AC 2010-1562: COMPUTER LAB EXERCISES FOR MEDICAL IMAGING USING SIMURAD

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Computer Lab Exercises for Medical Imaging Using SimuRad

Abstract

In this paper we present a series of computer lab exercises for an undergraduate Medical Imaging course using a newly developed computer simulation software – SimuRad, which has been designed to help students better understand the underlying math, physics and engineering principles of medical imaging. This paper includes the discussions on the architecture of the SimuRad software, the design of the computer lab series, preliminary assessment from student groups, and subsequent improvement and deployment plans. The development and deployment 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. It is a multi-discipline subject involving studies in biology, physics, mathematics, electrical engineering, and computer science. A comprehensive medical imaging course may cover 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]. Although it has been a typically a graduate level course in most of the radiology, medical physics, biomedical engineering, and computer engineering programs[3], it has also been frequently offered to undergraduate students as a required or elective course.

In order to offer this as an introductory undergraduate course, it is necessary to emphasize conceptual learning through lab exercises[4,5]. In this paper we present a series of computer lab exercises based on a newly developed computer simulation software – SimuRad[6], which can help students better understand the underlying science and engineering principles of medical imaging.

SimuRad is an interactive software which implements numerical algorithms to simulate physical and biological processes in most common medical imaging modalities. The software contains expandable modules, each to support a series lab exercises related to a particular modality. Currently implemented modules include math fundamentals, computed tomography (CT), x-ray physics, nuclear magnetic resonance (NMR), image enhancement and analysis. With these modules, seven computer lab exercises have been designed.

Lab 1, Convolution and Fourier Transform (math preparation)
Lab 2, Projection and Projection Slice Theorem (tomography)
Lab 3, Frequency domain reconstruction – number of projects, interpolation methods (x-ray CT, MRI)
Lab 4, Filtered back projection – number of projections, filters, noise (x-ray CT)
Lab 5, X-ray attenuation coefficient and survival probability (x-ray)
Lab 6, NMR signals – precessions, relaxation, basic sequences (MRI)
Lab 7, Brain activation detection in fMRI (image analysis)

These computer lab exercises have been adopted in the Introduction to Medical Imaging course instructed by the author at StevensInstitute of Technology for several semesters. This paper reports on the designs of these lab exercises using SimuRad, together with preliminary assessment results from student groups, and subsequent improvement and deployment plans.

Descriptions of the computer lab exercises

Lab 1. User generates different signals by selecting multiple simple waveforms, e.g. sine, square. The amplitude, frequency and phase of each simple waveform are specified by the user. Then Fourier Transform is performed and the frequency response is displayed for each generated signal. User is instructed to try a sequence of parameter sets to observe the changes of frequency responses corresponding to changes in signals. User then selects a filter. Convolution of a signal with the filter is implemented through multiplication in frequency domain, which is to demonstrate the concept that filtering is a process of frequency selective attenuation or amplification.

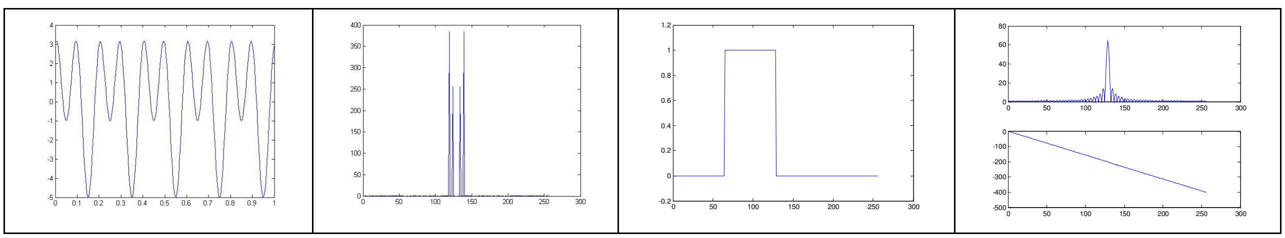


Figure 1. Samples of student works on frequency component analysis in 1D waveforms.

Lab 2. User first creates simple 2D objects from isolated points, simple shapes (rectangle, circle, ellipse etc.), and observes their projection (radon) domain presentations. The number and angle of projections are specified by the user. A phantom template is also provided so that user can manipulate the components to created different phantom objects for projection tests. User then use the phantom object to validate projection slice theorem. The process is to take one projection at user specified angle, then display this projection signal, the 1D FFT of this projection, as well as the corresponding slice of the 2D DFT of the phantom image. The user can observe the consistency of these two FFT results at any selected projection angle.

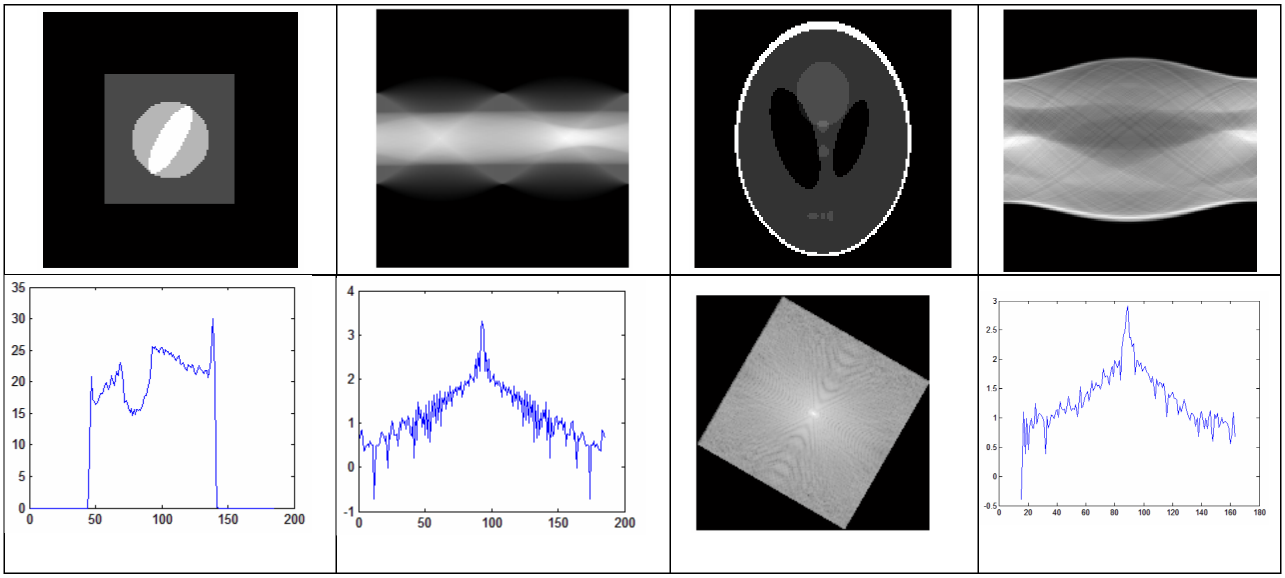
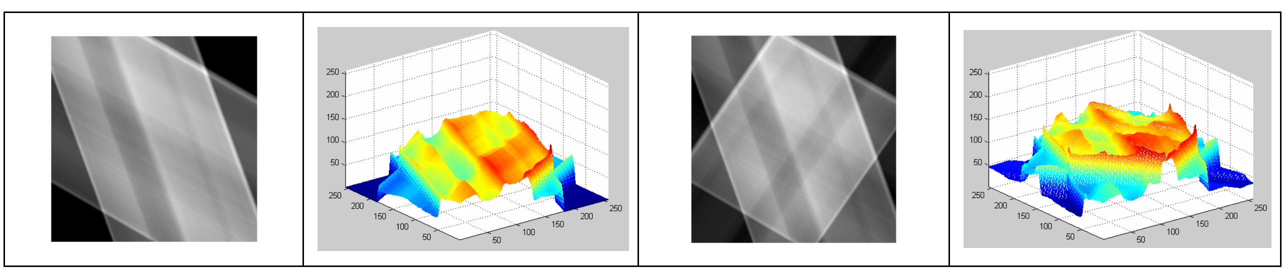


Figure 2. Samples of student works on projections of geometric shapes, and verification of projection slice theorem.

Lab 3. User selects a 2D object and specifies the number of projections, number of samples per projection and projection angles. The projection results are displayed. Each projection is then placed on a 2D frequency domain at corresponding angle, and this process is displayed in both 2D and 3D plots. After all projections are placed into this 2D space, interpolation is performed to create samples at Cartesian grid, and a 2D inverse FFT is performed to generate the reconstruction image. User is instructed to try a sequence of parameter sets to observe the changes in reconstruction image quality. In particular, frequency domain interpolation can only be observed clearly when the number of projections and the number of samples per projection are small, but good quality image can only be obtained when these numbers are large. User will explore these different settings and report the findings.



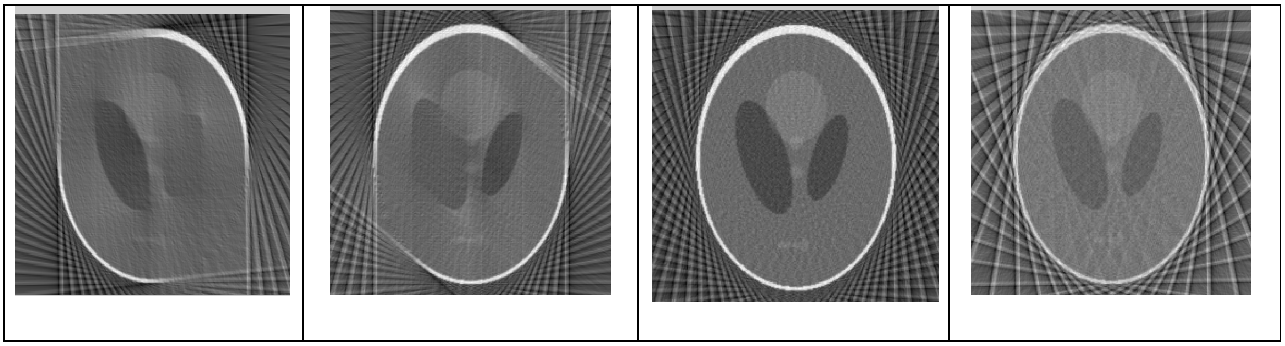


Figure 3. Samples of student works on image reconstruction through back projections.

Lab 4. User selects a 2D object and specifies a projection angle and number of samples per projection. The 1D projection is displayed. Then user clicks "back-projection", and observes the creation of a 2D back-projection image displayed in both 2D and 3D plots. User then specifies a series of projection angles, and observed the accumulation of all back-projections into one 2D reconstruction image. User should see that such reconstruction looks blurred and too bright. User then selects a filter and applies it to each 1D projection before the back-projection. User will observe a much clearer reconstruction image from filtered back-projections. User will further explore different filters, cut-off frequencies of filters, and projections with different levels of induced noise. The filtering effects become more evident. Given the large parameter space, this exercise is rather long and it usually takes users two weeks to complete.

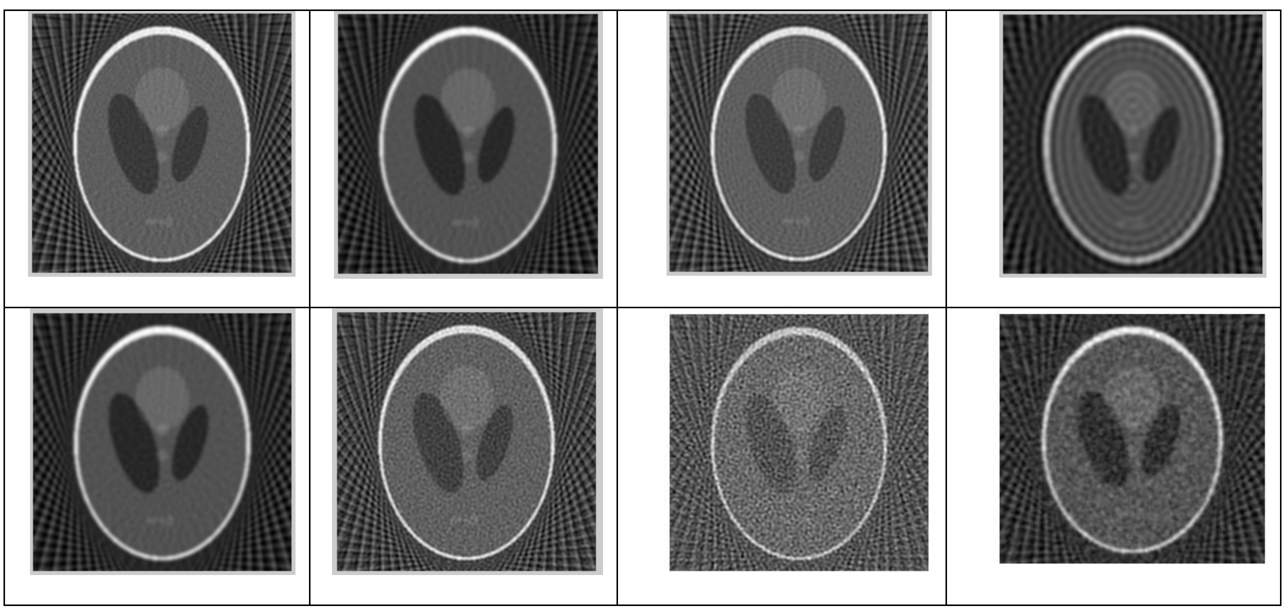


Figure 4. Samples of student works on various filter types and parameters, and effects on noisy images.

Lab 5. User selects a material from ("adipose", "air", "aluminum", "bone", "copper", "iodine", "lead", "lung", "muscle", "soft tissue", "water"), and changes the incident x-ray energy from 10 to 400 KeV. The mass attenuation coefficient is displayed for each material at each x-ray energy level. Absorption edges for some materials can be observed when the energy increment is small. In the second part, user selects a metal material, an incident x-ray energy and changes the thickness of the material to observe the numbers of survival x-ray photons after the penetration. The results are based on NIST dataset, and there is not much computation involved.

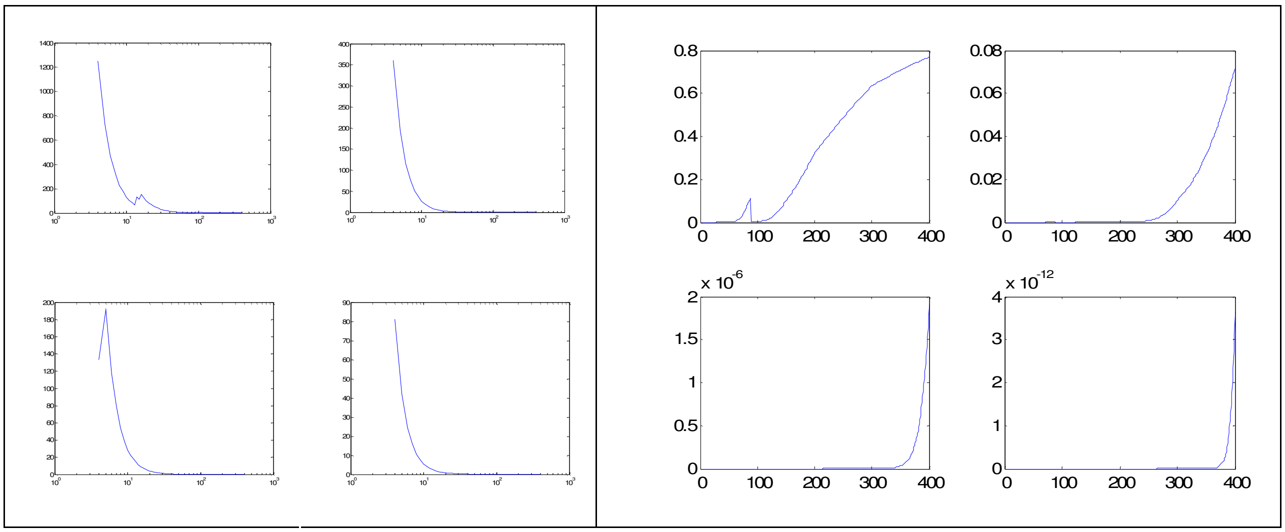


Figure 5. Samples of student works on x-ray attenuation coefficients and survival rates for various materials at different x-ray energies.

Lab 6. User first gets familiar with 3D vector representation of spin magnetization, by specifying an excitation on the equilibrium vector Mz, and observing the resulting 3D vector. Then user will observe spin dynamics including transverse (T2) relaxation, longitudinal (T1) relaxation, and free precession individually and jointly. User specifies T1, T2 times, initiates an excitation angle, and then observes the vector changes over time, typically for a range of 1 ~ 2400 ms. The display is progressive for 10 frames per second. At the same time, the user will also observe the FID (free-induced-decay) signal waveform generated from each session. In the second part, user simulates some basic NMR sequences, including saturation recovery (SR) and spin echo (SE). In SR simulation, user specifies the T1, T2 values, an excitation angle, the repetition time (TR), echo time (TE), and repetition number. User will observe the vector animation and FID that is generated. In SE simulation, user specifies number of spins, e.g. 10, off-resonance frequencies randomly distributed between -50 Hz and 50 Hz. User can observe the animation of all these spin vectors and the aggregated FID signals. In particular, this simulation is very helpful in explaining the divergence and refocus of magnetization on x-y plane in SE. This exercise is also very long, and it usually takes users two weeks to complete.

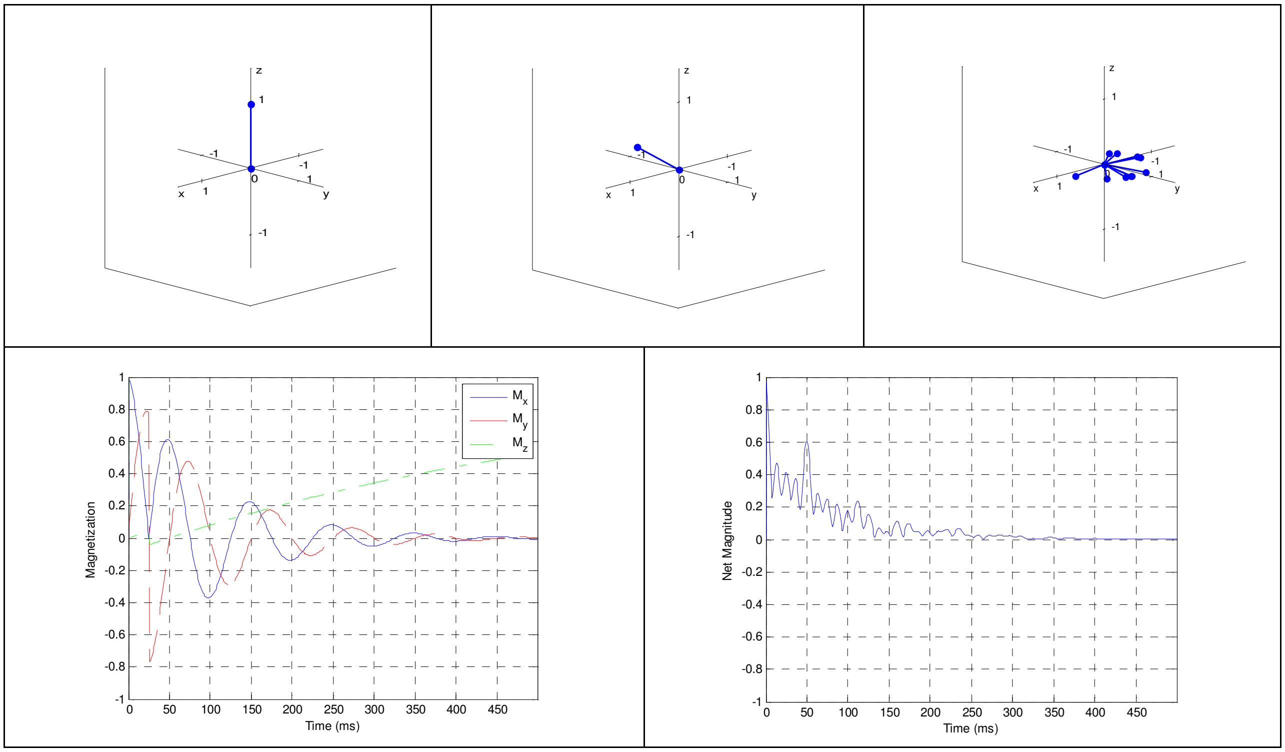


Figure 6. Samples of student works on relaxation processes of spin magnetization and resulting FIDs. Lab. 6 results are mostly in continuous animations, and the results shown are screen shots.

Lab 7. User is given a functional MRI dataset containing one axial brain slice for 68 time samples. Each image is of 46 by 55 in size. The data was collected by a 1.5T GE Echo Speed Horizon scanner for a finger-tapping test. The paradigm contains 4 on-periods and 5-off periods, which is explained to the user. The first image is displayed, and the user can click any pixel on the image to display the time sequence of that pixel. In the lab instruction, a few active pixels are listed, and user can locate these pixels and see the similarity of these time sequence with the paradigm. Then user is asked to find a few more active pixels, e.g. five. A t-test tool is provided, so user can obtain the t-value for any selected pixel, and can observe that higher t-values correspond to higher similarity between the selected pixel and the paradigm.

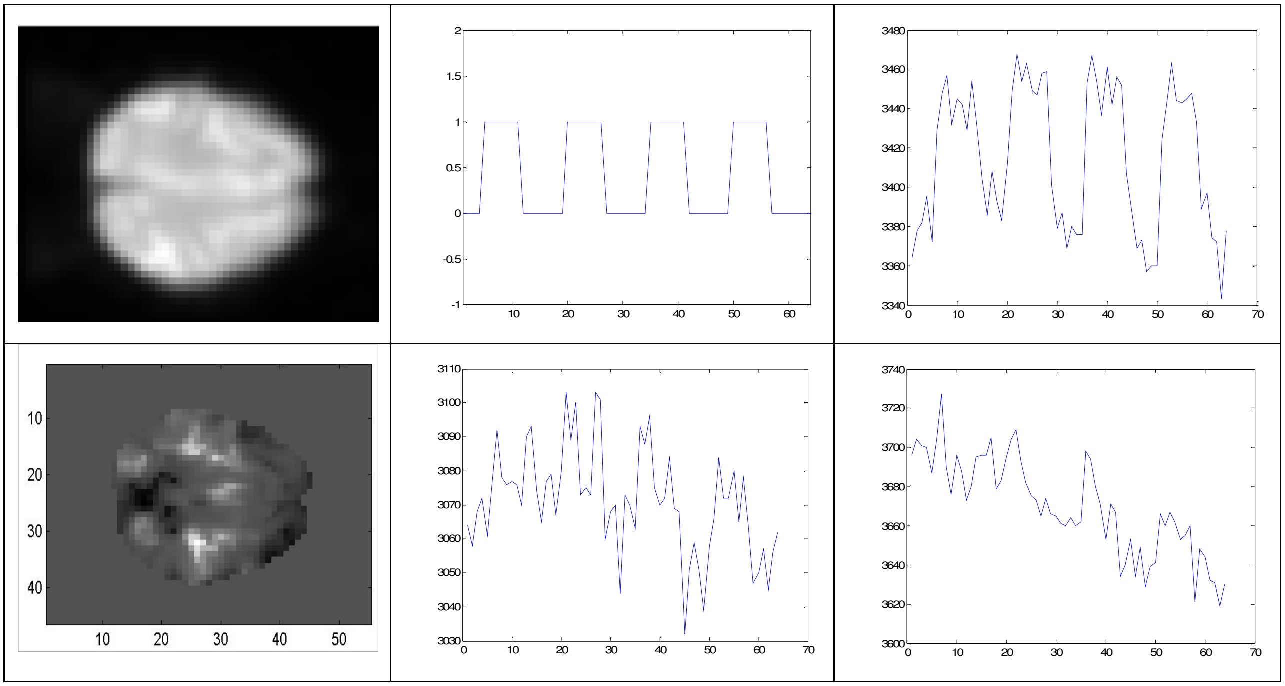


Figure 7. Samples of student works on brain voxel activation detection corresponding to an exercitation paradigm.

Our students typically used 9 to 10 weeks to complete all these labs. Upon completion of each lab exercise, students are required to write a lab report. The contents of the lab exercises, e.g. procedures and results, were included in the midterm and final exams.

Preliminary assessment

The seven lab exercises were deployed in the BME504 Medical Instrumentation and Image course in Fall 2008 on-campus section, and in Spring 2009 online section at Stevens. To assess the effectiveness of these lab exercises, we designed a simple set of survey questions for students to complete 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

In Fall 2008 on-campus course, each week students had a 1.5-hour in class lecture time and a 2-hour lab time. A total of twenty students were enrolled in this course section. The survey was voluntary. The response rate was about 50% in average. In Spring 2009 online course, all student interactions were coordinated online. Students were asked to commit comparable amount of time on course materials and exercises as in regular on-campus courses. (Our WebCampus surveys frequently confirmed such time spending.) A total of twenty nine students were enrolled in this course section. The survey response rate was about 75% in average. The survey results, as five questions per lab and a total of seven labs each semester, are provided in Figure 8.

Overall we think the results match our expectation well. In particular we see clearly an increase of score from Question 1 to Question 2 in all of the lab exercises, which indicates improved understanding of topics under investigation. From Questions 3-5 results we see that most of the students seem satisfied with the implementation and usability of the software, although complains of "too much time spent" can be observed from Question 4 results, especially in Lab 3 and 6. We think Spring 2009 results are more meaningful and reliable because of high enrollment and high response rates. We will provide detailed analysis on these assessment results and draw useful conclusions in our future reports and publications.

Obviously this assessment was our first attempt, and the results are not conclusive because of the relatively small scale of our survey. We will continue this exercise in the following years. In particular, we will introduce direct assessment measures for each lab exercises. The plan is to design some homework questions before and after each lab to assess the effectiveness of the lab exercise. Also when we move on to dissemination, we will design online survey and test tools.

Conclusion and discussion

We designed a series of computer lab exercises using SimuRad for an undergraduate medical imaging course, and our initial assessment on these labs 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.

During the development and deployment, we also learnt important lessons. 1) It is not advisable to ask student to explore many aspects of a topic in one lab exercise. Each lab should be focused and the objective should be clear. Therefore we think that, for some of the developed modules, each may be explored in several lab exercises. 2) Given the resource constraint in a typical BME program, it is not practical to develop and maintain a single stand-alone application over multiple platforms for large amount of students, especially online students. We started to migrate to an online platform in JAVA, and also implement most of the modules in well established and maintained platforms such as Matlab and OCTAVE, which has been widely available to most college students.

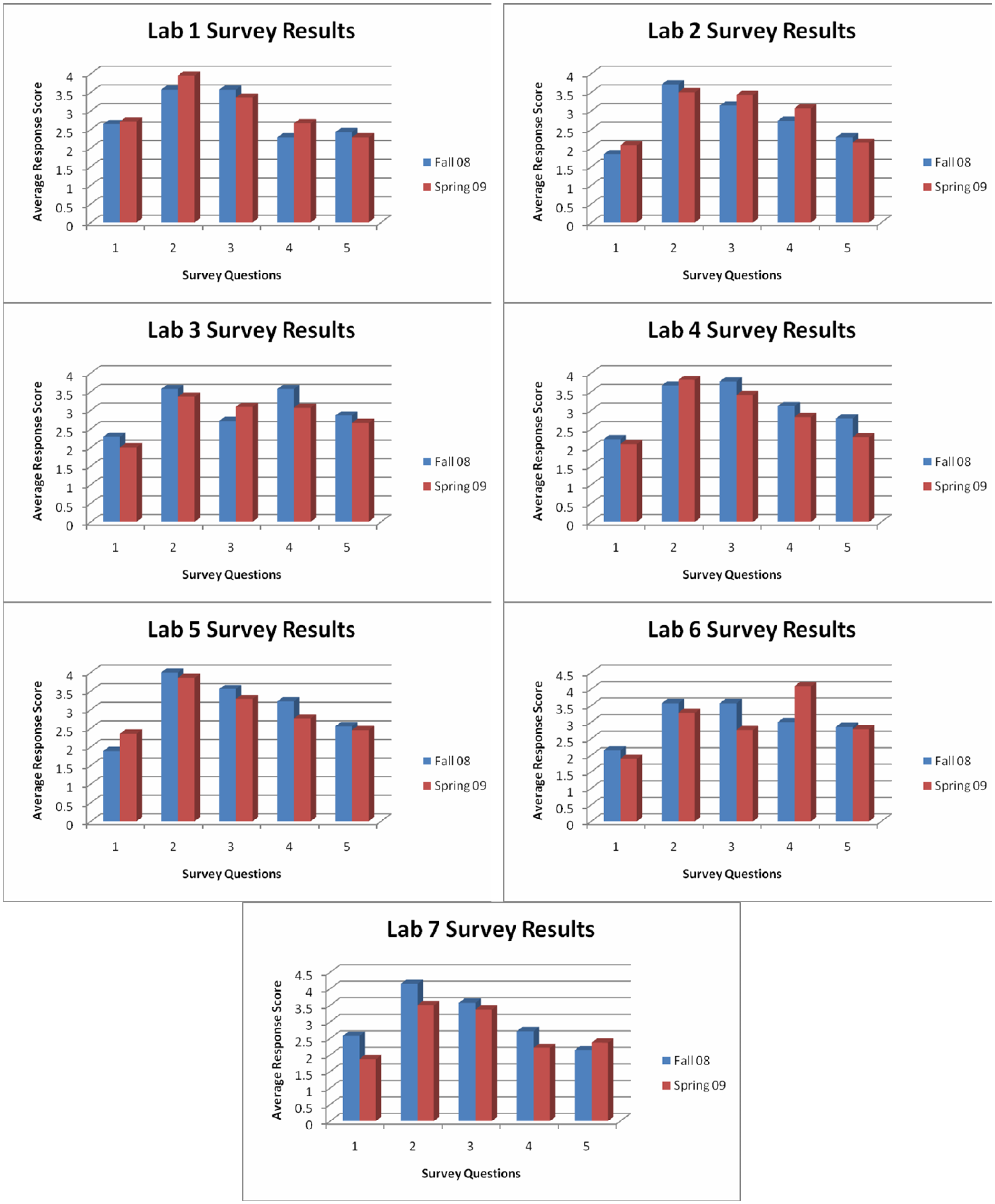


Figure 8. Survey results after each lab exercise during Fall 2008 and Spring 2009 semesters.

Acknowledgement

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