

# The Virtual Simulator

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# The Virtual Simulator

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## Abstract

We have undertaken to provide radiotherapists with Computer-Aided Design and 3D display tools to advance radiation treatment planning. A major part of this effort is a CAD tool for radiation treatment design that allows physicians to comfortably explore alternatives to traditional treatment geometries. Care has been taken to create an intuitive and highly interactive user interface and to incorporate high quality 3D display techniques. We have explored various control configurations for the input devices to make interactions more natural. We believe that such software will allow radiation therapy physicians to more precisely and optimally design and direct radiation treatments, leading to higher cancer cure rates with fewer side effects of treatment.

## Introduction

When radiation is to be used to treat a cancer patient, it is of great importance to specify precisely which organs and tissues are irradiated. In simplest terms, one wishes to maximize the radiation dose to the tumor area while minimizing the dose to healthy tissue. To do this accurately one must be able to visualize the 3D intersection of a radiation treatment beam<sup>1</sup> with patient anatomy. In conventional treatment planning, a modified X-ray device called a simulator is used for this purpose (Figure 1). The simulator mimics the geometry of the radiation treatment machine by replacing the powerful radioactive source with a standard X-ray imaging tube. A combination fluoroscope/film-tray

assembly is mounted opposite to the X-ray source. Films are taken while the patient and machine are in the proposed treatment position. Each film is then a projection of the anatomical structures onto the plane of the film, from the point of view of the X-ray source. This projection shows which anatomical structures will be irradiated by the proposed beam. For beam angles where the projections are well understood by physicians (front to back, back to front, and side to side), this is frequently adequate. However, for beam angles other than those mentioned, the projection of the three-dimensional body structures on a two-dimensional film becomes very difficult to understand. As a result radiotherapists have been reluctant to stray from the traditional cardinal angle approach even though more general angles may yield some therapeutic advantage [Ling, Rogers, and Morton].

We have undertaken a long-term project to provide Computer-Aided Design and 3D display tools to radiotherapists to allow them to comfortably explore alternatives to traditional treatment geometries. The keystone of this effort is a CAD tool for radiation treatment design. It provides the same high level functionality as a conventional simulator with the important difference that it operates not on the real person but on a computer model of that person which can be rendered in a variety of ways. Since the CAD tool operates on a virtual patient (and since "simulator simulator" is gruesome) we call it a *virtual simulator*.

Several investigators have described computer graphics techniques for designing radiation treatments [Chin, et al.] [Goitein, et al.] [McShan, Fraas, and Lichter] [Siddon]. Our work differs primarily in the level of

<sup>1</sup> The beam is a localized, collimated beam of high energy radiation emanating from an orientable source.

attention paid to the creation of an intuitive and highly interactive user interface and to the incorporation of high quality 3D display techniques.

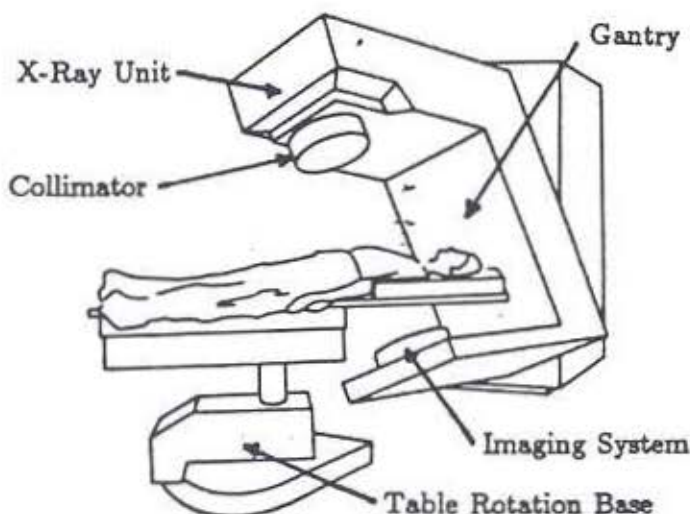


Figure 1. A conventional simulator

### The Virtual Simulator

The virtual simulator provides for three-dimensional visualization of the intersection of one or more beams with patient anatomy, and for the interactive design of those beams. This can be done in several ways: from the "beam's eye view", as projections on the CT slices, and from the point of view of a physician standing at table-side. Beam's eye view is the result of placing the viewer's eye at the (simulated) radiation source and generating a perspective view of the virtual patient. This relieves the clinician of the burden of explicitly considering the three-dimensional geometry of the patient. Any object that is seen inside a beam outline on the display will be encountered by the beam. In fact, our application is rather unique in that instead of merely providing depth cueing, the standard perspective viewing transformation precisely models the path of the divergent radiation field emanating from the radiation source.

The virtual simulator operates on a stack of two-dimensional contours that define

the tumor and organs that the physician desires to consider in planning the treatment. These contours are usually obtained from an automatic contouring routine that operates on CT slices. They can also be created by other methods (e.g., body outlines traced on a data tablet). The objects defined by the contours are displayed, with the viewpoint placed at the (virtual) source of the radiation. The model of the patient can then be rotated and translated to find the desired beam angle for treatment. Treatment machine positional settings are derived from the selected viewing transformation. Once the beams are defined, the virtual simulator draws the edges of the intersection of the beam outlines with each of the displayed CT slices, enabling the physician to see in greater detail the irradiated anatomy.

The beam description (consisting of the beam outline and positioning information) is used to generate templates for the construction of custom shielding, and to transfer the portal outlines<sup>2</sup> to the patient's skin for orientation. When the beam descriptions are combined with the patient's CT data, we can produce calculated simulation radiographs, calculated verification films, and calculated dose distributions for further treatment planning and verification.

### Display Issues

The key features of any display modality that we use are speed of update and image quality. These are almost always diametrically opposed goals. Since we require the interaction to be in real-time, we must sacrifice some image quality to update the images quickly enough. The most reasonable rendition of objects for rapid interaction in our system is as wire loops.

<sup>2</sup> These are indelible markings made on the patient's skin, used for beam registration on the treatment machine when the patient comes in for treatment.

For the prototype we use a raster implementation of a three-dimensional CORE extension vector graphics package that runs on the Adage/Ikonas RDS-3000 frame buffer and Bipolar Bit-slice Microprocessor. The planned acquisition of a graphics engine with hardware support for vector operations is expected to dramatically improve our update speed (which is marginal at present).

The current CAD tool implementation provides two (interchangeable) display screens (Figures 2 and 3). Figure 2 shows screen 1, which includes a (selectable) subset of the CT scans of the patient, a window where one scan can be enlarged to examine structures and beam projections in detail, a menu window, and one large and two small selectable windows. The user chooses what is to be displayed in these last three windows, selecting among beam's eye view, one of the other two orthogonal views, or one of two orthogonal iconic representations of the treatment machine (shown in the smaller windows of Figure 3).

The machine icons are updated with the current viewing transformation, always depicting the machine position necessary to achieve the current view. Figure 3 shows

screen 2, which has a menu window and two small selectable windows, plus a much larger selectable window. Actual beam design is typically done in this large window (with its better resolution), but can be done in any of the selectable windows. All command selections are made by pointing to a menu item with a mouse. The mouse is also used for drawing beam outlines.

One unforeseen problem was encountered when rendering the objects by simply drawing all of the contours. The objects tended to be so dense when the contours were drawn on every slice of a typical CT study that the image was hard to interpret. A facility was added to allow the user to specify the *density* of the contours for each object - i.e., to only display some fraction (say 1 out of every 3) of the contours of a particular structure. Objects that are to be targeted (such as tumors) are made very dense, while objects that one is trying to see through (such as skin) are rendered sparsely. This greatly improved the overall image quality. Intensity depth cueing, which was not implemented in the prototype, is badly needed and will be addressed in the future. Other display facilities that are currently provided are object visibility (toggled on or off),

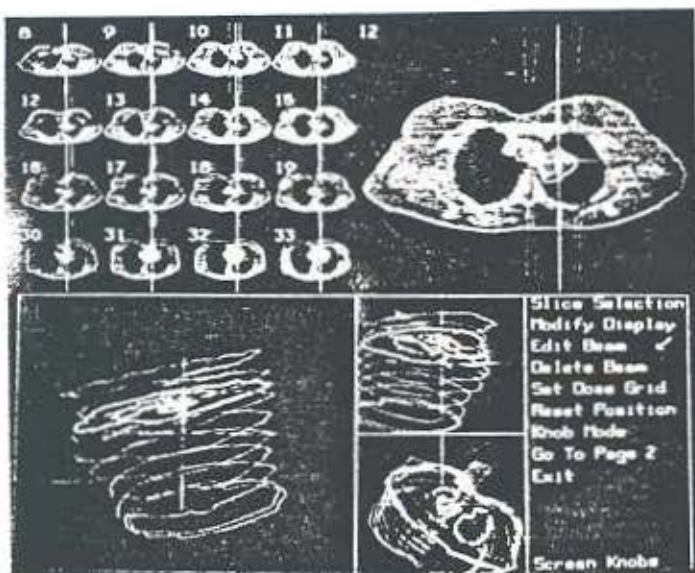


Figure 2. Screen 1 of the virtual simulator

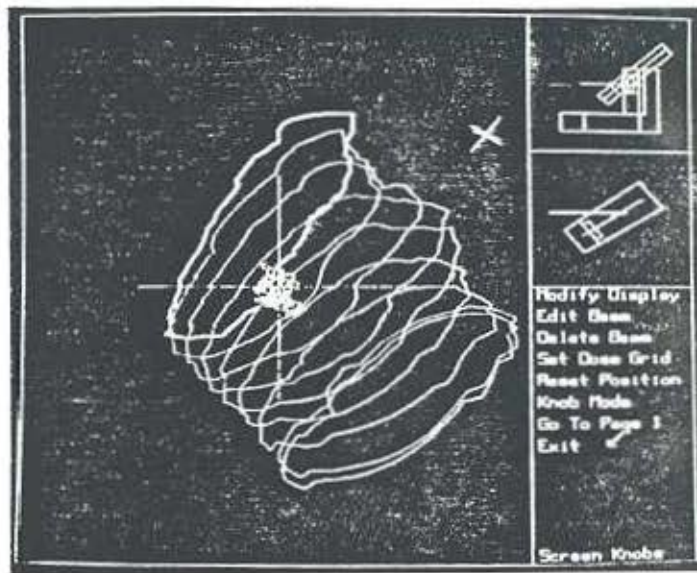


Figure 3. Screen 2 of the virtual simulator

object color (selected from a palette), and view selection among the selectable windows.

As the virtual simulation concept matures and with it our understanding of its 3D display requirements, we expect to add several additional features to the system, primarily through the use of cooperating display devices. Smooth shaded renditions of several patient models and treatment designs have been made, and a fast Phong renderer is being incorporated into the CAD tool to provide high quality images after a short wait. Interactive smooth shaded rendering will be explored as Henry Fuchs's *Pixel-Planes* graphics engine [Fuchs & Poulton] [Poulton, et al.] becomes available to us. We have displayed two case studies on the machine, and found that appreciation of the three dimensional relationships between organs, beams, and dose distributions is considerably augmented. Stereo display of wire loops, tiled objects, and smooth shaded renderings are also being explored. We plan to install a varifocal mirror arrangement to provide true 3D rendition of wire loops and density volumes.

### Interaction Issues

It is essential that physicians be able to interact with the virtual simulator in an intuitive manner. One approach is to manipulate the object on the screen in a screen-based coordinate system. While this is customary in most computer graphics applications, it has not been available to radiotherapy treatment planners, who have been constrained to specifying actual machine settings on the physical simulator and then looking at the result in a projective X-ray. With the virtual simulator, the user is able to manipulate the object in screen coordinates, while the program determines (in real-time) the machine settings necessary to achieve the displayed view. This is equivalent to the physician walking around a transparent patient, unconstrained by the geometry of the machine, in order to find an optimal

beam angle.

We have explored various control configurations for the input devices to make screen-oriented interactions more natural. For rotations around the three orthogonal display axes we have built a box with a knob on top, on the front, and one on each side (which are connected by a shaft through the center of the box) (Figure 4). The knobs have an obvious correlation to the natural coordinates of the screen, and the user can intuitively distinguish which knob governs each rotation. A similar device, a 3D trackball, was rejected by clinicians who prefer explicitly decoupled control for each axis. For translations, we are building a box with belts mounted on the four faces of the cube accessible to the user. Translation in a particular direction is achieved by stroking the appropriate surface of the box in the desired direction. Again, we expect that the user will be able to intuitively distinguish which belt governs each translation on the screen.

Another approach to providing an easy-to-learn paradigm for physicians to interact with the virtual simulator is to allow them to orient the view of the patient by giving the "machine settings" of the virtual treatment unit. Thus the user specifies table position and tilt, gantry tilt, and collimator

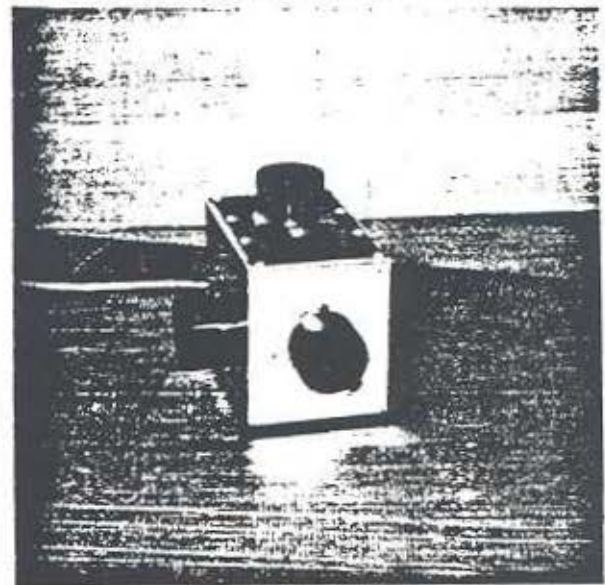


Figure 4. Screen rotations box

angle, in the customary way. This approach will help physicians make the transition from their usual simulation techniques to the virtual simulator. To this end, we are building a miniature of a conventional simulator that will function as an analog input device for these machine settings. Interaction with this device will be straightforward. To adjust the table, one adjusts the table on the mock-up. Similar control is provided for turning the gantry and adjusting the collimator setting.

For interactions with the virtual simulator which do not involve direct spatial manipulation of displayed objects we have built another device (Figure 5). There are several standard graphics controls: scale, hither and yon clipping planes for the displayed objects, and intensity windowing for the CT slices. The clipping and windowing controls use sideways mounted pots to which are attached over-sized wheels that protrude through the surface of the box. Adjustment of the clipping planes or windowing levels is achieved by stroking the appropriate wheel in the desired direction. Our experience is that users find this much more intuitive than turning labelled knobs. Another set of controls, specific to our application, are called the *delineator wires*. On a conventional sim-



Figure 5. Additional controls box

ulator these control the rectangular size of the radiation beam collimator. In a typical treatment planning session, a physician will narrow the beam as much as possible with the collimator, guided by the location of the delineator wires before refining the shape further (by drawing) to conform to the treatment volume. The virtual simulator implements this function, as well as providing the capability to "tack down" one of the wires, while adjusting the width and center of the beam simultaneously. This is the purpose of the *hold* buttons on the control panel. Clinicians have said that this will greatly improve their ability to center the treatment field about the target volume.

An exciting combination display/interaction modality that we are planning is what we call *feel-around*. Using either a head-mounted display or a suspended monitor viewed through a partially-silvered mirror, the illusion is created of the displayed objects floating in space in front of the user. The user can then directly interact with the object with their hands (to which are attached sensors that report location and orientation). This could aid considerably in the areas of object definition (for tumor and organ specification) and object editing (for beam design).

## Summary

We have developed computer software that implements a superset of the functions of a conventional radiation therapy simulator. It is our belief that such software will allow radiation therapy physicians to more precisely and optimally design and direct radiation treatments. This in turn could lead to higher cancer cure rates with fewer side effects of treatment. The virtual simulator provides an accurate portrayal and intuitive manipulation of the 3D geometry of the patient model. Armed with this tool physicians will be able to explore promising alternatives to traditional treatment geometries.

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