AC 2009-856: COMPUTED TOMOGRAPHY IN SIMURAD: MEDICAL-IMAGING SIMULATION SOFTWARE

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Computed Tomography in SimuRad – A Medical Imaging Simulation Software

Abstract

In this paper we present a component of a newly developed computer simulation software – SimuRad, which can potentially help students to easily understand the underlying math and engineering principles of computed tomography (CT) in an undergraduate Medical Imaging course. This paper includes the discussions on the pedagogical basis of the SimuRad software, the initial design of CT component, a preliminary assessment from student test groups, and subsequent improvement and deployment plans. The development of this software is partially supported by an NSF CCLI grant

Introduction

"Medical Imaging" is an important subject in most bio-medical and bio-engineering curricula. This subject usually covers fundamental science and engineering principles (e.g. atomic and nuclear physics, Fourier analysis and reconstruction, and computer assisted tomography), medical imaging modalities (e.g. x-ray radiography, x-ray CT, nuclear medicine gamma imaging, magnetic resonance imaging, and ultrasound imaging), and clinical imaging practices (e.g. image analysis, visualization, instrumentation, and radiological protection)[1,2]. Such course has been regularly offered to graduate students with majors in radiology, medical physics, biomedical engineering, and computer engineering[3]. At Stevens as well as many schools this course is also introduced to junior or senior undergraduate students in biology, chemistry, physics and engineering majors[4]. The major challenge of offering this course at introductory level is its extensive multi-discipline nature. The targeted students normally have different backgrounds and limited preparation. It is generally difficult for someone to comprehend medical imaging methodologies without understanding the underlying principles of biology, physics and mathematics. But it is also not advisable to spend too much lecture time to cover all these fundamental subjects in an introductory course. A possible solution is to keep these subjects at a conceptual (or qualitative) level and allow students to visualize the physical effects through lab exercises.

Developing and maintaining a medical imaging laboratory is quite expensive, and it may require many specialized equipment and hazardous materials. Although many schools and programs have been offering some kind of lab exercises for this course, not many of them can actually afford and support a comprehensive laboratory that can cover all the aspects and modalities of medical imaging[4,5].

The objective of this CCLI Phase 1 Project is to develop a computer simulation lab environment—SimuRad, that can help junior or senior undergraduate students from different majors to understand the concepts and theories of medical imaging methodologies, and gain hands-on experience on the design and implementation of medical image acquisition, reconstruction and processing schemes[6]. This software simulation tool can potentially help students to study this medical imaging course more effectively, and to have certain hands-on experience on the design and operation of most medical imaging modalities. This software is

also designed as an open platform, so that it can be expended and maintained by the students and teachers in the BME education community. Because of the portability, low cost and open-source nature of this software, the potential impact of this project can be significantly larger than the undergraduate population of the medical imagining course at Stevens. For well established BME programs, this software can help the students to "observe" the physical processes within the medical imaging instrument. For new BME programs, this software will provide a cost effective approach to deliver medical instrumentation and imaging course with appropriate lab component This tool can also be useful for professional training, and can be augmented with more detailed and accurate simulation modules on specific modalities for advanced users. This software may present an affordable solution to provide basic medical imaging training to under-represented student populations, and open a door for them to develop successful careers in bioengineering and healthcare industries

System Architecture

The SimuRad software simulation environment will be structured in three layers, as shown in Figure 1.
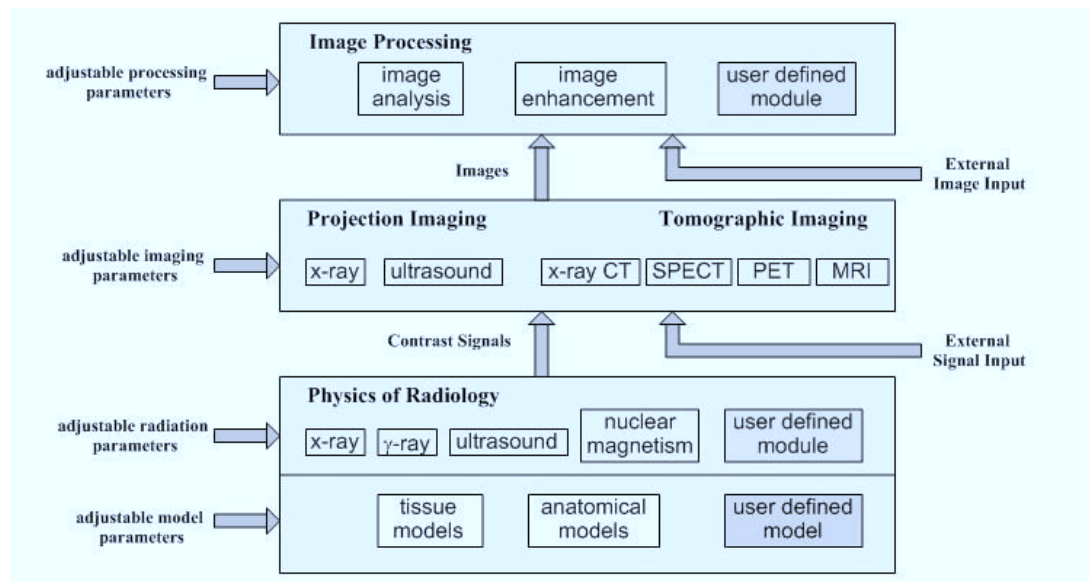

Figure 1. SimuRad system architecture

The first layer is "physics of radiology", which will be the most ambitious part of this project. At this layer, the physical processes of radiation, tissue reaction, signal generation and acquisition will be simulated based on underlying mathematical formulas. Computational or numerical models will be also built to synthesize human anatomy under various modalities.

The second layer is "projection and tomographic imaging", in which the raw data collected from the first layer will be used to reconstruct 2-D images based on various processing schemes and algorithms.

The third layer is "image processing and analysis", which will provide an open platform to implement and apply image processing and analysis tools on the output of the second layer, or on any real medical images.

SimuRad is a unique simulation tool, which will accommodate most medical imaging modalities with emphases on the following features.

- Accurate physical modeling: the software will model the interactions of various radiation sources (e.g. x-rays, γ-rays, magnetic pulses and ultrasound) with tissues and signal acquisition processes according to underlying physical principles and scientific data
- Flexible process control: the software will allow users to specify the material and physical dimension of the test subject, define the radiation source and dose, and take measurement from arbitrary position in a 3D space
- Progressive visualization: the software will display the process of signal generation, acquisition and image formation in an evolving graphic sequence
- System expandability: the software will provide an open structure that can allow user to develop new modules with minimum effort, and it will also have interface to import user defined test data and public available medical images

Virtual lab exercises based on SimuRad

The system is organized as a series of independent modules. Each system component is implemented as an individual function (or class) related to one of three layers. Many modules may share the same functions, and each module may contain components from multiple layers to provide one complete lab exercise.
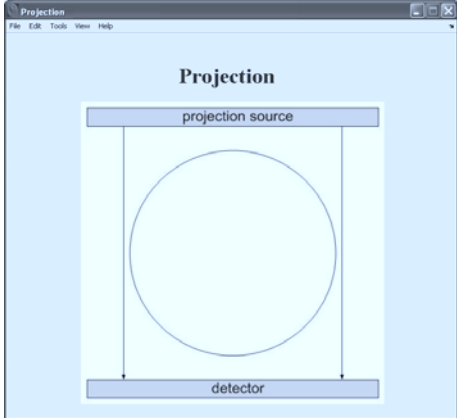
In this CCLI Phase I project, we planned a total of eleven modules. We believe these eleven modules will be adequate to provide lab exercises for a one semester course (thirteen weeks).

1. Convolution and Fourier Transform (math preparation),
2. Projection and Projection Slice Theorem (tomography),
3. Frequency domain reconstruction – number of projects, interpolation methods (x-ray CT, MRI),
4. Filtered back projection – number of projections, filters, noise (x-ray CT),
5. X-ray attenuation coefficient and survival probability (x-ray),
6. NMR signals – precessions, relaxation, basic sequences (MRI),
7. Localized NMR – slice selection, frequency coding, phase coding, image reconstruction (MRI),
8. Gamma ray detection – SPECT and PET (nuclear medicine),
9. Ultrasound propagation and imaging (ultrasound),
10. Medical image processing – enhancement and feature detection (applications),
11. Brain activation detection in fMRI (applications).

The CT component of SimuRad consists of three lab exercises. The first exercise is to demonstrate the "Project Slice Theorem"[1,2]. The software will allow the user to provide or select an input object image for projection. The software will calculate the 2D DFT of this image. Both

the image magnitude and the 2D DFT magnitude will be displayed as 3D mesh plots. The user is to provide a projection direction, and a project plane will gradually slide through the object image and finally obtain and display a 1D projection. The software then calculate the 1D DFT of this projection and compare it with the corresponding slice from the 2D DFT plot to show that they are identical. The second exercise is to demonstrate the Fourier domain reconstruction method[1,2]. The user will specify a set of projection angles, and the software will calculate the 1D DFT of the projections and place them at the corresponding positions in the 2D DFT space. After all projections are completed, a 2D interpolation process will gradually fill in all necessary 2D DFT points. After the interpolation is completed, a 2D inverse DFT is performed and the reconstructed object image is displayed. The third exercise is to demonstrate the convolution (or filtered) back projection method[1,2]. Again the user specifies a set of projection angle. After each projection is taken, the projection is filtered by a selected filtered and back projected to a reconstruction space, which is displayed in both 2D and 3D. The back projection of each new projection will be accumulated with all previous back projections. After all projection and back projection are completed, the final reconstructed object image is obtained. The user can select a set of filters as well as the cut-off frequency of these filters. The user can also introduce a certain amount of random noise into the projections and see the reconstruction results from different filters.

Figure 2 shows an example of lab exercise sequence.

Step 1. Select exercise "Tomography – filtered back projection"

Step 2. the software initiates the "Projection" component
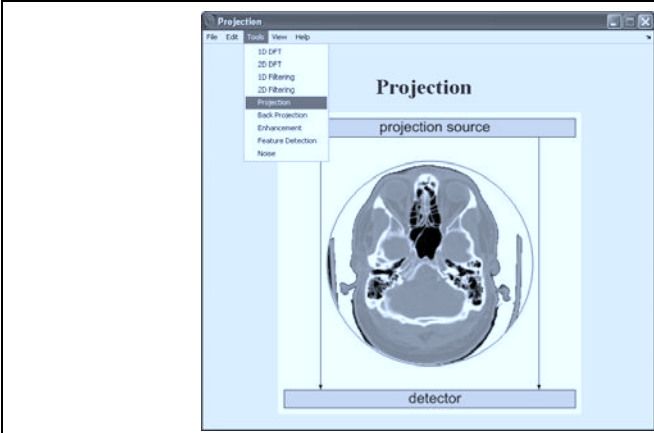
Step 3. Select a file as projection subject. The image is loaded into the program. Then select "tools – projection" from menu
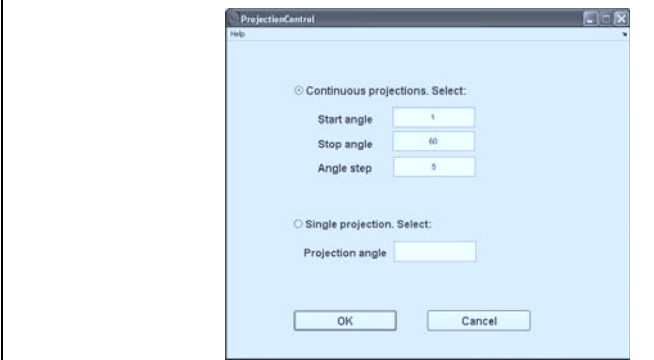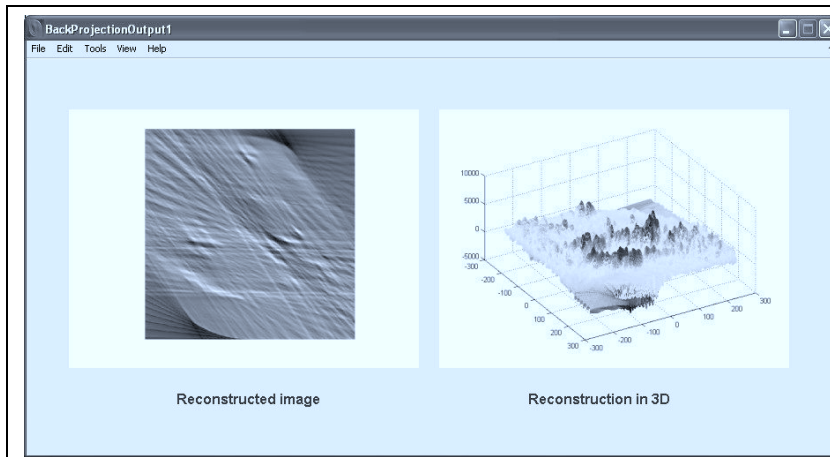

Step 4. A projection control window will allow the selection of "Continuous projections" at a set a angles
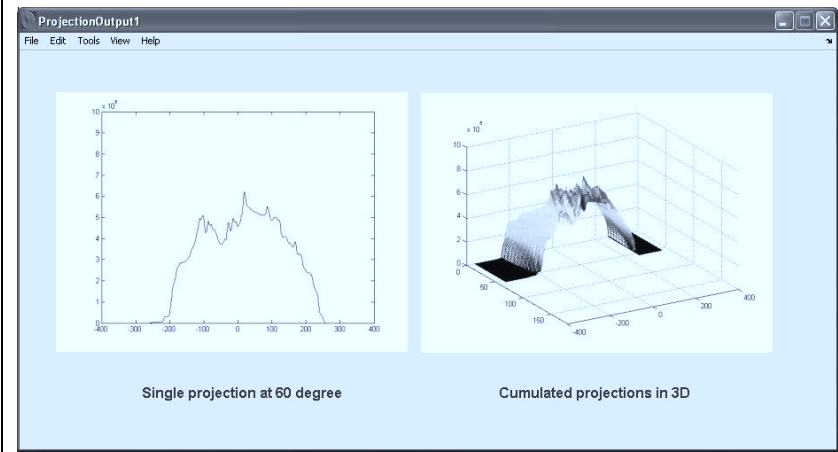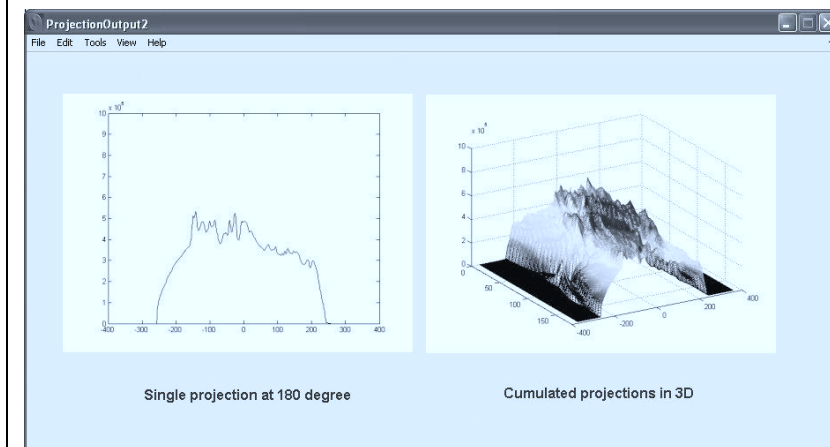

Step 5. Projection results are progressively displayed in 2D and 3D. Then select "Tools – Back Projection"
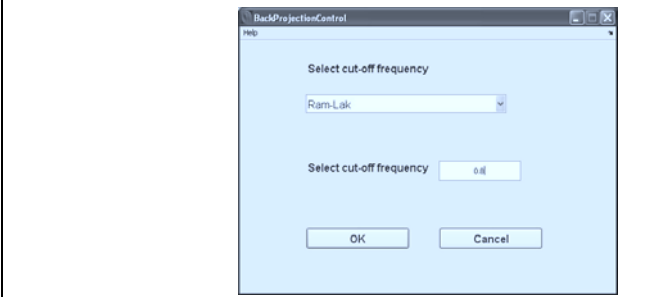
Step 6. A back projection control window will allow the selection of filter and its cut-off frequency

Step 7. Back projection (image reconstruction) results are progressively displayed in 2D and 3D.

Step 8. One may repeat 3~7 for different set of projection angles, and observe different projection and back projection results
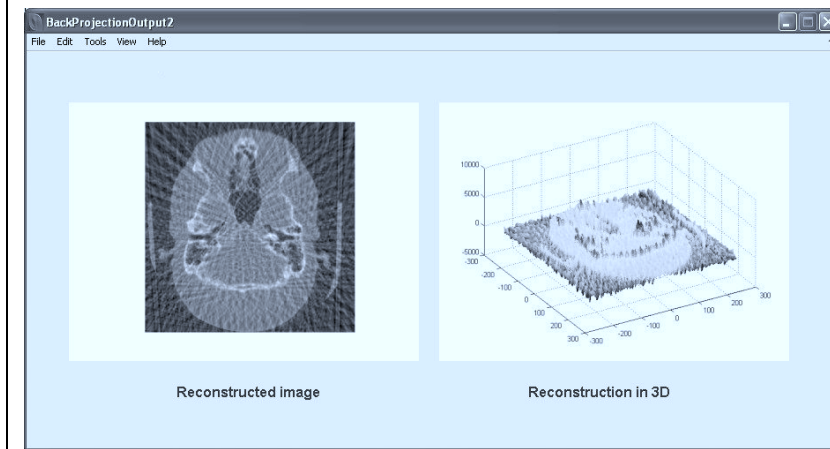
Figure 2. An example CT lab exercise sequence.

Preliminary assessment

Some components of the SimuRad software were evaluated in the BME504 Medical Instrumentation and Image course in Fall 2008 at Stevens. We designed a simple set of survey

questions for students to complete before and after each lab exercise. Following is an example of survey instruction provided in a lab assignment.

Answer the following survey questions using the scale 1 ~ 5 (1: strongly disagree, 5: strongly agree):

1. *You understand the concept of filtered back projection method BEFORE you take this lab exercise. 1 2 3 4 5*
2. *You understand the concept of filtered back projection method AFTER you take this lab exercise. 1 2 3 4 5*
3. *You have the knowledge and skill to complete this lab exercise without additional study beyond the lectures. 1 2 3 4 5*
4. *This lab exercise takes you too much time. 1 2 3 4 5*
5. *You think a better lab exercise can be designed to reach the objectives of this lab exercise. 1 2 3 4 5*

This was a regular on-campus course. Each week students had a 1.5-hour lecture and a 2-hour lab. A total of twenty students were enrolled in this course. The survey was voluntary. The response rate was about 50% in average, which should be improved in the future. Figure 3 shows the aggregated results of three lab exercises related to the "computed tomography".
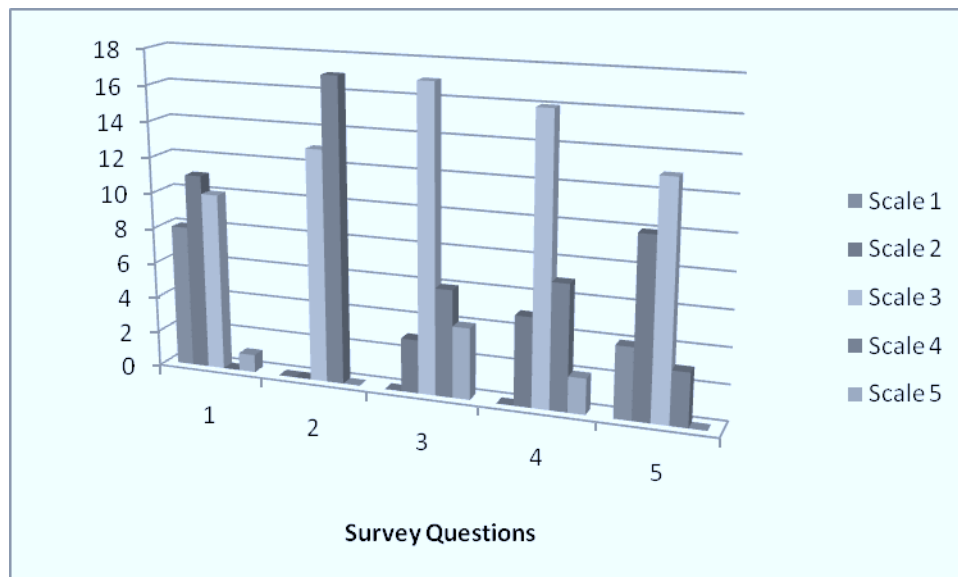

Figure 3. Preliminary assessment results on CT related lab exercises

From these results we can see that some students tended to select *Scale 3* when they did not have strong opinion on particular question, which is quite common in most surveys. We also see some obvious errors made by students in completing these surveys. However overall we think the results match our expectation well. In particular, from question 1 to question2, we see a significant number of students moved from *Scale 1~3* to *Scale 3~4*, which means that this software was indeed effective in helping students in learning computed tomographic imaging

methods. From question 3~5 results we also see that most of the students seem satisfied with the implementation and usability of the software.

Obviously this evaluation was our first attempt, and the results are far from conclusive. We will continue this exercise in the following years. In Spring 2009, the BME504 course is offered entirely online at Stevens Web Campus. We will be using this SimuRad software again for all lab exercises. Helping our distance learning students was one of our major motivations to develop this virtual lab software. We understand that the audience and learning behaviors are somewhat different in online classes, and we believe that online students may benefit more from such learning tools.

Conclusion and future works

We have developed an innovative SimuRad software for learning Medical Imaging through computer simulations. The software system consists of three layers, and currently supports eleven lab exercises. In this paper we introduced the system design and focused more on the computed tomography component. A lab exercise sequence on CT using SimuRad was presented, and our initial assessment on this component was obtained through student surveys. The survey results generally indicate that this software is a helpful learning tool and its usability is satisfactory. However we understand that further study and developments are needed in order to improve the effectiveness of this software.

For future works, we plan to refine some of the current modules, especially those related to nuclear physics. We will redesign user interface and with possible extension for web access. We will also investigate more effective assessment methods for using this tool in our on campus and online classes. After the system becomes stable, we will start beta tests in other universities, and we will disseminate this software through technical conferences as well as web presence. The software will eventually be made accessible to colleagues and students at any institutes wishing to utilize these materials within their curricula.

Acknowledgement

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