simulation of the dynamics of the radiotherapy system with an embedded virtual patient model, the planner can modify "on the fly" treatment plans that result in collisions. The web-based simulator also provides an adjustable viewpoint that will allow dosimetrist and physicists to virtually

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“ride down the beam”. The simplicity and robustness of the visualization tool, as well as its potential for distributed deployment, (i.e. the simulation can be executed in a Web browser) makes it an attractive addition to existing radiotherapy planning products worldwide.

In Section 2 of the paper, we review related work and summarize the current problems with radiation therapy computer-controlled systems. In Section 3, we describe the VRML components of the simulator. Section 4 presents the integration of the tool using Java Server Pages and the VRML packages. Section 5 discusses preliminary experimental verification of the simulator. Finally, Section 6 provides insights into the potential integration of the visual simulation in current radiation therapy treatment tools and future work.

2. Related Work

Advances in computer systems and linear accelerators design permit almost fully automated radiation therapy. The therapist may supervise the entire process from outside the treatment room yet potentially intervene in case of emergencies.

The complexity of the hardware components as well as the location of the treatment volume makes it difficult to completely automate the process. Moreover, the beam of radiation may intersect external objects that modify its properties. Methods for detection of the intersection of the beam with external objects have been investigated previously [Muthuswamy, 1999].

Collisions among the hardware components of the radiation device and or the patient are also possible. Analytical methods for collision detection for LINAC-based radiation surgery have been proposed as a means to improve the planning process [Beange and Nisbet, 2000; Hua, Chang et al. 2004; Humm, Pizzuto et al. 1995; Purdy, Harms et al. 1993].

Graphical simulations of the LINAC system have been attempted previously however the existing simulations have the following limitations: (1) sophisticated setups and additional software and hardware component. (2) The simulations involve only average patient body representations [Tsiakalos, Scherebmann et al. 2001], hence collisions with the patients are not accurately modeled or predicted. (3) The simulations are local and can not be deployed via the web for potential collaboration with remote experts during treatment planning.

The current trend in medical education and training leans toward heavy use of 3D imaging techniques. A survey of medical applications that make use of three-dimensional (3D) graphics technology supported by the World Wide Web (Web3D) is presented in [John 2005]. The advantage of such systems relies on the ease of deployment in a distributed configuration on the Internet as well as the low costs associated with the software components involved. The Virtual Reality Modeling Language (VRML) employed in such applications is slowly being replaced by X3D and new standard for real-time communication of 3D data across distributed web based applications. Since the X3D standard is in an early stage of development we decided to use VRML and Java technology for the current project as described in the next section.

3. The VRML-based Simulation

Virtual Reality Modeling Language successfully extends the web into the domain of three-dimensional graphics. Its simplicity and robustness can be used in engineering and scientific visualization, CAD and architecture, medical visualization, training and simulation.

The creation of an image using VRML has many advantages. The language is platform independent, requiring no special hardware. The software used is easily accessible and free of charge for almost any operating system. A web browser, such as Netscape®, Internet Explorer®, Firefox® using a plug-in that is freely downloadable (e.g. Cosmo Player®, Cortona®) can open and navigate complex VRML worlds. Another advantage of the VRML format is size. The VRML files created by the program are relatively small in size, facilitating the process of transmission over the Internet. Images generated can easily be posted to a web site for team collaboration or inspection. With the costs of personal computers continuing to drop, doctors can present the data to patients for review at home. VRML worlds are not static. They can be manipulated and viewed from a variety of angles, allowing for a true 3-D perspective of an organ or procedure.

A new evolving standard, X3D is slowly replacing VRML. While X3D is a considerably more mature and refined standard than VRML there are still some incompatibility problems with existing image processing tools and web based players. As the X3D standard receives more support from existing image processing tool vendors a simple conversion of our existing prototype from VRML to X3D will occur.

3.1 The LINAC VRML Model

The first component of the visual simulation consists in the development of a VRML model for the radiation device. Based upon a set of CAD models for a Varian’s 2100C/D LINAC we developed an initial representation of the radiotherapy device and associated components using VRML geometric primitives. We can accurately model any treatment LINAC provided the accurate CAD models are available. The VRML model is presented in Fig. 2 and consists of three independent components, the gantry (yellow), the treatment table (blue) and the device base (red). The fact that each component is an independent polygonal model enables relative position changes for the device dynamics simulation.

Having the main components of the radiation device and the motorized table in a format “playable” in a web browser, we next focused attention on the dynamics of the system. The motion of the accelerator arm (the Gantry) and the position and orientation of the Table are collected from the dosimetrist by a graphical user interface. A 3D VRML model of the patient is generated from a sequence of patient specific CT scans.

Once the treatment parameters are read, VRML GeometricSensor nodes and TimeSensor nodes are used to generate events at specific time intervals to accurately simulate the movement of the gantry and the table during treatment as further described in Section 3.2

The software layers involved in the deployment of the tool are represented in Fig. 3. The Operating System, Java Virtual Machine, the Web Browser as well as the VRML player are components available on most desktop systems that do not require special configuration for the deployment of the simulation.

The simulator can be deployed in a simple web browser as a result of this straight forward configuration and is also platform independent.

3.2 Time Sensors and Routes

The motion of the gantry and the table requires the definition of multiple VRML “Sensor” nodes and “Route” commands.

A *Time Sensor (TS)* node is defined, that loops continuously starting as soon as the VRML file is loaded into the browser. The TS’s change in value is routed (*via a ROUTE command*) to an Orientation Interpolator (OI) node, which contains the starting and the ending values of the gantry rotation angle. The OI’s current position and axis of rotation is routed to the node defining the gantry’s shape, translation and rotation. Because the TS is active, and the OI’s start and end values are the same, the shape rotates in a complete circle.

A ‘*domino effect*’ [Carey and Bell 1997] that is a sequence of consecutive rotations for the gantry can be simulated using a sequence of TSs. Using a *Script* node with simple JavaScript code, the event generated by a timer completing its run is routed to the script. The *Script* node reads that timer’s *endTime* reference and sends it to the next timer’s *startTime* field, starting it right were the last one left off. Such sequences of consecutive rotations are useful for simulation of gantry and table rotations from a treatment plan to visually check for potential collisions.

The combination of TimeSensors and Routing commands provides a scalable cascading algorithm that can be added to any geometry with relative ease. The algorithm can be adapted to any Gantry-Table-Collimator angle convention (i.e. different manufacturers may have different angle conventions).

4. The Graphical User Interface

A first attempt at creating the graphical user interface (GUI) was done using VRML and Java Applets within a frame layout in a HTML page. The Applet was set to dynamically control the VRML world by using the *j3d-vrml97* package along with the “*vrml.external*” package [Boetislav and Chludil 2000; Brutzman 1998].

Since the application requires local and remote file access to load different patient data, the applet security restrictions regarding local file systems access made us decide on another approach: VRML and Java Server Pages (JSP). Figure 4 is a snapshot of a 3D web page that shows the resulting interface.

The data (gantry angle, table angle and table horizontal, vertical and lateral) are collected from the user through a JSP form and processed at the server side. As a result a new VRML page is generated on-the-fly that illustrates the movement of the gantry, table and collimator of the LINAC. The VRML player allows the user to navigate and inspect the LINAC configuration from different viewpoints and decide if the current setup is correct.

5. Preliminary Experimental Verification

We have deployed the system on a secure web site and allowed medical personnel from MD Anderson Cancer Center in Orlando remote access to the web 3D simulation tool.

To check the validity of the simulation we have compared the existing table of collisions provided by MD Anderson (see Table 1) medical personnel with the simulation results using a specific angle convention illustrated in Fig 5.

Table Angle Range	Gantry Angle Range
270- clockwise to 309-	315- clockwise to 45-
310- clockwise to 337-	180- clockwise to 70-
338- clockwise to 357-	315- clockwise to 90-
358- clockwise to 2-	180- clockwise to 178-
3- clockwise to 22-	270- clockwise to 179-
23- clockwise to 60-	290- clockwise to 179-
51- clockwise to 90-	315- clockwise to 46-

Table 1: Allowable gantry angle ranges for collision avoidance for Varian™ 2100EX

To validate the quality of our tool, we have modeled two combinations of table and gantry rotations in which a collision is eminent based on visual assessment as shown in Fig. 6a and Fig. 6b. It is clear from both scenarios that our tool predicts collisions in agreement with measured values in Table 1. For every hardware configuration angle, the dosimetrist is able to navigate through the VRML world and visually analyze the configuration, as shown in Fig. 7.

A more extensive assessment of the efficiency improvement brought by the simulation tool is under investigation and will be presented in future articles.

6. Conclusion and Future Work

We have developed a 3D graphical simulation web-based tool that can be used as a stand alone application to assist in external treatment planning by visually simulating collisions between various LINAC hardware modules. The robust system is based on VRML and Java programming that allows for accurate simulation of any LINAC hardware module based on the manufacturer’s CAD drawings.

The tool has the ability to pre-determine the 3D collision space for any patient and is independent of any computing platform which makes it easy to deploy in conjunction with any treatment planning system.

We are currently building a VRML data base of CT scans for all disease sites. This will provide information to map all possible collision possibilities for all diseases locations with respect to LINAC isocenter. In addition, a VRML library of equipments and components of any linac can be easily created with the intention of including all possible patient setup gadgets that are currently available on the market.

Our future plans include extending the tools ability to import the patient CT images and convert those images on-the-fly into a 3D VRML patient model. A simulation of a “ride” down the beam visualization is currently under investigation. This facility would

allow for a detailed 3D visualization of the target and critical structures. Hence, the planner can search for beam paths with minimal critical structure interference.

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