Immersive Visualization Training of Radiotherapy Treatment

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Abstract. External radiation beam treatment of cancer tumours involves delivery of invisible radiation beams through the body where internal structures can not be seen. Beam targeting of patient anatomy has to very accurate to achieve the desired therapeutic result. Good understanding of radiotherapy treatment (RT) concepts is essential to training. This paper presents a virtual environment simulator developed by the authors for training and education of intensity modulated radiotherapy (IMRT) treatment of cancer. This simulator employs immersive visualization to provide a high fidelity spatial awareness of the complex relationships between tumour, organs at risk, treatment beam and radiation dose. All these visualization are provided by a 3D virtual environment based on the patient in a RT treatment room. Immersive visualization using this simulator is being used to train radiation oncologist and radiation physicists about radiotherapy treatment.

1. Introduction

External radiation beam treatment of cancer tumours involves the delivery of invisible radiation waves through the body where internal structures can not be seen. Furthermore beam targeting of patient anatomy has to be accurate to achieve the desired therapeutic result.

This paper presents a virtual environment (VE) simulator developed by the authors for intensity modulated radiotherapy (IMRT) [1, 2] treatment of cancer. For IMRT the therapeutic radiation fields are matched to the 3D profile of a tumour using a computer controlled delivery system. IMRT plans are typically created from a CT/MRI scan of a patient and a computerised optimisation algorithm guided by constraints based on patient volumes (tumour, organs at risk) and dose constraints for these volumes. The patient is irradiated using a linear accelerator with multiple shaped beams over a number of treatment sessions.

Immersive visualization has the potential to provide high fidelity spatial awareness of complex relationships between patient anatomy, treatment beam, radiation dose and equipment in the treatment room. This is helpful because IMRT delivers a complex 4D (i.e. 3D plus varying fluence) radiation dose on geometrically complex 3D anatomy. This is further complicated by issues such as patient set-up error [3], patient motion, etc.

This paper first presents the various visualizations of the VE simulator for radiotherapy treatment (RT) and then discusses uses of the VE simulator for training radiation oncologist and radiation physicists about the logistics of radiotherapy treatment.

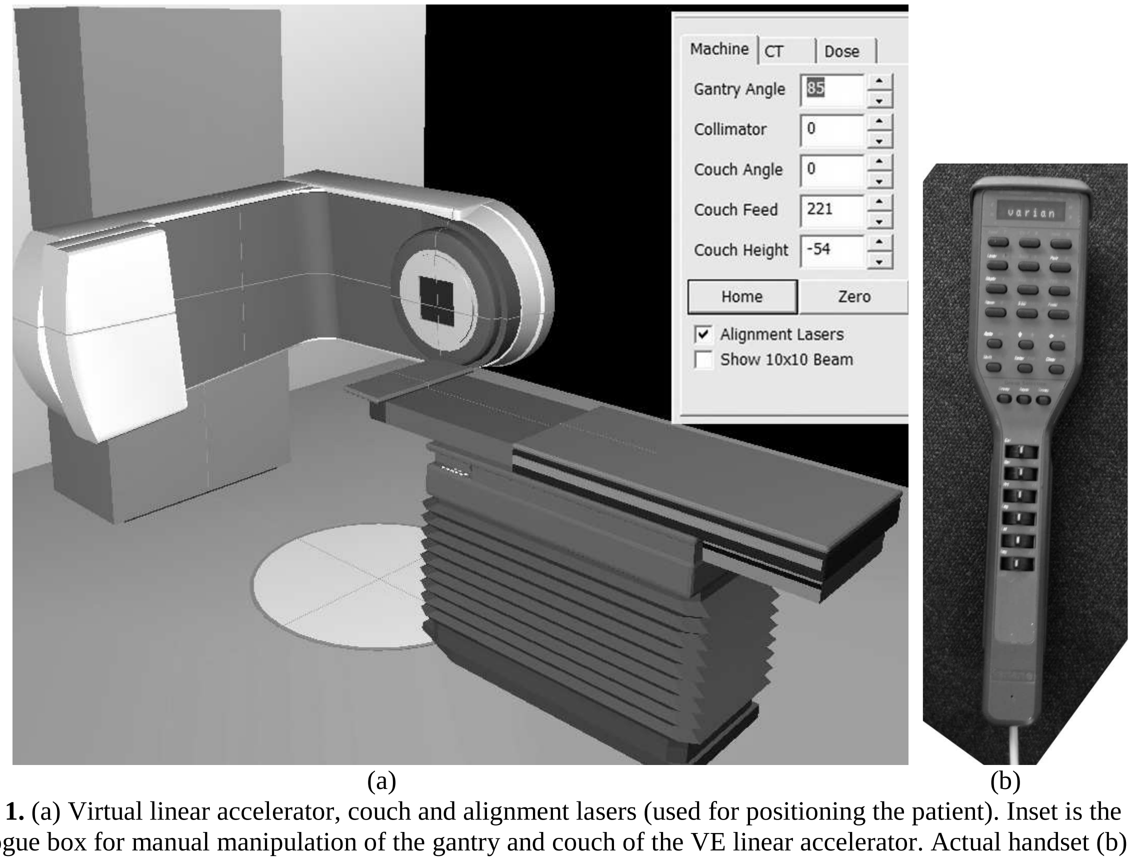
2. Visualization Facilities of the Radiotherapy Treatment VE Simulator

The authors have developed a generic virtual environment (VE) simulator for radiotherapy treatment rooms. The simulator is intended for training and education of medical physicists, radiotherapy treatment planners, radiation oncologists, etc. This VE simulator provides a range of visualizations that are patient centric. This simulator provides visualization for the following:

1. A radiotherapy linear accelerator that delivers the therapeutic radiation beams.
2. Anatomy of patient and segmented anatomical structures relevant to the treatment plan.
3. Therapeutic radiation beams and representations showing the planned radiation dose to be delivered.

2.1 Visualization of the Linear Accelerator and the Treatment Room

The VE simulator provides a virtual world of a radiotherapy treatment room at the Princess Royal Hospital in Hull (UK) that has a Varian 600CD linear accelerator with a 160 leaved multi-leaf collimator (MLC). This initial model was constructed from measurements and photographs taken in the treatment room, and from CAD drawings available on the web. We intend to extend the simulator to cater for a range of linear accelerators from various manufacturers and to create virtual worlds based on actual treatment rooms associated with the training context. To build these new virtual worlds, the treatment rooms and the linear accelerators will be laser scanned using a Leica CDS 3000. This will provide accurate surface geometry and true colour for the captured scene. This scanning approach provides a rapid means to produce highly accurate models of linear accelerators and room layouts.



(a) (b)

Fig. 1. (a) Virtual linear accelerator, couch and alignment lasers (used for positioning the patient). Inset is the dialogue box for manual manipulation of the gantry and couch of the VE linear accelerator. Actual handset (b) that is being adapted for control of the VE linear accelerator.

The virtual linear accelerator has the full articulation of a real accelerator. Thus the gantry and the delivery head rotate. Similarly, the virtual couch has a full range of articulation. The linear accelerator has manual virtual controls (see Fig. 1(a)), which is useful for training purposes. We are currently integrating an existing control handset (see Fig. 1(b)) so that trainees can move the VE linear accelerator and the couch using an actual handset.

The treatment room has three orthogonal lasers which intersect at the treatment isocentre. These are used to help position the patient on the couch during treatment. These lasers are provided in the VE model (see Fig 1(a)).

2.2 Visualization of Patient Anatomy

From the training perspective, an important feature of the VE simulator is that treatment plans of actual patients' IMRT treatment can be loaded into the virtual world. This flexibility provides the trainee with experience of the treatment of various cancer sites and it allows experience of complications that may arise during various treatment delivery situations. Being patient specific also means that it is easy to tailor the VE training session to match the needs of the curriculum. Currently, the plan is loaded from a native format of the commercial CMS (Computerised Medical Systems) RT planning system. This was chosen as it was the format used at the Princess Royal Hospital. We intend to extend this to cater for DICOM RT so that patient specificity is independent of treatment planning system suppliers. The following information is extracted from the CMS treatment plan for patient visualization.

1) Anatomy as defined by a CT and / or MRI slice stack.
2) Contours and 3D surfaces delineating the treatment volumes of interest. Such volumes include the tumour, gross tumour and planned tumour volume [4], and functional anatomy that is particularly sensitive to radiation such as kidneys, spinal cord, pituary glands, etc, which need to be taken account of specifically when designing the treatment plan for the patient. The latter are known as organs at risk (OARs). These volumes and their associated radiation dose constraints, along with the number and direction of the treatment beams, provide the inputs to an inverse planning optimisation algorithm. This algorithm computes both the shape and intensity distribution of each radiation treatment beam.

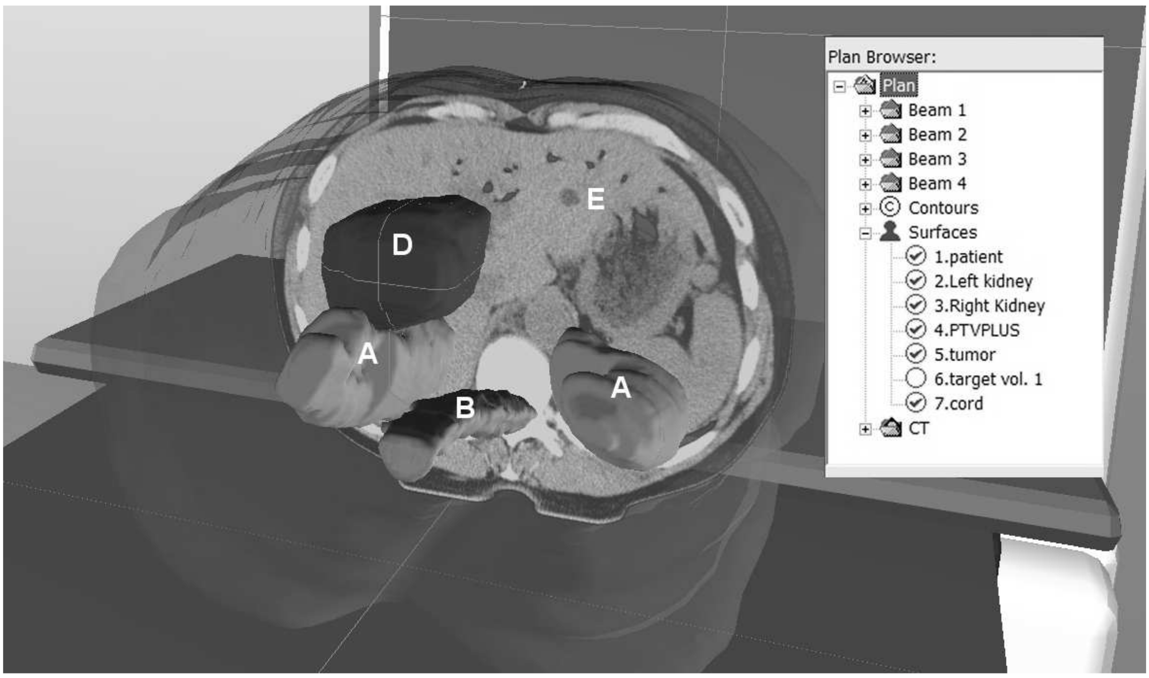


Fig. 2. Visualization showing patient anatomy on couch of radiotherapy treatment room. View shows tumour (D) being treated, organs at risks (A – kidneys, B – spinal cord) where dose must be below a specified level, (E) CT slice clipped to patient's skin surface. Inset is the dialogue box showing elements of the treatment plan.

The VE simulator provides various immersive facilities for anatomy visualization, all of which are displayed in 3D and registered to the patient space in the treatment room. The tumour and OAR volumes, and the patient's skin surface, can be visualized selectively either as contours or as surfaces. Colour and transparency of these volumes can be selected interactively to provide the best visualization for training purposes. The usual controls for viewing CT/MRI slices are provided in the VE simulator. To help trainees understand relationships between anatomy and treatment volumes, the displayed CT/MRI slice is registered to the patient space in the treatment room and displayed in 3D. In addition the slice can be clipped to the patient skin surface. Fig. 2 illustrates the 3D visualization of anatomy and planning volumes for a patient.

2.3 Visualization of Radiation Treatment Plans

An intensity modulated radiotherapy (IMRT) treatment plan comprises a set of therapeutic radiation beams each delivered from a different direction. Using a technique known as 'step and shoot' [5] each beam is delivered as a sequence of beam segments. Each segment is shaped individually using a multi-leaf collimator (MLC) inside the gantry head of the linear accelerator. The radiation time for each segment may also vary; this allows the intensity of the dose to be modulated over the beam's cross section.

In order to visualize treatment delivery the following information is extracted from the patient's treatment plan.

1) Details of each radiation beam.
2) Details of all segments that make up each beam.
3) The planned volumetric distribution of dose for the patient's anatomy.

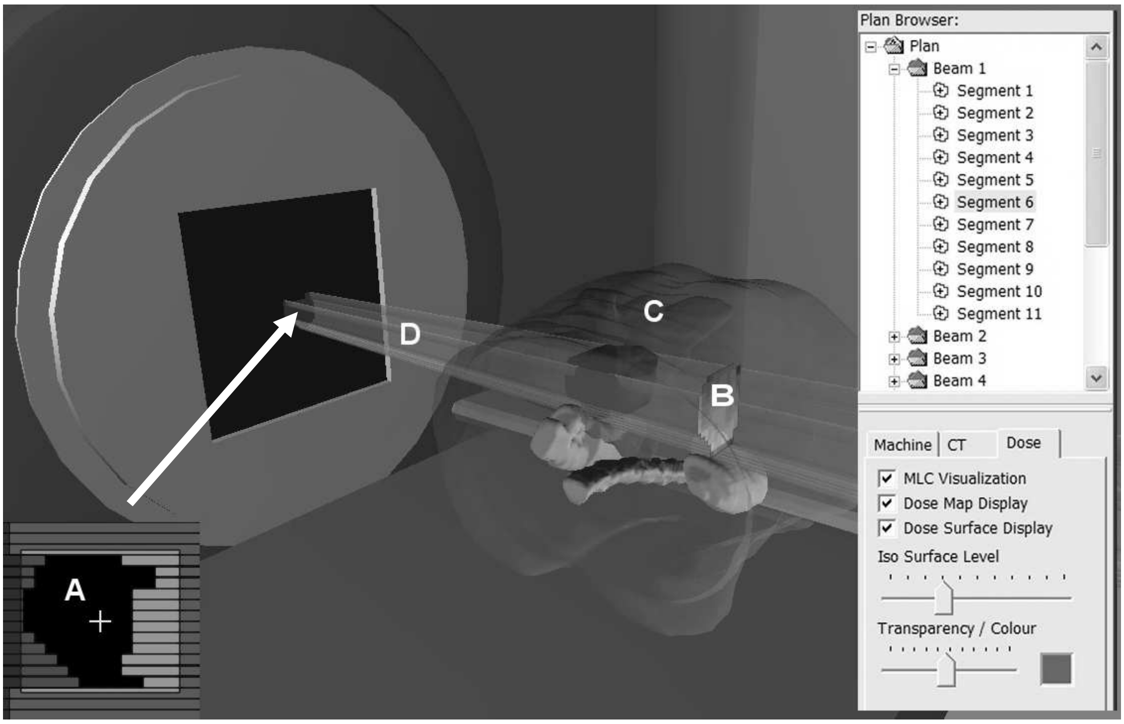


Fig. 3. Visualization of the radiation treatment. (D) visualization of segment 6 of treatment beam 1. The segment is shaped using a MLC inside the gantry head. (A) shows the leaf positions of this MLC. (B) dose map of the radiation intensity for beam 1. (C) dose isosurface showing the tissue volume that receives at least 30% of the maximum dose level. Inset is a dialogue box of dose visualization options.

To visualize a treatment beam, the simulator first moves the gantry and its head to the correct position. The beam is then visualized as a semi-transparent green projection (see Fig 3.) registered with the patient space. This visualization in fact represents the accumulation of all segments that comprise this beam. This allows the trainee to appreciate the margins between

OARs and the treatment beams, and to appreciate why a particular configuration of beams is used. Individual segments of a beam can also be visualized as a green projection. The MLC leaf settings for a segment can be displayed as an inset in the 3D view (see Fig 3.).

Visualization of dose distribution is also provided. A dose intensity map can be displayed that shows the intensity of dose delivered over the cross section of a beam (see Fig. 3). A very important issue in treatment planning (and thus knowledge to impart to trainees) is the coverage of the tumour with the prescribed dose and the distribution of dose to OARs. Visualization of planned dose distribution is provided by displaying a dose isosurface (see Fig 3.). By choosing a high dose setting for the isosurface the trainee can see how well the plan produces a dose that conforms to the planned tumour volume. By choosing a low dose setting for the isosurface the trainee can check the proximity of a harmful dose level to OARs.

3. Training Use of the VE Simulator for Radiotherapy Treatment

3.1 Modes of Training

The Hull Immersive Visualization Environment HIVE (www.hive.hull.ac.uk) at the University of Hull has an immersive visualization auditorium. This auditorium features an immersive work wall that has a display area of 5.3 x 2.4 metres. The workwall is back projected by 2 triple DLP projectors (each 2000 lumen) that together provide a display resolution of 2048 * 1024 pixels. The workwall supports stereoscopic 3D display using active shutter glasses. The workwall also supports head tracked stereoscopic display that provides motion parallax effects for a user’s head movements. For tracking the user’s viewpoint a real time optical motion tracking system with 7 cameras is used. These facilities allow a RT treatment room to be displayed in real size, and larger if needed. Users navigate around the room via a remote gamepad or simply by walking around the room using the head tracked stereo facility.

The VE simulator presented in this paper was developed specifically to exploit the capabilities of workwalls such as the one in HIVE. There are two main modes of using the VE simulator and the workwall. The first is where a small group of trainees view the workwall a distance of 2 to 3 metres. In this setting the tutor would typically demonstrate various treatment plans and demonstrate various operational scenarios in the treatment room. In this mode the screen more or less covers the trainees’ field of view with a stereoscopic 3D scene. This creates an excellent sense of being present in the treatment room. Combined with the rich set of facilities for visualizing the treatment plan and the patient, this creates a very compelling environment which seems to greatly enhance the learning experience for trainees.

The other mode is where a trainee would be given a task to perform within the treatment room. The trainee would use head tracked stereo and the trainee would have direct control of the virtual equipment and patient to complete the task. Again the sense of presence, now even greater through motion parallax, reinforces learning and assists the trainee in developing manipulation skills for positioning the patient and equipment. Our experience so far of using the VE simulator is limited. A number of classes are planned for the current academic session.

The VE simulator also runs on a range of other stereoscopic display technologies. These include a passive stereo projection system with a 2.4 x 1.8 metres screen, a Sharp auto-stereo LCD laptop computer and a PC with active stereo glasses. We have found the latter very useful for trainee education on a one to one basis.

The VE simulator has been widely used for lectures (in Hull and Sheffield) on RT treatment in a classroom setting. Here the simulator is often run during the lecture using normal mono projection facilities to demonstrate RT concepts. Alternatively, prior to the lecture, patient plans of interest can be loaded into the simulator and relevant screen grabs and animations output by the simulator for presentation in the lecture. Our experience indicates that by using the simulator’s facilities, the difficult spatial concepts of RT treatment can be taught more quickly, and it also results in better understanding by the trainees.

3.2 Training of Patient Set-up Errors

It is important that the patient’s anatomy be in the correct position prior to and during RT treatment. Positioning errors can arise due to mal alignment of the lasers with the isocentre, sag in the gantry of the linear accelerator, incorrect positioning of the patient on the couch, internal organs being in a different position from that defined by the planning CT/MRI, breathing motion, tumour reduction after a number of treatment sessions, etc. The impact of poor patient positioning can be demonstrated using the VE simulator.

In the simulator the patient anatomy is attached to the couch and the radiation beams and dose distribution are attached to the gantry head of the linear accelerator. Thus the couch of the simulator can be moved manually to mimic errors in patient position and anatomy. By then visualizing the beams and dose distribution of the treatment plan, the trainee can observe whether the positioning error is significant in terms of the tumour being under dosed or the OARs being overdosed. Similarly, some errors in equipment set up can be mimicked by manually moving the linear accelerator and observing the consequences.

4. Conclusions

Immersive visualization aids the understanding of complex spatial relationships of anatomy and radiation beam therapies such as IMRT. Stereoscopic views, large displays, immersion and motion parallax greatly aid the assimilation of these relationships. A key benefit of the VE simulator presented is its patient-specific approach. This allows trainees to experience a range of patient treatments selected to improve the skills and understanding of the trainees. Another key feature of the simulator is the close integration between the visualizations of patient anatomy, the treatment plan and the treatment room. We believe immersive visualization provides a cost effective training solution as it reduces learning time, improves trainee understanding and reduces the need for training in real linear accelerator treatment rooms.

Plans are well advanced to set up radiotherapy training centres (in UK and USA) based on the VE simulator presented in this paper and using immersive visualization facilities similar to that provided by HIVE. We are also investigating the use of the VE simulator for informing patients and relatives about their treatment.

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