Automated Quality Assurance System for Clinical CT Systems

BME 400

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Abstract
Computed tomography (CT) machines are tested regularly to ensure the machines are calibrated and functioning properly. Each time a scanner is tested, a medical physicist must conduct numerous tests to assess each component of the machine and the images it produces. The physicist must then record all testing results by hand and generate a report based on the results. The reports outline each testing procedure used by the physicist and the results of each test. These reports are sent to technicians who replicate the tests to decide which adjustments should be made to the machine. Currently, there are no standard protocols for CT quality assurance testing. Due to the inconsistency in quality assurance reports, miscommunication between the technicians and the physicists is common. Any misinterpretation of the reports can delay CT adjustments, creating a problem for the entire facility. In order to expedite and standardize CT quality assurance testing, a software program will be created to accept user input, automate calculations and CT image analysis, and generate testing reports. This program will consist of a graphical user interface created in MATLAB and will help to eliminate communication issues as well as significantly decrease the time and effort involved in CT quality assurance testing.

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Introduction

Motivation

It is not difficult to understand why quality assurance (QA) of CT machines is important. Physicians make diagnoses based on the images they see, and they rely heavily on the fact that they are actually seeing the regions the machine indicates they are seeing. Our motivation involves streamlining the testing and reporting process to save both the medical physicists and service technicians time. The program would allow for a universal and standard system as opposed to varying reports and tests depending on the specialists, machines, and facilities involved.

Additionally, our program will have the ability to look back on results of previous scans and include trend lines to see if certain characteristics of the machine are declining below desired values. This feature can help the medical physicists decide which parameters to pay attention to and can prevent scanner issues from becoming too serious. Lastly, our program will greatly improve communication between the medical physicists and the service engineers. This will ultimately reduce the time it takes to fix any issues with the CT machine once the medical physicist sends out a report.

Competing Designs

Two commercially available CT QA software programs include Image Owl and PIPSpro. Both of these programs highlight their database and trending capabilities, along with other advanced features such as built in test types and cloud-based services [2,3]. However, their complexity comes with a trade-off in the form of reduced flexibility and high cost. More details about these products can be found in the Product Design Specification in Appendix A.

Problem Statement

CT machines are carefully tested on a daily, weekly, monthly, and annual basis. Each time a CT machine is tested, many different components of the machine are analyzed to ensure the machine is properly calibrated and working correctly. The complexity of the testing procedures makes CT quality assurance testing and reporting an extremely time consuming task. The results of each test are recorded manually and entered into spreadsheet-based reporting tools.

The reports and testing procedures often vary between medical physicists making it difficult for the results to be replicated by CT repair technicians. The two main goals of this project are to create standardized testing protocols for use within the facility and to automate the reporting process. The client would like a software program capable of reading DICOM images (images produced by the CT scanner) from various quality assurance tests, evaluating the images without user interaction, generating a report from the results, and writing the results to a database to track scanner performance over time.

Background

Client Information

Dr. Szczykutowicz is an Assistant Professor in the University of Wisconsin School of Medicine and Public Health Departments of Radiology, Medical Physics, and Biomedical Engineering. He received his undergraduate degree in physics and earned his Masters and Ph.D. in medical physics at the University of Wisconsin-Madison. Dr. Szczykutowicz is involved in several clinical and research activities including optimizing CT scan protocols, patient dose monitoring, and developing protocol management methodologies. We will be assisting him in creating a system for optimizing the reporting process for CT quality assurance testing and standardizing the format and protocols used for these reports [1].

We will also be working with Jessica Miller, a physicist in the University of Wisconsin Department of Human Oncology and assistant professor in clinical health sciences. She will be collaborating with Dr. Szczykutowicz to create the design requirements for this project.

Computed Tomography

Computed Tomography (CT) scans combine X-ray images accumulated from multiple angles to create cross sectional images of a target object through digital computer processing [4]. This type of scan has “revolutionized diagnostic radiology over the past three decades” [5]. CT provides physicians with valuable information regarding the anatomy and structure of human tissue and organs without the need to make incisions. A disadvantage of CT scans involves the fact that the scans are performed using radiation doses that are applied to the patient. These can be potentially harmful if the dose is too large or if a patient receives a large number of scans.

CT Quality Assurance Tests

Quality assurance tests are performed on CT machines to validate whether they are functioning properly or if a certain part of the machine requires repair. The machines have various tests that are required at different time intervals [6]. There are simpler tests performed daily, more complicated tests performed weekly and monthly, and rather extensive tests performed on an annual basis. Daily tests, for example, may include multiple series of helical and axial scan evaluations with parameters such as detector coverage, speed, rotation time, and slice thickness. Annual tests may include artifact testing, noise and CT number uniformity, laser consistency, couch movement and levelness, dose, beam width, and gantry tilt, among others [7].

Image phantoms are objects used to evaluate CT machine performance that can be designed to mimic human or animal tissue. Phantoms can be used to test for position verification, slice width, and scan incrementation, among other characteristics [8]. Phantoms can be developed with different design interests in mind. These can include designs optimized for tests to ensure accurate and proper scanning for human scans, and also phantoms optimally designed for scans in small animals such as mice. This is important because human diseases can be modeled in small rodents and research studies are supplemented with CT scans of these disease ridden animals [9].

There are a variety of different quality assurance manuals that outline different tests that can be performed and their significance. A main goal is to produce quality diagnostic images at the lowest possible radiation dose [10]. This can only be achieved if quality assurance tests are performed to check whether the expected radiation doses are actually observed.

Design Specifications

The client would like a software program capable of reading DICOM images from various quality assurance tests, evaluating the images without user interaction, generating a report from the results, and writing the results to a database to track scanner performance over time. Ideally, the program will be packaged as an executable for distribution and will be capable of displaying machine trends in a chart. For further explanation of the design specifications, please refer to the Product Design Specifications in Appendix A.

Preliminary Designs

Design 1: Multi-GUI

Using MATLAB's Graphical User Interface (GUI) system, a program will be created capable of receiving user input, performing automatic calculations, and analyzing images. The code will be compiled into a single executable that is universally compatible with any operating system. The "Home Page" of the CT Report Builder will allow the user to select a DICOM image or a specific test to analyze the data received from a CT system. Once a test is selected, a new GUI will appear with the input parameters for the specified test (Figure 1). After all desired tests and

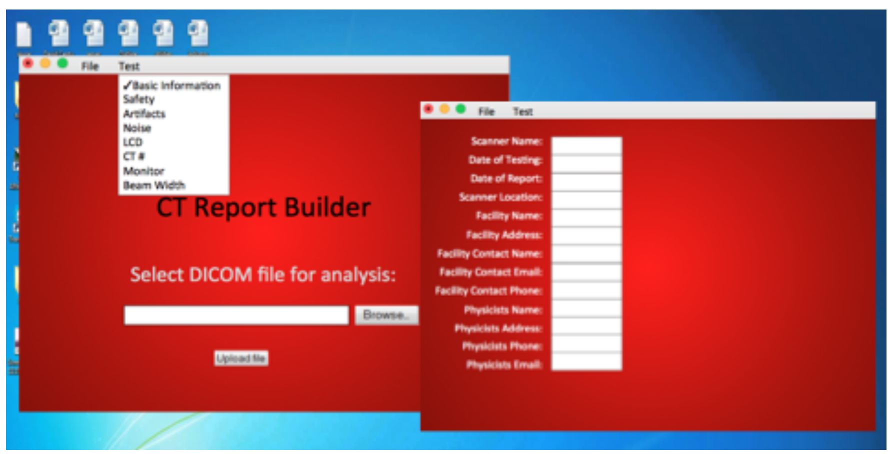
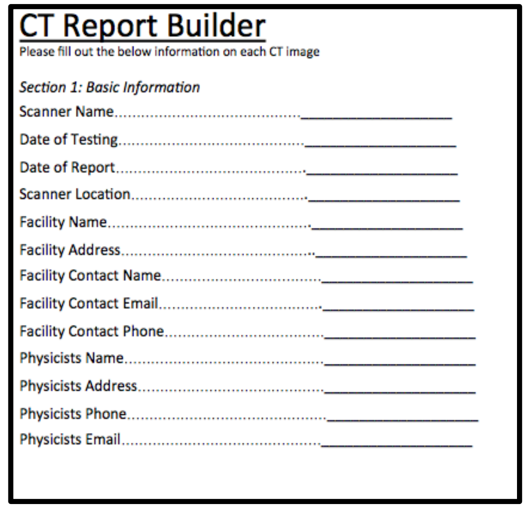


Figure 1. Representation of Design 1 showing multiple GUIs open simultaneously.

calculations are conducted based on the input parameters, the GUI will create a formatted text document with a full report on a specific CT scan.

Design 2: Text Document

Design 2 features a PDF or Word document template. The template will have a section for each test that is performed and will have a fill-in-the-blank format. This design may also feature checkboxes and other options for user input (Figure 2). The template will be used to generate a text or word document containing the testing protocols and results. The document can alternatively be printed and used in hard-copy format.



CT Report Builder

Please fill out the below information on each CT image

Section 1: Basic Information

Scanner Name.. ________________

Date of Testing.. ________________

Date of Report.. ________________

Scanner Location.. ________________

Facility Name.. ________________

Facility Address.. ________________

Facility Contact Name.. ________________

Facility Contact Email.. ________________

Facility Contact Phone.. ________________

Physicists Name.. ________________

Physicists Address.. ________________

Physicists Phone.. ________________

Physicists Email.. ________________

Figure 2. Design 2 featuring a PDF or Word format document of a CT Report.

Design 3: Master GUI

Design 3 will have the same functionality as Design 1. However, all the testing protocols and information will be contained in a single master GUI. Each test will remain in an individual panel that will become visible and editable when selected from the drop down bar in the top left corner (Figure 3). Alternatively, the user can select another test at any time and the GUI will automatically update its input parameters and save previous test data. The drop down bar, save, and export button will always be visible at the top of the GUI. The export button will allow the user to generate a report at any time and the save button will allow the user to save data during each step. This software design will allow the user to enter all testing information in a single program with a simple and user-friendly interface. Finally, all the testing results are saved to a database where the

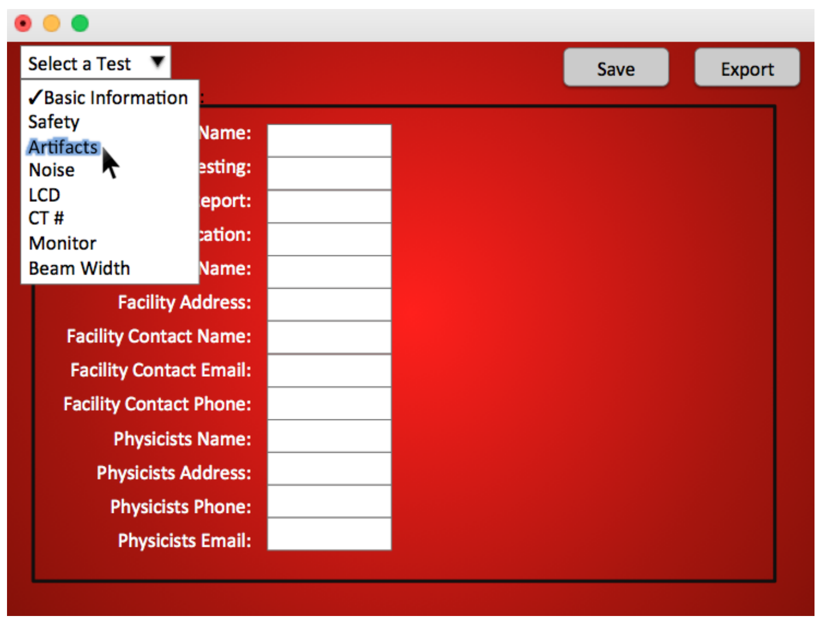
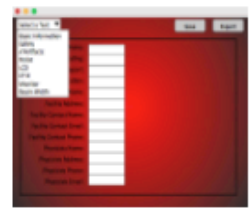


Figure 3. A representation of the dynamic functionalities of Design 3.

information can be accessed to display testing trends of certain parameters from a CT machine over time.

Preliminary Design Evaluation

Design Matrix

Design	Design 1		Design 2		Design 3	
Criteria (Weight)	 Multi-GUI		 Text Document		 Master GUI	
Ease of Use (30)	4/5	24	3/5	18	5/5	30
Degree of User Interaction (25)	5/5	25	0/5	0	5/5	25
Modularity (20)	2/5	8	0/5	0	4/5	15
Speed (15)	3/5	9	0/5	0	5/5	15
Safety (5)	5/5	5	5/5	5	5/5	5
Cost (5)	5/5	5	5/5	5	5/5	5
Total (100)		76		28		95

Design Criteria

Ease of Use

A logical and intuitive program is crucial to the success of providing effective quality assurance to the CT machine and images. The user conducting the various tests requires a sleek yet simple environment to input and manipulate data and ultimately create a concise final report. The program must be visibly pleasing and contain a structured workflow that allows variability for different test sets. The final product must be easily obtainable and should require minimal effort to download and install, packaged with all necessary libraries in order to offer standalone functionality on all types of computers.

Rationale: Design 2 is bulky and tedious to use and requires the user to complete the full report. Design 1 and 3 are far easier to use, but Design 3 has all the information, tests, and functionalities contained in a single interface which greatly increases the ease of use.

Degree of User Interaction

The overall goal of this project is to decrease the time and effort it takes to generate testing reports. We would like this program to be automatic with minimal user interaction. The user will need to enter all parameters from the test but then, ideally, the program should be capable of processing all data and performing the necessary calculations automatically.

Rationale: Using MATLAB to calculate data based on user input makes Designs 1 and 3 exponentially easier to use compared to Design 2; this significantly reduces the degree of user interaction. In addition, automatically creating and storing reports in a database will decrease the overall time and effort of testing and reporting.

Modularity

The code format is important, not only for ease of development and debugging, but also for future alterations. As new testing requirements and methods change, certain portions of the code must be easily accessible for modifications. This aspect of the design is essential for implementation of an open-source application that can be modified by the user.

Rationale: Unlike the single program featured in Design 3, Design 1 would require multiple files, figures, and GUIs for each test, which could cause issues when debugging and modifying code. Additionally, there may be complications in packaging Design 1 into a universal executable due to the multiple program files.

Speed

It is important that CT machines are tested on a regular basis to ensure all functions are working properly for research and patient imaging. Because these tests are performed so often, it is important for the program to process data and generate testing reports very quickly. A quick turnaround is essential in order for the CT machines can be adjusted before further use.

Rationale: MATLAB's capability to perform complex calculations and the simple user interface of Design 3 makes this design the most ergonomic and effective method to create CT scan reports.

Safety

Care should be taken to minimize visual strain, such as using sufficiently large font size and bright colors. Additionally, the overall accuracy and reliability of the program affects the calibration of the CT scanner, which ultimately contributes to patient safety.

Cost

Many CT scans are conducted daily and in rapid succession, so the efficiency at which quality assurance tests can be completed greatly influences cost of use. The speed at which CT scans can be analyzed will cut into cost. In addition, the designs require third-party software, which can vary in cost but is free for UW students and staff.

Proposed Final Design

Our team has chosen to pursue Design 3 which consists of a single GUI featuring multiple panels and a drop-down bar to select the type of test. This design was chosen for its compactness, user-friendly interface, and excellent low degree of user interaction. This design was chosen over the multi-GUI design for its increased speed, modularity, and ease of distribution.

We concluded that this design would be faster than the multi-GUI because, in design 1, a new GUI will have to be brought up for each test. It will also be easier to distribute and implement future modifications because all of the code is contained within a single program. If changes need to be made to the multi-GUI it is likely that the user would have to search through several programs to make the desired change. Furthermore, with multiple GUIs such as in Design 1, data would have to be shared between multiple programs, adding an additional challenge to the software fabrication. Overall, Design 3 meets all of the design specifications provided by the client and will feature a seamless user interface, automated calculations and image analysis, and historical scanner trending. A block diagram of the proposed final design can be seen below in Figure 4.

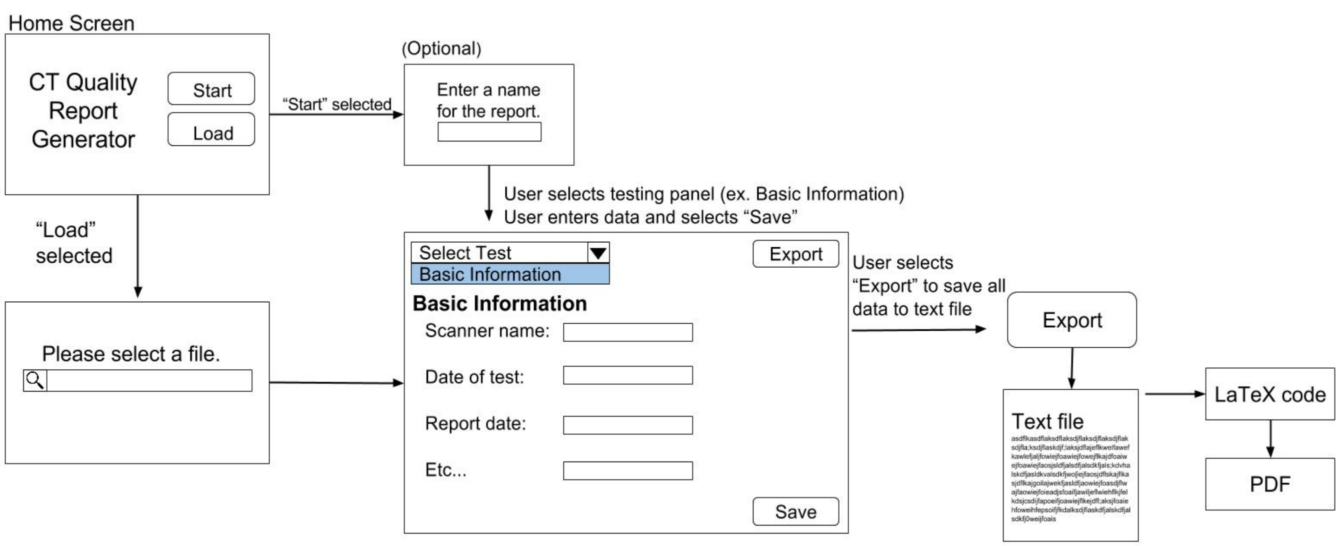


Figure 4. A block diagram of the final proposed design. This includes a main menu with the option to create a new test or load previous testing parameters, a drop-down menu to select the type of test, and multiple panels that become visible when selected by the drop-down menu.

Discussion

Ethics

The final software program will be used for research and clinical purposes. With that in mind, it is imperative that the program performs accurate calculations and image analysis. The values and test results outputted by the program must be verified to ensure they are not a result of faulty program function. Failure to do so could lead to inaccurate assessment of the CT machine, resulting in improper diagnoses and/or additional testing, which can increase patient exposure to harmful x-rays. Furthermore, there will be no malicious code in the downloadable software package. Overall, the code will perform the functions it cites accurately without harming the computer. This plays a vital role in proper calibration on the CT scanner and ultimately influences patient safety.

Fabrication Plans

The final design will be made entirely in MATLAB using the GUIDE tool and will require no outside fabrication. Sections of the GUI will be divided among individual team members who will build the testing sections individually. Once each section is complete, we will go through the program as a team to make any adjustments and work to seamlessly combine the sections. As a team, we will also work on the exporting functions as well as the database and trending functions.

Conclusion

The overall goal of this design project is to develop a software program that aids in CT quality assurance testing by decreasing the time and effort involved and by developing standardized testing protocols to eliminate communication issues. We hope to achieve this by developing a software program consisting of a graphical user interface to accept user input, perform calculations, and generate quality assurance testing reports.

Future Work

Moving forward, our team will continue to add functionality to the existing GUI. We will be working closely with the client to ensure all tests are represented accurately within the GUI and will also be teaming up to create the testing protocols featured in the report. The program will feature a clean and appealing menu screen and background and we will continue to improve the ergonomics of the program as it is built and tested. We would like to do this by evaluating user interaction between a few users and the program and then implementing any necessary changes or improvements. When the program is complete, we will run through the program with the client to confirm that that it works as specified and make any further changes based on suggestions. Once we have the final version of the software, we plan to package the program into an executable for distribution so that it will run on computers without the need for MATLAB.

References

[1] “Faculty and Staff,” University of Wisconsin School of Medicine and Public Health. [Online]. Available: https://www.radiology.wisc.edu/people/facultyContent.php?vaultID=552

[2] “Comprehensive QA Services in the Cloud,” Image Owl, Inc. [Online]. Available: http://www.imageowl.com/. [Accessed: 09-Oct-2016].

[3] “PIPSpro Software,” Standard Imaging, Inc.. [Online]. Available: http://www.standardimaging.com/qa-software/pipspro-software/. [Accessed: 09-Oct-2016].

[4] “CT Scan,” Mayo Clinic [Online]. Available: http://www.mayoclinic.org/tests-procedures/ct-scan/basics/definition/prc-20014610

[5] G. T. German, “Fundamentals of Computerized Tomography: Image reconstruction from projection” Springer 2nd edition, 2009.

[6] S. Mutic *et al*., “Quality assurance for computed-tomography simulators and the computedtomography-simulation process,” Medical Physics 30 (10). Oct. 2003.

[7] T.P. Szczykutowicz. “CT Scanner Annual Testing: East Clinic UWHC DHO,” UW-Madison Dept. of Radiology. Madison, WI. July, 2016.

[8] D. J. Goodenough, “Catphan 500 and 600 Manual” Salem, NY. 2006.

[9] L. Y. Du *et al.*, “A quality assurance phantom for the performance evaluation of volumetric micro-CT systems,” Phys. Med. Biol. 52 7087. Nov. 2007.

[10] D. D. Cody *et al.*, “Computed Tomography: Quality Control Manual,” ACR, 2012.

Appendices

A. Product Design Specification

Title: Automated Quality Assurance System for Clinical CT Systems
Client: Prof. Timothy Szczykutowicz
Advisor: Prof. John Webster
Team Leader: Heather Shumaker
Communicator: Connor Ford
BPAG & BWIG: Rachel Reiter
BSAC: Sam Brenny

Function:
A software program will be designed and built to aid in computed tomography (CT) quality assurance testing and reporting. The software will process testing results and export them to a report analyzing the results and reporting corrections that must be made to the CT system. The report will also specify how the tests are conducted.

Client requirements:
The client would like the software to be capable of:

- Processing DICOM (Digital Imaging and Communication in Medicine) images that represent quality assurance test scans
- Automatically analyze images
- Create reports from the test outputs into easy to read report using LaTex [1]
- Write test results to a database
- Ability to pull up past results in trends chart

Preferably, the program will consist of a graphical user interface (GUI) with a user-friendly interface. Ideally, the program will be capable of doing several automated calculations for the client.

Design requirements:
The program will be developed in MATLAB and be exported to LaTex and then to a PDF. The client prefers that the program be capable of allowing user input of test values in whichever order the user chooses.

1. Physical and Operational Characteristics

a. **Performance requirements:** The program should have capabilities for a variety of tests, including daily, monthly, and annual tests. All uploaded images and/or data should have the ability to be saved in separate subfolders in reference to the report. The text file needs to be accessible to accommodate the addition of alternative tests for specialized scanners.

b. **Safety:** N/A

c. **Accuracy and Reliability:** The software must be reliable in the sense that the program functions as designed during each use. The reports must be generated consistently throughout the use of the program and the program must function without crashes or bugs. The calculations computed by the program must be consistent and accurate. A pop-up window should appear as the calculations are being done for analysis by the user to ensure sanity of the results before compilation in the PDF file.

d. **Life in Service:** The program will be used indefinitely with the potential for modifications and improvements in the future.

e. **Shelf Life:** The program should be able to run indefinitely.

f. **Operating Environment:** The program will mainly be used by radiologist and physicists at the WIMR. However, the software may be shared in the future with other radiologists via forum boards.

g. **Ergonomics:** The software should have a user-friendly interface that makes sense to the user. All text within the program and the PDF output must be well organized and readable.

h. **Size:** N/A

i. **Weight**: N/A

j. **Materials:**
    - MATLAB
    - LaTeX
    - Sample testing data and reports will be provided
    - CT scanner available

k. **Aesthetics, Appearance, and Finish:**

The finished software package should have a clean and pleasing interface for the user. The software may be packaged into an executable for users without MATLAB.

2. Production Characteristics

a. **Quantity:** One software program will be created.

b. **Target Product Cost:** $0 or cost of MATLAB licensing fees

3. Miscellaneous

a. **Standards and Specifications:** The tests outlined in the exported PDF will outline the testing procedures and the testing results. The goal of this project is to automate the testing report to increase the consistency of the CT quality assurance testing reports in the department.

b. **Customer:** The customer requests for the code to be well commented and easily modulated so others can easily understand and modify for their own use. Additionally, the user should be able to enter testing data in any order they choose.

c. **Patient-related concerns:** In order to achieve an accurate CT scan with proper dosing, the CT scan must be well tested prior to use. This program will help analyze CT system testing results and compile them in a report detailing the testing procedures and results. This report will be sent to technicians to fix the CT scanner.

d. **Competition**: There are two software programs on the market that have many of the design specifications. These programs include ImageOwl and PIPSpro.

Image Owl is a cloud based system, which facilitates the retrieval of data and tracking trends over time, along with other features such as mobile apps [2]. While these features are convenient, they also greatly increase the price. Customization is another source of expense. Given their data analyses are specialized for Catphan® and Tomophan® phantoms, their more comprehensive and customizable testing options are more expensive [2].

PIPSpro, created by Standard Imaging Inc., provides quantitative analysis of scanner performance on a variety of phantoms sold by the same company [3]. Additionally, complexity of the program itself requires training to use properly [3]. As with Image Owl, the program does not lend itself to alterations and testing protocols are not included in the report.

References

[1] T. Szczykutowicz. “CT Scanner Annual Testing: East Clinic UWHC DHO (GE LS16 Pro)” Department of Radiology, University of Wisconsin-Madison. Jul. 2016.

[2] “Comprehensive QA Services in the Cloud,” Image Owl, Inc. [Online]. Available: http://www.imageowl.com/. [Accessed: 09-Oct-2016].

[3] “PIPSpro Software,” Standard Imaging, Inc.. [Online]. Available: http://www.standardimaging.com/qa-software/pipspro-software/. [Accessed: 09-Oct-2016].

B. Semester Schedule

Task	September		October				November				December		
	23	30	14	19	21	28	4	11	18	25	2	9	15
Project R&D													
Research	X	X											
Design Alternatives and Matrix	X	X											
Decide Final Design													
Design Development													
Deliverables													
Progress Reports	X	X	X										
PDS	X												
Preliminary Presentations			X										
Final Deliverables													
Meetings													
Client	X												
Team	X	X	X										
Advisor	X	X	X										
Website													
Update	X	X	X										

C. Materials

Description	Supplier	Part/Model #	Link to Part	Qty	Date	Price	TOTAL
MATLAB	MathWorks	(licensed through UW-Madison)	https://www.mathworks.com/products/matlab/	NA	NA	$0.00	$0.00
						TOTAL	$0.00