The use of a virtual reality simulator to explore and understand the impact of Linac mis-calibrations

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Abstract.

\textbf{Purpose:} In recent years there has been interest in using Computer Simulation within Medical training. The VERT (Virtual Environment for Radiotherapy Training) system is a Flight Simulator for Radiation Oncology professionals, wherein fundamental concepts, techniques and problematic scenarios can be safely investigated.

\textbf{Methods:} The system provides detailed simulations of several Linacs and the ability to display DICOM treatment plans. Patients can be mis-positioned with 'set-up errors' which can be explored visually, dosimetrically and using IGRT. Similarly, a variety of Linac calibration and configuration parameters can be altered manually or randomly via controlled errors in the simulated 3D Linac and its component parts. The implication of these can be investigated by following through a treatment scenario or using QC devices available within a Physics software module.

\textbf{Results:} One resultant exercise is a systematic mis-calibration of 'lateral laser height' by 2mm. The offset in patient alignment is easily identified using IGRT and once corrected by reference to the 'in-room monitor'. The dosimetric implication is demonstrated to be 0.4\% by setting a dosimetry phantom by the lasers (and ignoring TSD information). Finally, the need for re-calibration can be shown by the Laser Alignment Phantom or by reference to the front pointer.

\textbf{Conclusions:} The VERT system provides a realistic environment for training and enhancing understanding of radiotherapy concepts and techniques. Linac error conditions can be explored in this context and valuable experience gained in a controlled manner in a compressed period of time.

1. Introduction.

Recently simulation training has received a lot of attention within medicine and conferences, such as Medicine meets Virtual Reality (MMVR) \cite{1} and Computer Assisted Radiology and Surgery (CARS), offer many examples where computer simulation has been explored. The use of computer simulation
Simulation training offers the option to mirror real world equipment and conditions in a virtual reality (VR) environment which is safe for all the participants (trainers, clinical tutors and simulated patients), it also allows the exploration of experiences not normally or easily available in the real world. Visualisation of the isocentre concept is a relatively trivial demonstration to provide, but is extremely effective in discussions with early career professionals, especially for the subset of trainees who find it particularly challenging to understand. For all professionals, no matter what their level of experience, the exploration of treatment errors or Linac mis-calibrations can be extremely informative. These are easily generated in a simulation environment and provide opportunities for staff to learn from unfortunate or errant events.

The VERT system (Virtual Environment for Radiotherapy Training) was developed [3] as an education tool for therapy radiographers/ therapists/ RTTs in order to provide a simulation environment that offered alternative facilities to combat lack of clinical resources for training. Development began in 2002 and continued as a ‘garage research’ project for a number of years. In 2006 it gained interest from the Society and College of Radiographers and the National Cancer Director (Professor Sir Mike Richards) as a potential solution to a number of identified problems with the training, recruitment and retention of Therapy Radiographers in England. Recommendations within the 2007 NRAG (National Radiotherapy Advisory Group) report and subsequent 2007 Cancer Reform Strategy suggested it be adopted nationally within England. In 2007 a company was created in order to manage activity including the ongoing research and development work of the Radiotherapy Simulation training concept alongside commercial activity.

2. Methods/ materials

VERT comprises of software and hardware that provide a fully interactive and articulated virtual Linac that enables it to be used as a functional surrogate [4] of a real world machine. Various pieces of treatment positioning and QC equipment can be used and imaging devices can be deployed. Patients can be placed on the treatment couch and accurately aligned to the isocentre, having been created from DICOM files generated from any commercial treatment planning system. The graphics are created using large scale Stereoscopic projection and viewed by the users/ participants using 3D glasses.

The virtual Linac is almost fully functional in that it can mimic the motion and operation of its physical counterpart, with the only major exception being the generation of ionising radiation. Contemporary conventional Linac models from Varian, Elekta and Siemens are available. The operation of the machine is controlled via OEM (original equipment manufacturer) hand pendants and/or by GUIs available as part of the main screen or on separate touch screen (or normal) monitors and wireless tablet technology. A high level of attention to detail is provided with features such as set up lasers, field light, TSD indicators all being available and controlled via the appropriate hand pendant to enable the user to set the patient up in the same manner as they would expect to in the treatment room. Features such as couch-side controls (available via the touch screen) and in-room monitors are context specific to the Linac currently displayed. Patient position can be checked using DRR or fluoroscopic mode or using the IGRT module where the current position can be assessed against referenced images. All the images used in the VERT process simulations are generated in real time, including the fluoroscopic images acquired when the user rotates the gantry (manually or during VMAT delivery). In order to achieve the required interactivity these calculations are performed on the GPU.
Patients are represented using plans from treatment planning systems (fig 1), loaded via a DICOM interface. This allows every user to create patients that represent typical planning/delivery technique appropriate to their practice. These data sets can be sent directly from the planning system, or loaded via memory media, allowing the data to be anonymised. The planning CTs, structure sets, dose and plan descriptions are transferred using the appropriate DICOM objects and are used to construct a 3D representation of that section of the patient they represent. Sagittal and Coronal CT planes are generated from the axial CT planning data set. Structures can be represented as native contours and as volumetric objects created by default when the patient data is first loaded.

Fig 1: VERT simulation of Linac and an IMRT patient loaded from a commercial planning system.

Whereas, by default, the patient is initially placed in the correct treatment position, an error simulation function is available such that random or known positional errors can be introduced with six degrees of freedom. This functionality, along with various dose visualisation tools and MV/kV image generation tools, allows the implication of patient mis-positioning to be explored.

A number of QC activities or work flows are available within the simulation that allow the output and beam profiles of the Linac to be measured, the laser alignment and light-radiation field coincidence to be checked. For these a suite of QC devices are available and can be loaded in place of the patient. These devices are interactive and 'produce measurements' via 6MV and 15MV beam models built into the simulation which have representative depth dose/energy characteristics. All measurement simulations made within the virtual system reflect the accuracy, or otherwise, of the equipment alignment and positioning. Similarly as with the patient set up error simulations these allow the trainee or user to explore a range of situations where the equipment has not been correctly set up and be able to appreciate the consequences of such.

The available equipment includes:

- a QC dosimetry phantom which has an ion chamber that can be placed at different depths (dmax for the two beam qualities and 2 to 20 cm depths at 1 cm increments).
- a plotting tank that needs to be levelled correctly, the accuracy of which can be judged using the integrated spirit levels
- a simple radiation field- light field coincidence phantom which fluoresces when irradiated
- a laser alignment phantom
- a water tank that has a reference class chamber and a farmer / departmental chamber mounted side by side to allow the calibration of the departmental chamber
With the exception of the beam models, dosimetric features can be customised to the users own preference such as calibration point/ depth of the Linac, energy response/ calibration factors of the chambers. Additionally the temperature and pressure within the Linac bunker are randomised, within realistic limits, for the last activity listed above and the output of the Linac are subjected to user controlled random fluctuations and offsets. This theme is expanded with the ability to introduce mis-calibrations or variances from the ideal for Linac parameters such as Gantry, Collimator, couch travel parameters, isocentre wobble, calibration of the TSD and the light field projectors, jaw positions and the laser positions. This feature allows the machine to be presented to a trainee in an incorrect state to give them the opportunity or exercise in diagnosing a Quality Control problem and be able to work through the solution. Scenarios can be programmed and captured in order to be repeatedly and exactly reproduced in order to allow (fair) competency testing for individuals or a group/ class of students.

3. User Case scenario: Correct set-up, wrong output?

To illustrate the use of the Physics tools/ activities within VERT and the utilization of the capability to mis-calibrate the virtual Linac the following user case scenario was developed. For this exercise the choice of Linac was arbitrary.

The activity using the output phantom and Farmer ionization chamber was loaded with the chamber set at 5 cm depth and a 10cm x 10cm field was set. This configuration was chosen, being the calibration conditions for the Linac. The vertical height of all the horizontal lasers in the virtual bunker were altered by 2mm, such that they indicated an isocentre position to be further from the target than intended. This was achieved by entering a systematic offset in the errors and machine variances menu. The vertical lasers themselves were not altered to ensure the isocentre was still indicated to lie along the CAX of the beam. This 3D scene was captured using the virtual presenter feature in order to be able to repeat the exercise easily without having to set up the errors/ offsets following any final recalibration of the virtual Linac.

The couch height and general position was altered in order to set the dosimetry block such that the chamber was centered on the isocentre. This process is performed as if one were using a real Linac using the Lasers and light field; However by making the phantom transparent and zooming in and out of the display additional confirmation could be seen! On accessing the associated virtual electrometer (via iPad display) the output was found to be 0.996 rather than the expected 1.000 Gy.

The set up of the block was then explored further, again following a typical clinical troubleshooting process. For example, in this instance:
- Reconfirmed the position by the lasers
- Switched on the TSD projector / ODI (optical distance indicator)
  - Which indicated that the surface of the block was not precisely at 95 cm as should be expected and therefore raised the question regarding the laser calibration integrity
- Load the linac’s 100 cm front pointer and check the laser projection of the isocentre against the position of its tip
  - Which indicated the position of the isocentre as indicated by the lasers to be below that indicated by the mechanical front pointer
- The surface of the block was set to the lasers
  - This demonstrated the previous observation, given the surface of the block was below the tip of the front pointer.
- Selection the Laser alignment phantom – set the phantom up by aligning its markings to the light field crosshairs (fig 2) with the gantry at 0, 90, 270 degrees. Then assess laser alignment against the phantoms markings.
Fig 2 Illustration of the use of the QC activities to investigate the integrity of the set-up laser calibration. Setting the alignment phantom with the light field crosshairs at cardinal angles (a,b,c) and proving the lasers to be ‘below’ the isocentre plane (d).

Having performed these checks the trainee should conclude that the horizontal lasers were mis-calibrated such that they indicated the isocentre was 2mm further from the target than was really the case and therefore explaining the 0.4% reduction in output of the Linac. Confirmation of this conclusion would be gained by setting the ion chamber/ output block up by the ODI or using the mechanical front pointer and checking the output at the actual isocentre.

4. Discussion

The VERT system was originally created in order to provide a flight simulator system for radiographers (therapists, RTTs) in training. It was designed to provide both: 1) the opportunity to gain practical experience away from the busy clinical setting and 2) to give educators a tool for explaining concepts and process issues which was vastly superior to using slides or white-boards to illustrate their presentations. It was immediately apparent that VERT provided a platform to explore treatment errors and patient setup issues and at its outset features were included in the system to facilitate this and simulate such errors using treatment plans from commercial planning systems.

The VERT system was rolled out across all the radiographer teaching schools in England in early 2008 and has been integrated into the teaching of every radiographer trained in England since the beginning (October) of the 2008/9 academic year. Part of the feedback and experience gained was that simulation of Physics concepts and workflow would be helpful for all staff groups. One of our particular interests and continuing areas of research is the use of simulation training and, specifically the VERT system, in the understanding of errors/ process deviations and ultimately treatment integrity and patient safety. The intended use of VERT now expands to all Radiation oncology personnel and the presented scenario is more suited towards, though not exclusively intended for, Physicist trainees and Dosimetrists. In this paper we have explored the use of VERT to provide an (arguably simple) example of how a system mis-calibration might be explored during the routine QC of a machine. We
have chosen a scenario that used various existing features of the system in order to illustrate the systematic implementation of features throughout the software. In actual fact this extends across all activities and any mis-calibration of the lasers (in this instance) would be apparent and affect the setting up of any loaded patient, until the calibration was corrected.

Computer simulation training is not expected, nor intended to replace practical experiential training, however it most certainly provides the opportunity to understand a wide spectrum of error conditions and their implications in a compressed time frame. It can often take a number of years to be able to experience such things clinically, simply due to their infrequent nature. As described here scenarios can be staged, explained and therefore understood in the classroom, as part of a planned course on quality control, using virtual simulation on demand and in a safe and controlled environment. Once the exercises are completed, the virtual Linac can be quickly recalibrated

As stated above the presented example is considered to be fairly simple, however it demonstrates that the process simulation capabilities within the VERT system can reproduce the clinical/ quality control work flow. More complex troubleshooting scenarios can be generated by compounding mis-calibrations or mixing these with set-up errors. In certain activities the output of the Linac can be varied and measurement uncertainties can be assigned to the metrology equipment. In the calibrate the ion chamber activity the ambient temperature and pressure are modulated in the treatment bunker in order to demonstrate the importance of making the appropriate corrections to the measurements. In the future we will explore making further systematic fluctuations to simulate calibration drift and further random fluctuations in parameters to simulate, for example a sudden thunder storm.

5. Conclusion

The VERT system is a commercially offered simulation training system that has evolved from the research and education interests of a radiation physics and computer science collaboration. More recently it has been broadened to encompass features that are designed to facilitate training pursuant to a better understanding for patient safety. Simulation training can be used to demonstrate the basic concepts, processes and work-flow of radiotherapy, but it can also be used to simulate errors and process failures and allow participants to examine such scenarios leisurely in the class room setting. Furthermore, experiences typically gained over many years of clinical work can be efficiently demonstrated by experienced professionals to their trainees in the simulation environment where there is zero risk to patients or staff even if a virtual linac is intentionally mis-calibrated. We are continuing our research interest in developing further physics activities and process simulation within our simulation training platform.

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