RSNA Education Seed Grant

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NOTE: Personal information for the applicant and other investigators has been removed from this sample application.

Title:
Towards a Comprehensive and Accurate 3D Visual Simulation Tool for External Beam Radiation Therapy Planning

Abstract:
This project explores the application of visual simulation and 3D modeling in the field of radiation oncology for training and educational purposes. To design an optimal patient-specific treatment plan would require the planner, as a complementary part of the computerized treatment planning process, to be inside the treatment room with the patient on the external beam delivery machine (linac) table to account for the motion and relative positions of all the linac components surrounding the patient. However, in reality, and due to the busy treatment rooms' schedules, treatment planning is performed remotely on a treatment planning computer using only patient CT data. Unfortunately, current treatment planning systems have limited or no available visual aid that combines patient volumetric models extracted from patient specific CT data with the treatment device in an inclusive 3D interactive simulation. Therefore, students and trainees often find it difficult during their external beam rotations to design "optimal" and deliverable patient-specific plans. In some cases, patient treatment is delayed or postponed due to unforeseen factors that arise on the first day of treatment when the patient is on the treatment table such as setups issues or possible collision scenarios among the linac components or between the linac components and the patient. In addition, the demand for better cancer targeting has created a host of additional linac components such as immobilization and on-board imaging devices which often adds to the complexity of the planning process.

We are proposing (1) a comprehensive web-based 3D visual simulator of external beam radiation therapy linacs (2) a plan to integrate the web-based system in the existing education and training system for radiation oncology staff and patients. The users can access the online simulator from any PC including the treatment planning system PC since the simulator is platform dependent. The simulator can present accurate 3D geometries of any linac model and all associated accessories in combination with patient CT anatomy in a realistic 3D web-based simulation. A graphical user interface will be available to the user with various controls to allow the motion of all linac components around the patient just as if the planner is performing an actual dry run with the patient inside the treatment room. High-resolution simulator models of the linac and various treatment accessories will be embedded in interactive 3D web-pages using latest industry standard for 3D information visualization and sharing X3D. The simulator will be made freely available online to the educational community.

The use of the simulator benefits are two fold: educational and clinical. For the education component, the targeted trainee groups in our department include physics residents, dosimetry trainees, and radiation therapy techs. The web-based system will allow trainees and students to:
(a) Familiarize the trainee with the various components of the linac including table, gantry, and collimator translational and rotation motion limits and angle conventions
(b) Validate patient setup, plan deliverability, and to check for possible collision scenarios and beam-couch intersections
(c) Educate patients about their treatment delivery technique and help reduce pre-treatment anxiety.

On top of its educational benefits, the web-based system will be used clinically to improve the overall quality of radiation therapy patient treatment. This is particularly important for patients undergoing stereotactic body radiotherapy in our department were the simulation tool can reveal any issues related to patient setup or collision scenarios before the start of patient treatment, and hence minimizing the need for in-room "dry runs" to simulate various gantry, collimator, and table positions which can take several hours of unnecessary patient waiting. Last but not least, the project will spawn interdisciplinary research collaborations that will bring together researchers from Radiation Oncology and Computer Science.

Percent of Time Dedicated to this Project: 10%

Priority Statement:
The simulation educational tool project is currently being developed at the department of radiation physics at the M.D. Anderson Cancer Center Orlando (MDACCO) in collaboration with Armstrong Atlantic State University (AASU) department of computer science. Both departments have dedicated educational goals that provide the opportunity to enhance and expand student and instructor learning. The interdisciplinary nature of the project will bring together students and instructors from the following disciplines at both institutions: Radiation Oncology and Computer Science. The targeted trainee groups at the department of radiation physics at MDACCO are:

(a) Radiation therapy physics residents
(b) Radiation therapy dosimetrists
(c) Radiation therapy technologists

Educational Relevance: Department of Radiation Physics at MDACCO The physics residents and new dosimetry students in our department go through several external beam rotations during their training program. In these rotations, they learn about the various linac components such as the gantry, couch, and collimator and their motion angle conventions. The trainees find it occasionally hard to visualize in 3D the relative positions of all these components in space during the treatment planning process. It is often a challenge for the planner to create a collision-free optimal plan given that most treatment planning systems, including the systems in our department, has no built-in collision detection tool or realistic "beam-eye view" of the linac. Using the proposed system, the planner can run a simulation of the linac components for any beam during the planning process on any computer that has an internet connection, including the treatment planning system itself, since the tool is platform independent. The simulation will accurately depict the motions and orientations of the linac with all degrees of freedom available for the planner to manipulate just like if he/she is doing it from the inside of the treatment room. The planner can check each and every gantry, couch, and collimator relative positions for a given beam from an infinite number of projections by a click of a mouse. The freedom to move all linac components in every possible direction by mouse or by typing in exact positions, allows the user to explore a host of different couch, collimator, and gantry combinations quickly. In addition, beam-couch intersections can be easily visualized by simulating the beam as a light prism projecting at isocenter and collimated to match the radiation beam geometry.

Educational Relevance: Department of Radiological Sciences (AASU) The benefit of online learning tools is that they provide students the option to learn at their own pace without being under the pressure of day-to-day clinical duties. The students in the four-year radiation therapy program at AASU can start learning about radiation therapy delivery devices before they get into their clinical rotations in their third and fourth year of the program. The simulation tool will allow the students to learn about linac motions and hardware manipulations and controls. In our project we aim to include 3D models of the most widely used linacs including Varian, Elekta, and Siemens machines. The students will be able to visualize and understand the basic operations of these linacs before they start their clinical rotations and get overwhelmed by the different hardware and controls of different radiation delivery systems. The project will include in the simulation all types of linac accessories such as electron cones, wedges, and patient immobilization devices built in as a library that the student may choose from and attach them virtually to the linac and treatment couch. The simulator will allow the students to apply what they learned in class and observed in the treatment room to better understand equipment functionality.

Clinical Relevance: Department of Radiation Physics (MDACCO) Many of our external beam treatments require complex orientations of gantry, couch, and collimator angles. This is especially prudent to stereotactic radiosurgery (SRS) and stereotactic body radiosurgery (SBRT) treatments. In many cases, the physicists and radiation therapy techs perform pre-treatment beam delivery simulations to make sure there are no clearance issues between different linac components for a particular delivery plan. This is, of course, time consuming and is carried out AFTER an "optimal" plan is generated on the treatment planning system. Any subsequent modifications due to some collision issues before or during the treatment will result in complete recalculation and re-optimization of the delivery plan which reduces the overall treatment flow efficiency and causes unnecessary patient discomfort due to treatment delay. The simulator we propose provides precise 3D geometrical rendering of the linac components that allows for an accurate check of collision scenarios during the planning process and before an optimal final plan is generated. Hence, considerably reducing the possibility of clearance issues for any deliverable plan.

On top of its educational benefits, the web-based system will be used clinically to improve the overall quality of radiation therapy patient treatment. This is particularly important for patients undergoing stereotactic body radiotherapy in our department were the simulation tool can reveal any issues related to patient setup or collision scenarios before the start of patient treatment, and hence minimizing the need for in-room "dry runs" to simulate various gantry, collimator, and table positions which can take several hours of unnecessary patient waiting.

<u>Other Investigators</u>:
Felix Hamza-Lup, PhD

The co-investigator and project coordinator of the web-based 3D simulation project is Dr. Felix Hamza-Lup. Both the principal investigator, Omar Zeidan, and the co-investigator have established strong interdisciplinary research collaboration for nearly two years. There collaboration on the web-based 3D simulation project has resulted in three presentations at national conferences in 2006. Dr. Hamza-Lup is the main designer and developer of the X3D simulation environment in which the web-based tool is currently being built. His pivotal role will be in building and processing the 3D interactive models from laser scanning data of the linac hardware components. As a project coordinator he arranges for (1) the vendor laser scanning sessions (2) coordinating subsequent data analysis with the students in his research group (3) coordinating regular meetings between both investigators and between investigators and students at both institutions. He is the webmaster of the 3DRTT website: http://hyperion.armstrong.edu:8080/3DRTT/. He integrates the 3D models in the website server and maintains a user database, site registration as well as user feedback. In addition, he is responsible for implementing the goals of the education plan at his institution, Armstrong Atlantic State University.

<u>Resources and Environment</u>:
The project development and implementation will take place simultaneously at two institutions. The first institution is the M.D. Anderson Cancer Center Orlando where the PI, Omar Zeidan, is a staff member at the Department of Radiation Oncology/Physics. The department has several external beam radiation therapy linacs that are readily available to the investigator and they are all located on the same floor of the cancer center. Two of the linacs are new Varian 23iX dual energy linacs and one of them is equipped with an On-Board Imaging capability. There is also a dedicated linac for stereotactic radiation therapy treatments (Novalis by BrainLab). These types of linacs are one of the most widely used modalities in external beam radiation therapy and they are inherently designed with many degrees of motion to allow delivery of radiation for the most complex treatment cases. An essential component of our project is to model in 3D with great detail all of the hardware components of these devices including linac accessories such as electron cones and other linac head attachments. In addition, part of our project goal is to model various patient immobilization and fixation devices available in our department in order to generate a comprehensive database of all hardware accessories that are used for all types of patient treatments.The second institution is the Armstrong Atlantic State University in Savannah, GA, where the Co-PI, Felix Hamza-

Lup, is a professor at the Department of Computer Science, School of Computing. Dr. Hamza-Lup has a dedicated lab space for his group of graduate and undergraduate students. The lab has several PCs equipped with NVidia performance GPUs and 3D Visualization systems (Shutter Glasses). The supporting available software includes Raindrop Geomagic and 3D Studio Max. The lab has basic capabilities to process large data sets generated from laser scans of the linac hardware components. In addition, a server in the lab is hosting the website where the entire project models are accessible to registered students and scholars through the web.

Detailed Education Plan:

Rationale and Relevance

Simulation-based medical training in the virtual reality environment is emerging as an accepted scientific discipline in medicine. The complex functionality and interplay between various components of external beam radiation therapy devices (linacs) makes it difficult for radiation therapy students and trainees to visualize beam orientations with respect to the patient and other linac components: couch, table, and gantry. Unfortunately, commercially available treatment planning systems currently have little or no 3D representation of linac and its associated components; thus making it difficult for the inexperienced treatment planner to achieve and optimal and collision-free plan without accurate 3D picture of the relative orientations of all treatment beams in 3D. In addition, the demand for better cancer targeting through image guidance (IGRT) has created a host of accessories to the linac such as on-board imagers and various patient immobilization devices, and thus making the treatment setup rather complicated. Therefore, we propose an interactive 3D simulation tool that will model the exact geometry and functionality of any external beam radiation therapy device for training and clinical purposes. The web-based tool will be easily accessible by radiation oncology personnel with the needed functionality for both trainees and experienced staff.

Educational Relevance

There is currently no interactive online or otherwise educational tool that the students and trainees in radiation oncology could use to familiarize themselves with operation and functionality of this sophisticated equipment. During their external beam rotations physics residents and radiation dosimetrists usually resort to generic miniature wood models or to known “clearance” motion ranges of various linac components: gantry, collimator, and couch to assess them during the planning process of a conformal plan. However, those resources are grossly inaccurate and can only be used as a basic “visual guides”. An actual bird’s eye view of the actual treatment conditions inside the room is normally unavailable for students during normal working hours. Unless the students are in their clinical rotations, it is normally hard for students to have an interruption-free access to the radiation equipment making it difficult initially for the students to build confidence in the equipment functionality and understand its versatility.

Radiation therapist training: Due to the normally busy treatment machines schedules, training of the therapy staff about new procedures is often problematic. Many new procedures require added staff of physicists, dosimetrists, and physicians to be present because the therapists have not had time to adequately practice the setup and the procedure for new treatments. The simulation tool would provide a means for the therapists to practice complicated patient setups and treatments in the virtual environment when time permits at their own pace.

Clinical Relevance

Currently, our institution has an open stereotactic body radiation protocol that allows the treatment of lung patients with a single fraction of high dose radiation. Currently available vendor planning tools do not provide adequate visualization of the patient and the treatment machine components (gantry assembly, table & peripheral equipment). Because of this limitation, the patient is required to be on the treatment machine for longer than necessary to check each of the treatment portals prior to any radiation delivery to ensure that the planned course of treatment can be delivered. This added time can be as much as an hour and can potentially require additional treatment planning due to unforeseen collision scenarios between the patient and the linac’s collimator and head or between different linac components. Our current solution is to use fewer beam angles to try to eliminate potential collisions, however, this does not always give the optimal dose distribution. The proposed simulation tool will provide a method of accurately checking the treatment plan without the need for the patient on the treatment table. The tool will be able to create a patient-specific treatment simulation by including actual patient CT data in the model

Patient Education: patients undergoing new procedures such as stereotactic body radiotherapy are often only in the treatment room for a single treatment sessions. This session may last several hours due to issues in setting the patient up and doing a “dry-run” simulation to ensure that no collisions would occur. In addition to the added time for the patient on the table to simulate various gantry, collimator and table positions to deliver and effective treatment, there is added time in educating the patient about the procedure itself. A web-based simulation tool would provide a method to accurately simulate all of the treatment positions based on the CT anatomy of the patient without the patient having to be on the table for added time at the time of treatment. This tool would also be useful in educating the patient about the procedure prior to them being on the treatment table. This makes the treatment more efficient and will help ease patient tension and fear of radiation devices.

Patient Safety: Our approach to collision detection using the simulation tool is unique. The highly-accurate, high-resolution 3D models of the linac allows f the planner to examine the relative positions of all linac components and associated accessories to an accuracy of few millimeters. Previous approaches for collision detection as a means to improve the planning process have used either analytical or geometrical representations of the linac or both [1-4]. These approaches provide local solutions (i.e. for specific linac model and treatment setup) and normally inaccurate due to errors from manual measurements of the linac geometries [5,6] and often lack the ability to represent actual patient geometries.

Simulator Description

Proposed Simulator Features

We are proposing a premier web-based educational tool that accurately simulates in three-dimensions the radiation therapy process and hardware. The preliminary version of the web-based educational tool will present a virtual 3D interactive model of one of three clinically available external beam radiation therapy linacs in our departments. The simulation tool is platform independent and can easily be accessible from any PC in our department with internet access. The software components will be developed using the X3D standard for 3D images sharing and interactive 3D web-based environment development. A website will make the simulator available online for worldwide user access. Using the X3D standard [7] (web-based format for 3D data sharing and visualization) we have developed [8-10] a preliminary web-based 3D simulation as illustrated in Fig. 1.

The 3D linac model of one our department's clinical linacs can currently be accessed at the following site: http://hyperion.armstrong.edu:8080/3DRTT/.

The simulator can provide an intuitive floating graphical user interface (GUI) for controlling the angles and locations of the machine's parts. The user can also show/hide a patient or the radiation beam generated by the collimator by turning designated switches on/off. Besides the mouse manipulation capability, the user's viewpoint can be easily changed on the orthogonal axes. As a part of X3D, viewpoints provide handy control and fast overview potential. As in most X3D viewers, a user can switch between preset views with a single keystroke. In addition, the tool can easily predict beam-couch intersections during the planning process without the need for linac-specific geometrical-based analytical solutions [11] by allowing the user to visualize the actual beam path for any possible beam collimation. The simulator can be used as a standalone application or it can be deployed on the hospital/university intranet as well as the world-wide web.

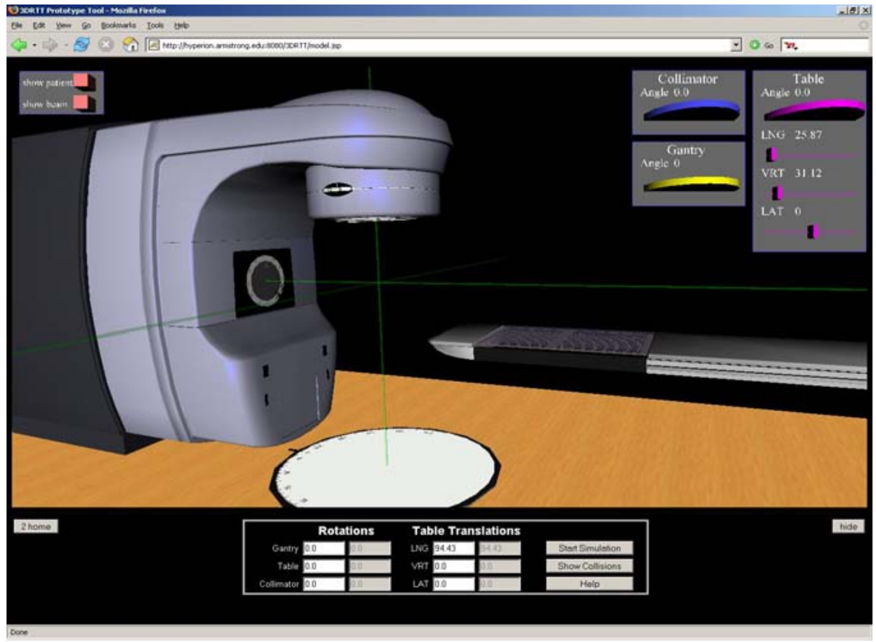

Fig. 1 Preliminary proof of concept, a 3D linac model embedded in a web-based simulation

Data Acquisition and Processing

One of the short comings of analytical models is lack of accurate representations of curved surfaces. In reality, all of the current treatment machines are constructed in complex geometrical curved surfaces that often can be difficult to manually reproduced through conventional measuring tools (ruler, tape …etc). We will overcome these challenges by using in–room 3D laser scanners. Fig. 2 highlights the sequence of procedures to build a 3D model.

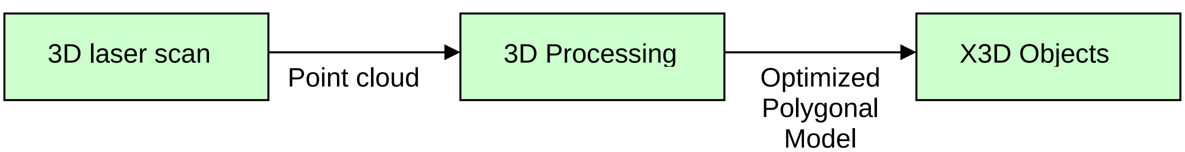

Fig. 2 Flow chart of data acquisition and processing of 3D models

Educational Connections

Knowledge is embedded in people and unlike information, knowledge creation occurs in a process of social interaction. We propose a tightly integrated, distributed collaborative environment for radiation therapy simulation and training that will integrate people, data, and work into one engine of knowledge, creation and use. The M.D. Anderson Cancer Center Orlando (MDACCO) as well as Armstrong Atlantic State University (AASU) are exceptional education facilities that provide the opportunity to enhance and expand student and instructor learning. Three dimensional simulations of the radiation therapy procedures in a web-based environment will increase student/trainees understanding of the relationships among different components as well as provides a validation mechanism that increases the trainees' confidence in manipulating the sophisticated equipment and associated software. The interdisciplinary nature of the proposal will bring together students and instructors from the following disciplines: Radiation Oncology, Physics and Computer Science.

Targeted Trainee Groups

- Radiation therapy physics residents at MDACCO
- Radiation therapy dosimetrists at MDACCO

- Radiation therapy technologists both at MDACCO and AASU department of radiological sciences
- Students from any radiation oncology training program
- Radiation oncology caregivers for the purpose of patient education

Learning Objectives

1. Understanding the hardware components and motion controls of radiation therapy delivery devices
2. Patient setups including actual shifts from external marks using actual patient CD volumetric data
3. Understanding the use of various types of immobilization devices for specific procedures: head mounts, wing boards, ...etc and table indexing
4. Collision detection: learning how to manipulate various linac motions and controls with the graphical features of the simulator to detect and search for collision scenarios
5. Learning the controls and operation of vendor-specific linac types : Varian, Elekta, and Siemens
6. Learning different angle conventions for gantry, couch, and collimator motions: IEC, Varian, …etc
7. Beam-couch intersection visualization- improving the planning and delivery accuracy
8. Allows caregivers and medical personnel to help patients understand the nature of there treatment by educating them through the use of the simulation room.

Trainee Learning Assessment and Feedback Mechanism

A website will make the simulator available online. Associated with the project a web portal will maintain a set of online-learning resources available for interested students. For example, electronic feedback, electronic newsletters regarding the project and discussion forums. For the assessment of the student learning a temporary cross-disciplinary committee will be formed that will provide feedback on the teaching material enhancements with 3D content. The feedback from the committee will enhance our understanding of the teaching need for the radiation oncology discipline and improve our teaching abilities by understanding specific teaching methods using advanced 3D simulation technology. Once the simulator is developed and adopted, initially as a special topic course, we will hold in-service training for instructors/trainers to become more familiar with the simulator. A preliminary set of in-service training course can be arranged locally onsite or through web conferencing. Project development and research progress will also be shared with interested faculty and students at both hosting institutions through seminars and talks.

Project Development

Resources

- *Available:*
  - o People:
    1). Omar Zeidan, clinical radiation therapy physicist and project PI, MDACCO
    2). Felix Hamza-Lup, Computer Scientist and project Co-PI, AASU
    3). Computer Science students from Dr. Hamza-Lup's research group, AASU
    4). Medical physicists at MDACCO
    5). Radiation therapy staff, Radiological Sciences Department, AASU
  - o Facilities and Equipment:
    1). Three clinical Varian linacs available for testing and modeling into the 3D environment at MDACCO
    2). Radiation therapy clinical sites available for AASU radiation therapy program students
    3). Computer laboratory space for Dr. Hamza-Lup research group, (200 square feet) at AASU for software and graphical support including the simulation tool web server
- *Needed:*
  - o People: Research and development Assistants for computer simulation and data processing/analysis
  - o Software: 3D modeling, imaging and visualization
  - o Miscellaneous: equipment loan for laser scanning and rental expenses, travel, and conferences

Implementation Plan

Summer 2007 – Scanning data acquisition for different linac types using rented vendor laser scanning equipment followed by data processing and model building
Summer 2007 – Prototype of a few simulation models will be released to the public and feedback channels on the simulation tool features, ease-of-use, and functionality will be open for continuous tool development
Summer 2007 – Manuscript submissions for publications to relevant journals in Medical Physics and Computer Science and to relevant society conferences.
Fall 2007– In-service training offered to educators
Spring 2008 – Curriculum training for educators

Long Range Plan

In order to fulfill our vision for the use of advanced 3D Web-based tools for simulation and training of medical procedures, we have identified the following goals:

[1] Train instructors and assistants to feel comfortable teaching students about the radiation therapy procedure using advanced computer-based simulators.
[2] Create a plan for adoption in the curriculum of advanced 3D simulators for teaching purposes.
[3] Develop a solid educational scope and sequence for students to maximize learning.
[4] Continue to manage and enhance the existing simulators based on the feedback provided by its users.
[5] Include in-room imaging components as part of the 3D model. The user should be able to manipulate and extend the imaging components in the imaging position with respect to the patient and be able to generate a "fake" X-ray of the relevant patient region of interest at different magnifications: Example Varian On-Board imager (OBI).

As part of the future developments of this project is the inclusion of 3D patient data sets obtained from conventional CT data. The 3D external contours can be used to help in assessing the plan deliverability and obtain a better picture on collision issues for patient-specific plans. Also a large scale assessment of the system for teaching and training purposes is underway.

Communication Plan

A website will be maintained reporting on the project progress. The website will make available publications and reports. It will also report on student involvement and activities. The results of this project will also be shared with interested faculty and students from both hosting institution in the form of seminars and colloquia. In parallel, the results of the research will be submitted to conferences such as the American Association of Physicists in Medicine (AAPM), The Radiological Society of North America (RSNA), American Society for Therapeutic Radiology and Oncology (ASTRO), Medicine Meets Virtual Reality (MMVR), IEEE Virtual Reality, ACM and IEEE Computer Graphics and Applications Journals

Preliminary Committees and Members

Management Team

Omar Zeidan, Ph.D., Radiation Oncology, M.D. Anderson Cancer Center Orlando, Orlando, FL
Felix Hamza-Lup, Ph.D., Computer Science, AASU, Savannah, GA

Education Team

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Lee Barswell, M.P.H.R.T (R)(T), Radiological Sciences, AASU, Savannah, GA

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[9] F. Hamza-Lup, Ivan Sopin, and Omar A. Zeidan, "Comprehensive 3D Visual Simulation for Radiation Therapy Planning," accepted paper at Medicine Meets Virtual Reality 2007 meeting, Long Beach, California.

[10] F. Hamza-Lup, L. Davis, S. Meeks, O. Zeidan, "A 3D Collision Avoidance Tool for External Beam Radiation Therapy Treatment Planning," Oral Presentation, AAPM annual meeting, Med. Phys. 33, 2175, 2006.

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<u>Budget</u>:
Salary, Wages & Benefits:
Research & Development Assistant 1, $15/hour, 650 hours, 1 year: $9,750
Research & Development Assistant 2, $15/hour, 650 hours, 1 year: $9,750
Subtotal Salary: $19,500
Justification: design and development of software modules associated with the project. Data acquisition and post processing

Expenses
Travel related to project development, meetings:-$2,700
Presentations / Posters for Information Dissemination: $800
Subtotal Expenses: $3,500
Justification: travel expenses related to regular meetings between AASU
and MDACCO investigators

Equipment
3D Laser Scan Equipment Rental (e.g. Minolta, Z-Scan) $3,900
Image Processing Software (Raindrop Geo-Magic, 3D Studio Max)$3,000
Subtotal Equipment: $6,900
Justification: for 3D model conversion to a web-based X3D standard

Total Project Cost: $29,900

Other Sources of Support:

M. D. Anderson Cancer Center Orlando Foundation
Date of receipt: September 2006
Amount: $10,000 for one year
Type: project development seed grant

Justification: partial support for AASU computer science graduate student working on the initial phases of the project