The George Washington University

The School of Engineering and Applied Science
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Final Project Report (FPR)
Physiological Tremor Detecting System

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Abstract

Persistent and uncontrollable physiological tremors are usually indicative of a medical ailment and are a prevalent symptom for many conditions including Parkinson's Disease and aging. In the past, accelerometers and lasers have been used to analyze the physiology of tremors and have shown potential to serve for clinical diagnosis of tremor-related illnesses. This project builds upon past works by designing, constructing, and testing a device that will incorporate data both from inertial sensors and from an optical system. A sensor device will be made with both a three-axis accelerometer and a three-axis angular rate sensor. The optical data will be captured by an imaging device while data from the inertial sensors will feed directly into the computer. Both types of data will be collected simultaneously and analyzed using Fourier transforms and other algorithms. The data, after analyses, will give information about the tremor's frequency, intensity, duration and displacement. The resulting system will be used to test physiological tremors of specific conditions in anticipation of its of use for clinical diagnosis. One of the primary goals of the project is to compare and competitively evaluate the different means of measuring tremors. We seek to determine which of the two inertial sensors and optical subsystem provides the most clinically useful information.

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Introduction

The goal of this project is to create a system that can detect and analyze tremors for various medical purposes. A tremor is defined as any involuntary muscle contraction and results from many conditions, such as overexertion of the muscle, to various neurological disorders, such as Parkinson's disease. Because a tremor can result from so many different sources, studying tremors has a very wide variety of applications from examination of extreme stress upon the body to diagnosis or studying of neurological disorders to aging studies pertaining to natural muscle atrophy with age. For this project a device will be built that will measure the intensity and frequency of a tremor using a sensor subsystems and an optical subsystem. The majority of tremors occur in the hands and as such the device will designed and tested for primary use on the hand. However the device will also be designed to work for other limbs or areas on the body which will be achieved by simply changing the strap that attaches the device to the area of interest.

This project concerns the fabrication of a system designed to characterize body tremors. Tremors are defined by the oscillation of a limb through prolonged cycles of muscle contraction and relaxation. They are caused by underlying neurological conditions such as Parkinson's disease or dystonia. Tremors are also induced by outside factors such as stroke and traumatic brain injury. While voluntary movements create imperceptible tremors in every single person, known as physiologic tremors, more violent and noticeable ones can bring about drastic lifestyle changes to their sufferers. Patients with severe cases of tremor can have difficulty performing small tasks that require fine motor skills, including writing and eating. They see this inhibition as both a hassle and an embarrassment, leading to physical and social insecurities. Clinically, it is important to characterize these tremors in order to understand their biomechanics, diagnose any underlying neurological conditions, and to develop therapies to reduce or treat them.

This project will attempt to characterize different types of tremors through frequency data obtained by processing positional and angular information from muscles undergoing an episode. The detection system, known as the sensor subsystem, will consist of an accelerometer and an angular rate sensor attached to a limb. It will interface with software that records acceleration and angular rates as a function of time. These time plots are then transformed into data in the frequency domain. While previous projects have used accelerometers and angular rate sensors, this project incorporates a novel subsystem to compare to the sensor subsystem. This optical subsystem consists of two LEDs attached to the limb undergoing tremor, which point at an imaging device. The imaging device again interfaces with the software in order to record the position of the resulting light on the image as a function of time. This time series can be converted into the frequency domain and compared to the frequency plot of the sensor subsystem. If both the optical system and the sensor system convey equally valuable information, then the optical system represents a cheaper and more time-efficient way to measure tremor frequency.

The estimated retail cost of the device per unit is $413.21. There is currently no device available in the market that measures, analyzes and diagnoses physiological tremors. Devices have been created to study physiological tremors for specific conditions such as Parkinson's Disease, but these innovations are only used for studies and are not available to be purchased. If this project succeeds, it has the potential to become to first device to be available on the market for physiological tremor studies for specific medical studies and diagnostic purposes.

The following pages in this Critical Design Report describe how this project will be implemented to its completion. The tremor detection system will be divided into three subsystems, consisting of the sensor system, the optical system, and the analysis software system. Each subsystem will have its own requirements, specifications and detailed descriptions of its development. Subsystems will be broken down into smaller modules. Each module will demonstrate how it helps perform the subsystem's intended function.

Historical Perspective

Through the three semesters spent on creating and updating each subsystem of the Physiological Tremor Detecting System, two goals remained constant. The first goal attempted to maximize the hand-worn device's ease of measuring physiological tremor. The second goal was to achieve accurate data measurement and display in the data analysis system. Changes were made to all three subsystems while keeping these two goals in mind.

The sensor and optical subsystems evolved through changes in design and the inclusion of additional components. Additions included an angular rate sensor to the sensor subsystem and a ring version of the LED device to the optical subsystem. Changes in design included updating subsystem components. For example, longer cables and a smaller housing were used for the sensor subsystem, while conductive thread was used in place of a printed circuit board for the hand-worn devices of the optical subsystem. These changes in design reflect upon the goal to fulfill the requirement of an unassisted, wearable hand-worn device that does not impede the movement of the physiological tremor while taking measurements.

The data analysis subsystem also evolved in many ways. For instance, the GUI was updated to not only display data in real time, but also to highlight selected data. To determine of the accuracy of the data measured in the data analysis subsystem, a testing subsystem was developed and incorporated into the project. Being able to accurately measure and display information taken from the testing subsystem served to confirm the efficiency and reliability of all three subsystems to work in synchrony and produce usable data in a clinical setting.

Overall System Requirements and Specifications

Functional Requirements	**Specifications**
System must be able to capture the motion of a limb	• System must be able to capture tremors with frequency from .5 Hz to 15 Hz

Non-Functional Requirements	**Specifications**
The system must be small and light enough to not interfere with limb tremors	• Under 75 grams • Housing for accelerometer and angular rate sensor should be under 3 cm x 3 cm x 1 cm • Housing for LED in optical subsystem should be under 2 cm x 2 cm x 1 cm
The system must be capable of being attached to various parts of the body	• Strap for use on wrist will fit wrists from 12-28 cm in circumference
The system must be wearable by the user without assistance from another	• Strap will use Velcro to attach

Table #1 – Overall System Requirements and Specifications

The overall system will conform to standards pertaining to medical device software and electrical medical devices. This system design shall conform to engineering standard ANSI 62304:2006 – Medical Device Software – Software Life Cycle Processes, ASNI/AAMI ES60601-1:2005 6.2 – Protection against electrical shock, ASNI/AAMI ES60601-1:2005 8.5.2 – Separation of patient connections. It shall also conform to engineering standard ASNI/AAMI ES60601-1:2005 8.10.1 – Fixing of components, ASNI/AAMI ES60601-1:2005 8.10.2 – Fixing of wiring, ASNI/AAMI ES60601-1:2005 9.2.5 – Release of Patient, and ASNI/AAMI ES60601-1:2005 15.3.4.1– Hand-Held ME Equipment.

Overall System Design

Current Design

The objective of the project is to develop a device that detects and analyzes different types of bodily tremors for various medical purposes. It is required to be patient-friendly and lightweight to prevent compromising the behavior of the tremor. The device will measure the intensity and frequency of tremors by simultaneously incorporating information from its sensor and optical subsystems. The input data of the tremor's mechanical motion will be analyzed in the tremor analysis system. The computed outputs are Fourier transforms graph from the sensor subsystem and a comparison between the optical and sensor subsystems that gauges the efficacy of the novel optical subsystem. Since the majority of tremors occur in the hand, the device will be designed primarily for tremor tests in the hand. However, the device will also be designed with adjustable straps for tremor tests on other limbs and areas of the body that are also affected by tremors. The figure on the following page is a context diagram for the system as a whole:

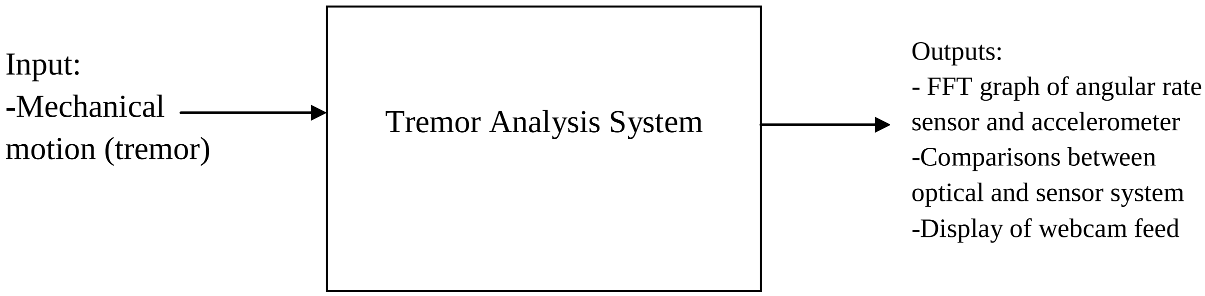


Figure #1 – Context Diagram

There have been many ways of measuring tremors in the past. Early efforts to measure a tremor included mechanical methods wherein the movement of a patients hand per se would cause a needle to move across a paper to record the physical displacement of the hand. This method, though simple, provides very little numerical information. This method fell out of use as soon as medical information was beginning to be digitized. As one might expect, EMG (electromyography) is a good way of measuring tremors. In the past, it has been used to measure the amplitude of tremors. However, it also has its limits. For one thing, the signal of an EMG is not necessarily directly correlated to the intensity or duration of the tremor. Many other factors contribute to an EMG signal such as the state of relaxation of the muscle at the time. This makes it hard to retrieve information from an EMG signal pertaining specifically to the tremor. In a clinical setting, a doctor might have a patient perform certain tasks with their hands to measure how much a tremor affects this task. However this method does not allow for analysis of all types of tremor and is also partly subjective. In addition, such clinical tests provide no numerical information as to the intensity, frequency or duration of these tremors.

This new device seeks to improve upon earlier methods of detection. The tremor analysis system will consist of three major subsystems. There will be two methods in which the motion of the tremor will be recorded and a data analysis system to analyze the characteristics of the tremor and to compare the accuracy of the two tremor capture methods.

The first method by which tremors will be recorded is a traditional three-axis accelerometer and three-axis angular rate sensor combination to be attached to the area of interest. These two sensors together provide six degrees of freedom to track the motion and orientation of an object over time. The accelerometer will provide the acceleration an object is subjected to in three axes. The angular rate sensor will measure the rate of rotation of the object in three axes. From the accelerations, position can be determined through a double integration of the data with respect to time. From the rate of rotation, an angle of rotation can be determined using a single integration with respect to time. In the past, clinicians have often used these two sensors, especially the accelerometer, to record and characterize tremor. As such, because it is necessary to confirm the validity of this method when recording tremors, this sensor subsystem will serve more as a gauge to which the optical subsystem can be compared.

The sensor subsystem can be broken down into three main modules. These modules are the accelerometer, the angular rate sensor and the microcontroller. The microcontroller interprets the outputs of the two sensors and sends the information to the data analysis system.

The second subsystem that will record the motion of a tremor will be an optical system. The optical system will consist of two LEDs, spaced a known distance apart, attached to a limb or location of the body that is experiencing a tremor. A camera will record the motion of the two LEDs. From the camera feed, coordinates in the x and y axes can be determined for the position of the two LEDs over time. In addition it may be possible to use the line between the LEDs in the feed to get information about rotation as well. This methodology to record tremor has not been used in the past and as such, its validity is unknown. It will be important to compare the information recording using this subsystem to the information received from the more tested sensor subsystem to determine the validity of this optical subsystem.

The optical subsystem can be broken down into two different modules: the LED housing and the camera recording the tremor motion and sending it to the data analysis subsystem.

The third subsystem is the data analysis system. It will receive the data from the other two subsystems and analyze and compare them. The data analysis system will calculate the positions over time from the accelerometer data and will calculate the angles of rotation from the angular rate sensor. Using the webcam feed from the optical system, the data analysis system will determine coordinates in the x and y axes for the light produced by the two LEDs. Using the three inputs from the accelerometer, the three inputs from the angular rate sensor and the optical position readings, the data analysis subsystem will find the frequencies present in the x, y and (in the case of sensor data) z axes using Fourier transforms. The data subsystem can use these Fourier transforms to analyze the important characteristics of the tremor. It will also compare the position information acquired from the sensor subsystem to the position information acquired from the optical subsystem and determine how close the two readings are to each other.

The data subsystem can be broken down into three modules: the analysis of the sensor subsystem data, the analysis of the optical subsystem data and the means to compare the two.

The following diagram is a tree diagram showing the relationships between the three subsystems:

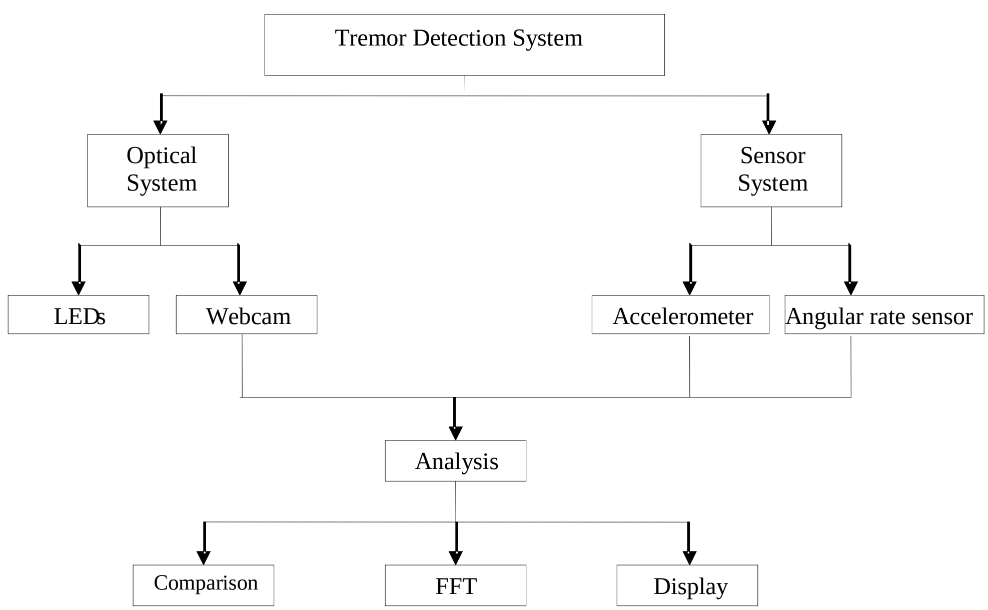
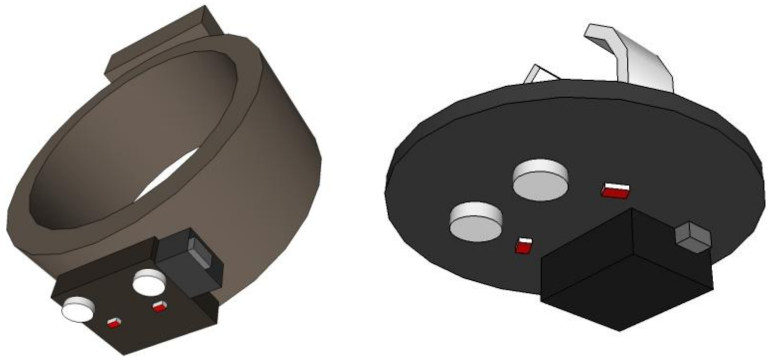


Figure #2 – System Components and System Functions



(a) (b)

Figure #3 – Mechanical Drawings of the Device:
(a) Hand Strap, (b) Ring

As seen in the left two mechanical drawings of Figure #3, the hand-worn device will encompass both the sensor and optical subsystems. The components of the sensor subsystem will rest on top of the strap of the device inside of a 3 cm x 3 cm x 1 cm housing. In both devices, the red components represent the LEDs, while the white circular tablets represent resistors. Wires are not shown because they will be covered from contact exposure with non-reflective, black material. In the drawings of the hand-worn device, the small black box attached to the side of the LED circuit is the housing of the battery for the LED circuit, while the miniscule gray box represents a switch to turn the LEDs on and off.

The ring version of the device, as shown in the right two drawings of Figure #3, will not incorporate the sensor subsystem. The optical subsystem is designed similarly to that of the hand-worn device. However, the battery and switch are placed on the same platform as the LED circuit. The devices are painted in various shades of black for the sake of presenting the different components, but the entire device will be uniformly black in reality.

Evolution of the Current Design

The evolution of the Physiological Tremor Detecting System involves several, but important, changes to the hand-worn device. The sensor subsystem initially did not incorporate the angular rate sensor. It was later added since the accelerometer measures only linear acceleration, which does not provide information regarding the rotational nature of the tremoring limb. Furthermore, accelerometer data may be biased by the force of gravity, making the presence of an angular rate sensor unaffected by gravity necessary. However, relative angles can be calculated from the accelerometer data. This gives two ways of measuring and comparing angles from the sensor subsystem: calculated relative values from the accelerometer and integrated values from the angular rate sensor. Positional displacement data from the accelerometer and angular displacement data together provide a complete picture of the mechanical motion of the physiological tremor. Due to the oscillatory nature of the tremor, its intensity and frequency can also be derived from the information provided by the accelerometer and angular rate sensors.

The optical subsystem was initially a laser-based system. However, the switch from laser to an LED was necessary, considering its ease of use in an electrical circuit, adjustability of size and brightness, cheaper cost, lighter weight and clearer appearance on the webcam. The laser "bled" non-uniform light across the webcam image when it was shined into the camera. Despite being a collimated light source, the light of the laser appeared less precise compared to the concentrated circle of light from the LED. These factors will be crucial to the commercial development of the device in a clinical setting.

Other important changes included creating a second version of the optical subsystem as a wearable ring. The device was designed to be worn on the hand, where many tremors tend to occur. Building the device as a ring allows it to be more compact, as well as having smaller impedance due to the movement of the limb experiencing the tremor. In addition, it becomes more sensitive to tremors present in the finger. Automatic white balance from the webcam, light from sources outside the LED, and reflection from the LED surface also posed difficulty for the data analysis subsystem. Therefore the data analysis subsystem was improved to maintain the accuracy of the data by locating and mapping only the light from the LEDs, two largest sources of light, from the webcam feed. The LEDs themselves were also made significantly brighter to make them stand out against background and ambient light.

The device also underwent changes in physical design. Aesthetics of the device was not a cause for concern until reflected light from metal parts made it more difficult for the data analysis subsystem to isolate the light of the LEDs. To compensate for this problem, all parts of the device are painted black to prevent light from reflecting from metal sources.

Impact of Standards on Design

An example of how standards impacted the design is as follows. The LED housing uses elementary circuits in order to give power to the two LEDs. While the current and the voltage that the LED circuit uses is small, it is still necessary to avoid electrical shocks. As such, the optical subsystem is subject to guidelines in ASNI/AAMI ES60601-1:2005 6.2, a safety standard titled, "Protection against electrical shock" and ASNI/AAMI ES60601-1:2005 8.5.2, a safety standard titled, "Separation of Patient Connections." This standard states that internally powered medical equipment having a means of connection to a main supply shall comply with the requirements for Class I medical equipment or Class II medical equipment while connected, and with the requirements for internally powered medical equipment while not connected. Since the LED subsystem for this project will not be connected to a power main, "Separation of Patient Connections" applies. According to this section, the maximum mains voltage cannot exceed 250 V. For our internally powered LED subsystem, both the batteries and the voltage required to power the LEDs remain below this limit.

Implementation Plan

The most important aspects to consider in the implementation of the design are mostly aspects concerning how the device affected the test subject. It is important that the device be small and as light as possible. Though the weight of the device would not impede the sensor or optical subsystem from taking data, it might affect the clinical validity of the data taken. If the device weighs too much, then it would be unclear as to whether the tremor that is being measured is being affected by the device. The purpose of the system as a whole is to detect and analyze tremor, not affect it. For this reason in implementation of the design, the goal is to make the device as small as possible. This is possible for the optical subsystem because the LEDs are so small that the small circuit of LEDs and battery can also be very small and weigh very little.

For the sensor subsystem, the sensor breakout board is relatively small as well and it will be housed in as small a housing as possible made of plastic to keep the weight down. The Velcro strap that will attach the sensor subsystem and the optical subsystem as well as the ring with the optical subsystem will also be very lightweight so as to keep the overall weight of the system down.

Another small aspect to consider in the implementation of the design is the connection of the sensor subsystem to the Arduino. Again the cables that connect the two must be lightweight and flexible enough to not impede the motion of the test subject. Also the cables must be long enough so that the patient's overall motion is not impeded by where the length of the cable. For these reasons, flexible ribbon cable that is plenty long will be used to connect the sensor breakout board to the Arduino.

It is also important that the device be able to fit a wide range of patient hand or finger sizes. This will be easily solved with adjustable Velcro for the hand strap and a ring that can be pulled open more to fit larger fingers.

On the software side, it is important that the interface that the physician giving the test will interact with is clear and easy to operate. This is important so that the physician can read the results from the test easily. The design of the GUI for the software will have clear labeling for various functions and the outputs will also be clearly indicated

Sensor Subsystem

Module Level Requirements and Specifications

Requirements	**Specifications**
System will capture motion of a limb with a three axis accelerometer	• Accelerometer will detect acceleration in the range of ± 2g • Accelerometer sensitivity 240 LSB/g (in the case of a digital accelerometer)
System will capture motion of a limb with a three axis angular rate sensor	• Angular rate sensor will be able to detect a rate of rotation of up to 500 degrees/s • Angular rate sensor sensitivity should be at least 60 LSB/degree/s (in the case of a digital angular rate sensor)
System must be able to capture and store data for the subsystem	• Frequency of data capture will be at least 30 Hz for the accelerometer and the angular rate sensor

Table #2 – Module Level Requirements and Specifications: Sensor Subsystem

Module Design

As mentioned earlier the sensor subsystem consists mainly of a three-axis accelerometer and a three-axis angular rate sensor that will be attached to the tremor's location. The two sensors will be encased in a housing that can be detached and reattached to a strap so that it can be moved to an ideal location for measuring tremors.

The two sensors will read measurements for a set amount of time and will send the measurements to a microcontroller. The microcontroller will control the speed at which readings are taken, interpret the data coming in from the sensors, and transfer the data to the data analysis subsystem for storage.

One of the first considerations in the choosing of parts for this subsystem was whether to use digital or analog sensors. A digital sensor would output sensor readings in sets of zeros and ones representing a larger binary number for a reading whereas an analog sensor would output a voltage which would scale to the correct reading as dictated by the sensitivity of the sensor. Because the digital sensors give better control over the sensor, including the ability to set the sensor's range to give the desired sensitivity, digital sensors became a better option to use.

The next part which requires consideration is the choice of a microcontroller. The microcontroller would have to communicate with the sensor. It would have to be able to send and receive the registers in order to tell the sensor what functions to perform, what settings to enable, and interpret the sensor readings. The sensor, and therefore the microcontroller, would need to be able to take readings at 100 Hz which is twice the maximum frequency to be detected in accordance with the Nyquist frequency. Even accounting for the need to send registers to the sensor occasionally, this would not require the microcontroller to perform operations much faster than this (which is far lower than a standard microcontroller processor speed), and so the sampling frequency is not a limiting factor in picking the microcontroller.

The final element of the design was the housing in which the sensor subsystem resides. It was necessary to have a lightweight box in which the sensors could be secured so that the orientation would be stable while not adding too much weight to the system. The sensor was eventually glued into a small plastic box which was fastened shut with screws. A modified ribbon cable attached the sensor outputs to the Arduino for stable connections. The following images show the final design of the sensor subsystem in its housing.

Figure #4 – Final Sensor Subsystem

Key Components Selection

The sensor that was chosen was the IMU Fusion board containing the ADXL 345 accelerometer and the IMU 3000 angular rate sensor. The board interfaces with a microcontroller using the I^2C serial bus which operates by sending and receiving 7-bit registers to and from the sensor which will program the various settings of the sensor and receive back the sensor's measurements. The sensor has several registers, which are binary arrays for which a zero or a one in each part activates a different setting or represents a part of a measurement. Some of the registers are sent by the microcontroller to the sensor to adjust properties and some are sent by the sensor to the microcontroller which sends the readings back for storage. Both the ADXL 345 accelerometer and the IMU 3000 angular rate sensor met the specifications laid out for the accelerometer and the angular rate sensor. Both sensors also have options to lower the overall range that could be measured, giving a higher sensitivity. This lower range and higher sensitivity option for these sensors is a better option for the system as the application does not require measurements of high accelerations or rates of rotation but might need more sensitivity to smaller values.

The Arduino Uno microcontroller was picked as the microcontroller for this device because the software is free, the hardware is relatively affordable and there are many online resources should a problem arise.

The following diagram is a block diagram illustrating how the two sensors will interface with the Arduino:

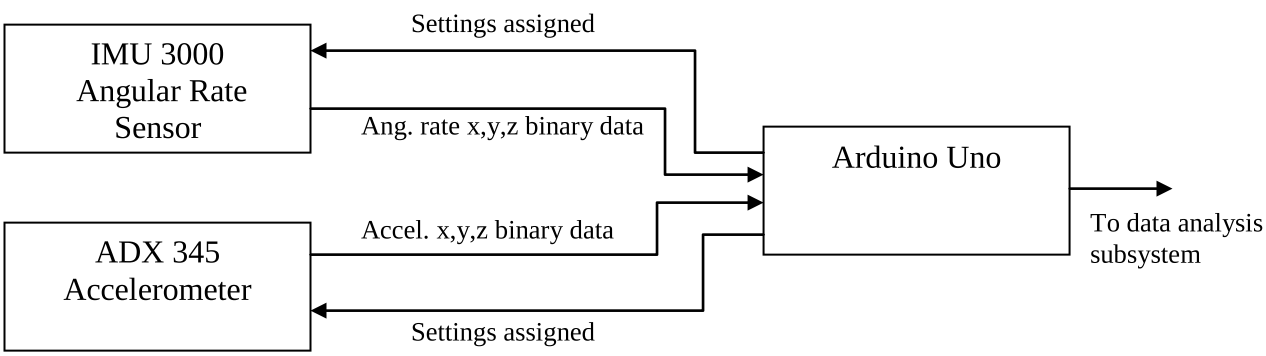


Figure #5 – Block Diagram for Sensor Subsystem

Module Matrix

Phase of Project	**Actual Time**	**Estimated Time Left**	**Percentage Complete**
Design	15 hours	0 hours	100%
Implementation	25 hours	2 hours	90%
Testing	10 hours	20 hours	30%

Table #3 – Module Matrix: Sensor Subsystem

In the module matrix above the design phase includes the design of the subsystem and choosing parts. The design as of the writing of this report is compete. The implementation phase includes the prepping of the sensor for use, the coding for the Arduino to interact with the sensor, and general debugging of the subsystem. The remaining implementation phase will be cleaning up the enclosure of the sensor subsystem and working to optimize the connection between the sensor subsystem and the Arduino. The time for the testing phase currently only covers time used verifying that the sensors were giving reasonable data. The remainder of the testing phase will occur after the device has been built and should include a large amount of clinical testing to get real life data for the subsystem in addition to testing done on a testing apparatus that has been built.

Optical Subsystem

Module Level Requirements and Specifications

Requirements	**Specifications**
System will capture motion of a limb with an optical system consisting of an LED and capture device	• Will detect displacement across the maximum range of pixels in both the width and height of the image • Will detect a change in position of 1.0 mm
System must be able to capture and store data for the subsystem	• Frequency of data capture will be at least 30 fps for the optical subsystem
The system must be capable of being attached to various parts of the body	• Strap for use on wrist will fit wrists from 12-28 cm in circumference
The system must be wearable by the user without assistance from another	• Strap will use Velcro to attach

Table #4 – Module Level Requirements and Specifications: Optical Subsystem

Module Design

The two primary components that are integral to the optical subsystem are the image capturing device and the LEDs. The first important consideration to consider is the decision to use LEDs instead of lasers as the light source for the optical subsystem. While lasers also provide the advantage of a bright source as LEDs do, laser emission cannot be captured on the image capturing device when the object tremors move it past the dimensions of the image capturing device. Due to the collimated nature of the laser, the image capturing device cannot detect the light point source when the trajectory of the laser goes outside the boundary of the image. In contrast, the wider viewing angle of the LED allows light to be captured in the image regardless of the tremor's angle of rotation. LEDs are also lightweight and will not impede a rapid tremor by force of gravity. This is important because the LEDs will be attached to the palm of the hand, or other limb affected by tremors, where they will shine light into the image capturing device that is oriented towards the ceiling. Furthermore, LEDs are much less expensive, less dangerous and more accessible than lasers, making them ideal light sources to utilize for wide use in the clinical setting.

Another important design consideration was the making of two forms of the device. The first is the wrist form, which is to be worn around the palm of the hand. The LED circuit is stitched into an adjustable Velcro strap. A Velcro strap was chosen for its versatility. It not only adjusts over varying circumferences of hand sizes, but it also allows for the attachment of the sensor subsystem at the top of the hand. This way, data from both the optical and sensor subsystems can be taken from the hand undergoing a physiological tremor. The ring device is composed of two parts: a detachable LED circuit and a shorter adjustable Velcro strap. The LED circuit is made detachable from the ring device so that it could attach to the testing subsystem when needed.

Below is the schematic for the simple LED circuit:

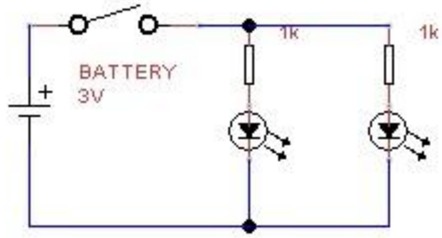


Figure #6 – Schematic of LED circuit

The following images show the final versions of the optical subsystem devices.

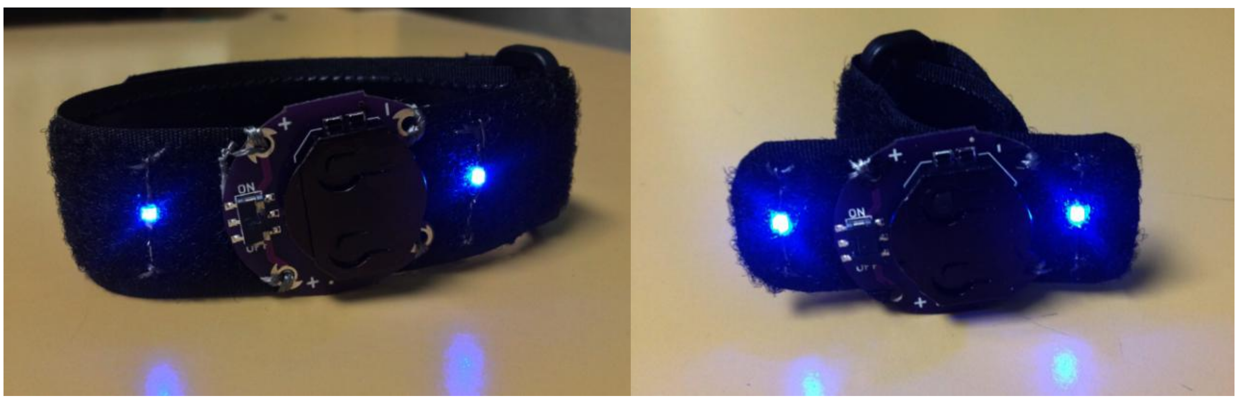


Figure #7 – Final Versions of Wrist and Ring Devices (left and right respectively)

Figure #8 – Separated Ring Device

Key Components Selection

The image capturing device of choice is a 5.0 Megapixel, 30 frame per second webcam. Its resolution is sufficient enough to capture the motion of LED's during a stimulated tremor. The frames per second of the camera has to be twice the maximum frequency to be detected which in this case is 15 Hz. LED's purchased from Lite-On Inc. show as clear, bright point sources on the webcam. The intensity of light is adjustable and the LED's are very small (3.20 mm x 1.60mm) and lightweight. Other critical components were conductive thread and battery encasing with an on/off switch. Both components contributed to the lightweight requirement and ease of wear of the devices.

The following is a block diagram that illustrates the sequence of inputs and outputs from the LED's to the data analysis subsystem:

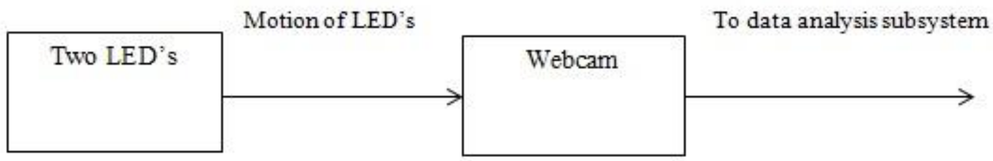


Figure #9 – Block Diagram of Optical Subsystem

Module Matrix

Phase of Project	**Actual Time**	**Estimated Time Left**	**Percentage Complete**
Design	6 hours	0 hours	100%
Implementation	30 hours	1 hour	97%
Testing	10 hours	20 hours	33%

Table #5 – Module Matrix: Optical Subsystem

Critical designs such as the designs of the hand-worn and ring devices and LED circuit, as well as the considerations for the optimal components used for each device were made in the design phase of the project. The device was built during the implementation phase and was modified several times, such as being painted black and made more compact, to accommodate other subsystems. The remainder of the implementation phase will be used to create the final versions of the device, in its hand-worn and ring forms. The testing phase was used conjointly with the data analysis subsystem to test how the LEDs appeared on the webcam feed as well as its effect on the data analysis subsystem's efficiency. Furthermore, tests were done alongside the sensor subsystem to gauge the performance of the data analysis system in its ability to collect data from both subsystems. The remainder of this phase will be used primarily in clinical testing.

Data Analysis Subsystem

Module Level Requirements and Specifications

Requirements	**Specifications**
System must be able to analyze measured limb motions from the three subsystems	• Fourier transforms ○ Complexity no greater than O(n log n) • Determine intensity of center of LEDs based on video feed to within a half a pixel

System must display data in a way determined by the user	• System must display the user's choice of the following data over time and its corresponding Fourier transform ○ Accelerometer data: ▪ Accelerations ($\ddot{x}, \ddot{y}, \ddot{z}$) ▪ Velocities ($\dot{x}, \dot{y}, \dot{z}$) ▪ Positions ($x, y, z$) ○ Angular rate sensor data ▪ Rate of angle change ($\dot{\theta}, \dot{\varphi}, \dot{\rho}$) ▪ Angles ($\theta, \varphi, \rho$) ○ Optical data ▪ Position in x ▪ Position in y • System will have options to display graphs comparing: ○ Positional data from accelerometer converted to angles with angles from angular rate sensor (all three axis) ○ Position data in x and y from optical system and position data in x and y from accelerometer. • System will display the mapping of the optical system ○ In either Cartesian coordinates (x, y) or polar coordinates (r, θ) about the origin (center point)
System must compare values obtained from the three subsystems	• System will compare angles from the angular rate sensor in all three axes with derived angles from the accelerometer. The comparison should result in a 1:1 slope • System will compare the positional data in the x and y axis from the accelerometer and the positional data from the optical system. The comparison should result in a 1:1 slope

Table #6 – Module Level Requirements and Specifications: Data Analysis Subsystem

Module Design

The purpose of this subsystem is to create a software program that can simultaneously receive data from the sensor system through an Arduino microcontroller and the optical system through the webcam, convert the data into frequency spectra, and compare the two results. This software will be written in LabVIEW, a development environment for National Instrument's graphical programming language "G." An alternative for LabVIEW would have been MathWork's MATLAB. However, LabVIEW was chosen for its ease in designing GUIs and its capabilities as a data acquisition software. Since the processing for the sensor subsystem and the optical subsystem have to be running simultaneously, LabVIEW's use of parallel processing makes it an ideal environment to write the analysis software in.

Key Components Selection

Components:	**Selection Justification:**
Sony VAIO Laptop with Intel Core i5-2430 CPU @ 2.40GHz, 4.00 GB RAM, a 64-bit OS, and Windows 7 Home Premium Edition	This laptop is powerful enough to run LabVIEW 2010 smoothly.
LabVIEW 2010 Student Edition	LabVIEW 2010 was chosen for its ability to work as an intuitive GUI designer, a data acquisition software and for its abilities to perform parallel programming.
NI LabVIEW Interface for Arduino Toolkit	This toolkit allows LabVIEW to interface with an Arduino board, the microcontroller being used to communicate with the breakout board on the sensor subsystem.
Vision Acquisition Software	This is driver software for compatibility in acquiring, capturing and monitoring images from many different imaging sources.
Vision Development Module	This module develops machine vision applications through the use of image processing functions and algorithms.

Table #7 - Key Components Selection for Data Analysis Subsystem

As a brief overview, the data analysis subsystem has requirements and specifications that depend on the capturing and displaying of information from the other two subsystems. It will need to take inputs from both subsystems simultaneously. A block diagram for the subsystem can be found on the next page:

Figure #10 –Input/Output Diagram for Data Analysis Subsystem

The LabVIEW program will sample both time values and scalar values in the planar and rotational directions from the sensor board. It will also capture a live feed at the rate of 30 frames per second from the webcam. Processing the information from both sources, the system should be able to compare the x and y positions from the accelerometer to the x and y positions derived from the webcam images. In addition, the subsystem will then compare angles from the rate sensor to calculated angles from positional data using the optical subsystem. This way, the system can make corrections to determine the true positional and rotational values for the limb.

Visually, the GUI for the software has to be intuitive, versatile, and user friendly. The user should have control over particle filtering and Fourier transform properties. The video feed from the webcam, time/frequency-graph plots, and statistical analysis plots should be displayed on the front panel. The software should be able to output all plots, including positional, angular, and frequency plots, in a way determined by the user. The user should also be able to overlay positional graphs between the accelerometer and the optical system for comparison.

For the sensor portion, the software will receive data from the Arduino as six columns of information. The columns represent the $\dot{\theta}$, $\dot{\varphi}$, $\dot{\rho}$, $\ddot{x}$, $\ddot{y}$, $\ddot{z}$ axes found in the angular rate sensor and accelerometer. This data is collected directly from the serial port on the Arduino at a baud rate of 9600, which corresponds roughly to 26 Hz (fig. #A.1.a). The user selects which USB port that is connected to the Arduino as a resource to be used. This information is passed into a looped sub .vi called “Data Reading from Breakout Board” (fig. #A.3.e). The sub .vi reads the data that comes from the serial port for 100 bytes. It takes this information and converts it into a spreadsheet array of doubles. The data is still preserved in the columns indicated earlier. It breaks up the columns into such information and passes it into the main .vi. The main .vi displays the information as a strip chart of continuous data in real time as it comes from the Arduino (fig. A.1.b). The data is then removed of DC bias by using the “Averaged DC-RMS” .vi supplied by LabVIEW (fig. A.3.g). Next, the data is integrated using the Trapezoidal rule, singularly integrated for angular rate data and doubly integrated for accelerometer data (fig. #A.3.g). A .vi was also created to turn accelerometer data into angular data (fig. #A.3.a) using documentation from “Using an accelerometer for inclination sensing.” When the user decides to stop recording by pressing the “stop” button, the data will be passed into the “FFT conversion” sub .vi (fig. #A.3.f). The operations of the “FFT conversion” sub .vi will be mentioned later. The FFTs are then displayed as the frequency spectra of the data (fig. #A.1.c).

For the webcam portion, the image will display the optical system being worn by a patient above the camera. Given that the optical system has two different LEDs, the positions of both LEDs must be tracked. After thresholding (fig. #A.2.c) and filtering (fig. #A.2.d) the image, there should only be binary spots corresponding to places of light intensity that appear above a certain threshold. Given that light falls on the 2D plane of the camera as a circle, the software should look for or approximate circles in the thresholded image (fig. #A.2.e). If filtering is correct, the light from the LEDs should be the two largest circles (#A.3.j). These circles will appear as the first two in an array of information about all the circles in the image. There are two tasks which must be accomplished at this point. The first task is to take the x and y positions for the center of both circles and draw different colored dots on them in the live video feed (fig. #A.1.b). The user can choose the colors of the dots. The second is to calculate the line that connects the centers of both circles. This is done in a sub .vi called “creating midpoint” (fig. #A.3.d). “Creating midpoint” takes the values of the circles in the x and y positions and averages them into a single value. This single value is the midpoint between the two circles in a Cartesian plane. The angle can be found between this line and the extending x axis at the circle farthest down the y axis (fig. #A.3.b). It involves finding the inverse tangent of those two line segments described before that form an imaginary triangle. This angle will be arrayed with respect to time and plotted. The x and y coordinates of the midpoint will then be plotted with respect to time. These three plots will also be passed into the “FFT conversion” sub .vi (fig. #A.3.f). The resulting frequency domain data will be displayed correspondingly (fig. #A.1.c).

The “FFT conversion” sub .vi (fig. #A.3.f) takes input time plots and converts them into frequency plots. The time plots are pulled though a Hanning window and then into an FFT converter low level .vi. The resultant complex values are changed into polar ones. An array of magnitudes is extracted. However, only half of this data actually ends up in the final output frequency array. This creates a single sided spectrum instead of a double sided one with redundant information. In addition, the sampling frequency from which the original input data was taken at is divided by the number of data points in order to create an x-scale factor. The x-scale factor is an x-axis multiplier used to properly display the frequency scale.

The next step involves verifying the positional values of the optical subsystem with respect to the sensor system in order to determine the accuracy of the optical subsystem. The x and y plots from the accelerometer will be compared to those of the optical subsystem. The x plot of the angular rate sensor will be compared to that of the optical subsystem as well. This step will take the time plots from both systems being compared and divide them. The x and y plots from the accelerometer will be divided from the x and y plots from the optical subsystem. Similarly, the x plot from the angular rate sensor will be divided from the angular plot produced from the optical subsystem. Ideally, the quotient should be linear, meaning that the two plots being compared are proportional to each other. If the two subsystems are linear to each other, then the data analysis subsystem has succeeded. If they are not, then the data analysis subsystem has failed.

In addition, the program can now save data from the breakout board, the FFTs of the breakout board data, the data from the optical subsystem, and the FFTs of the optical subsystem data into .csv files (fig. #A.3.i). The program automatically formats these files without the need of user interference. There is a separate program which is a waveform and FFT viewing screen. The viewing screen can import data from a .csv file of previously saved FFTs and waveforms (fig. #A.3.k). All the waveforms from that file, including the names of the waveforms will be displayed. Clicking on the name of a waveform will highlight it on the screen. In addition, the frequency with the highest magnitude is displayed (fig. #A.3.l). Waveforms can also be deleted from the screen (fig. #A.3.m).

The LabVIEW code for the optical system at the time of the completion of the critical design review can be found in Appendix 1-2 as fig, #A.1.a-A.2.e. A block diagram of the software analysis subsystem is found on the next page:

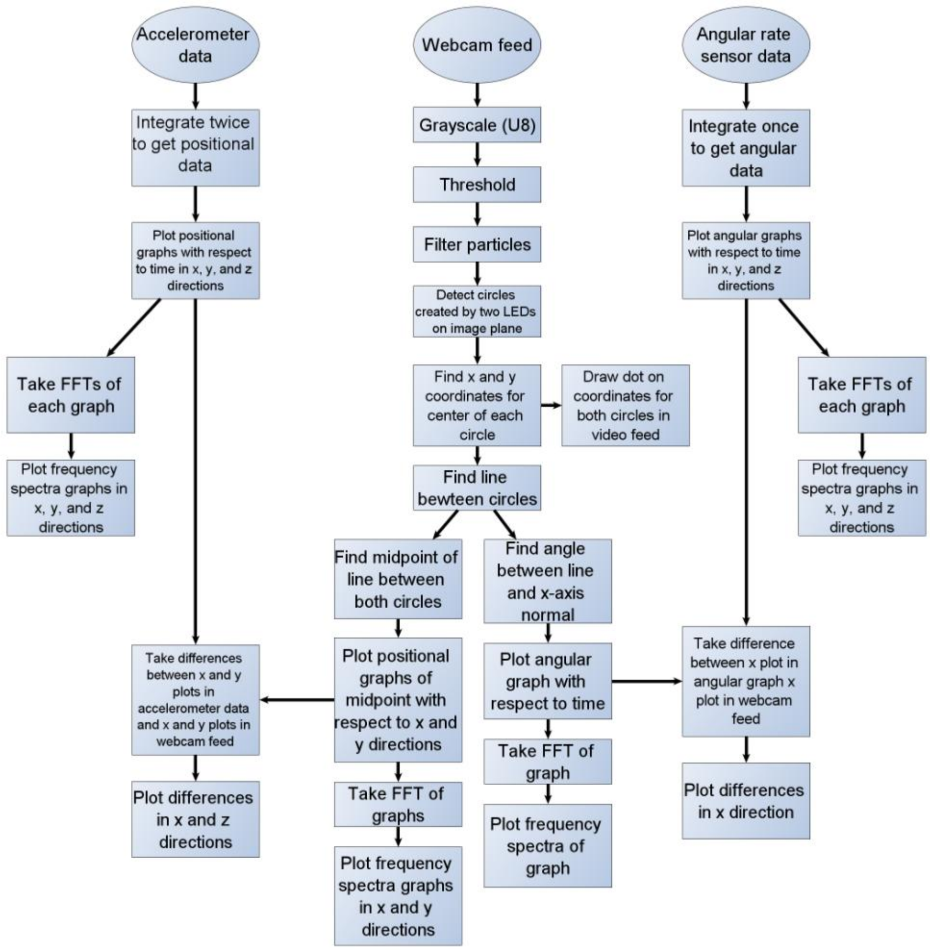


Figure #11 –Data Flow Diagram for Data Analysis Subsystem

Module Matrix

Phase of Project	**Actual Time**	**Estimated Time Left**	**Percentage Complete**
Design	10 hours	2 hours	83%
Implementation	25 hours	5 hours	83%
Testing	8 hours	6 hours	57%

Table #8 – Module Matrix: Data Analysis System

The module matrix describes the amount of time put into each phase of the subsystem project. For the design phase, the general idea for what is to be written in code exists. The major part that is missing is a more detailed option for the comparison between the optical and the sensor subsystem. While taking the difference works, there could be a more statistically relevant way to prove that the compared waveforms are correlated, if not the same. This will take more research. Coding is roughly finished for both the optical and the sensor subsystem. However, the comparison portion needs to be implemented. Finally, testing has been done for both subsystems. However the statistical analysis of the testing subsystem has not been started yet.

Module and System Tests

System Testing

One of the most important aspects of this project is its possible clinical applications. The intent is that by next semester, clinical tests can be performed with the device to show that it functions as it should, and also to see what kind of data can be obtained from real life applications. It is also important to use real life testing to examine how valuable the data obtained from each subsystem or sensor. The amount of information obtained from each subsystem is not uniquely important. Rather, what is important is the usefulness of the information compared to its cost. Should the information from one subsystem become redundant, then it will be possible to streamline the device to have the most information in the most cost effective manner. After using the device in clinical testing, the distinctions between the alternatives of measuring tremor will become clearer.

Testing Subsystem

One of the key components of testing the two tremor detecting system is the testing apparatus. The point of the testing apparatus is to create a periodic motion that can be controlled that the two tremor detecting systems can measure. The testing apparatus was originally going to consist of a thin board attached to an anchoring board with a hinge that had a cam attached to a motor between the two. The cam, which was simply a cylinder with a hole drilled off center for the motor shaft, would cause the thin board to move up and down at the speed at which the motor was rotating. It was decided to use a stepper motor for this system because a stepper motor gives greater, more accurate control over speed than a DC motor would have. However, due to the limits on how fast a stepper motor can take each step it was necessary to add another shaft to the rig to gear the motor up. In this way the cam was moved to the secondary shaft at one end, while at the other end a small gear lined up to a larger gear that was attached to the motor shaft. The gear ratio between the larger gear and the smaller gear caused the secondary shaft to spin five times as fast as the motor shaft. After cleaning up and lubricating any joints and points of contact, the testing rig was able to create periodic motion of up to 15 Hz which is the top of the frequency range for the two tremor detecting systems. Below are some pictures of the finished design followed by a detailed description of the design.

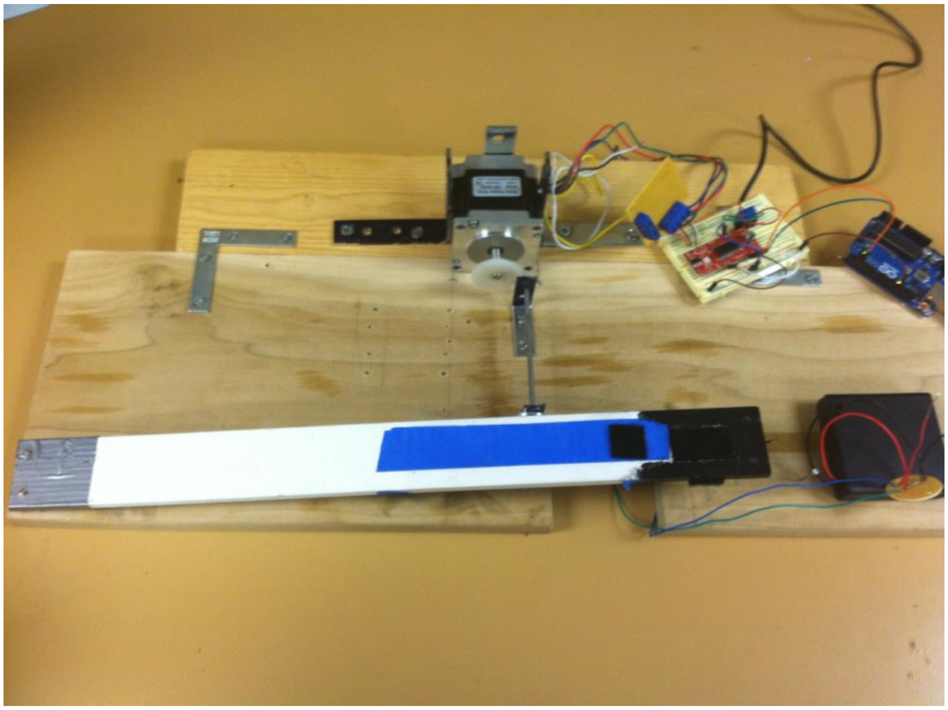


Figure #12 – Testing Apparatus: Top View

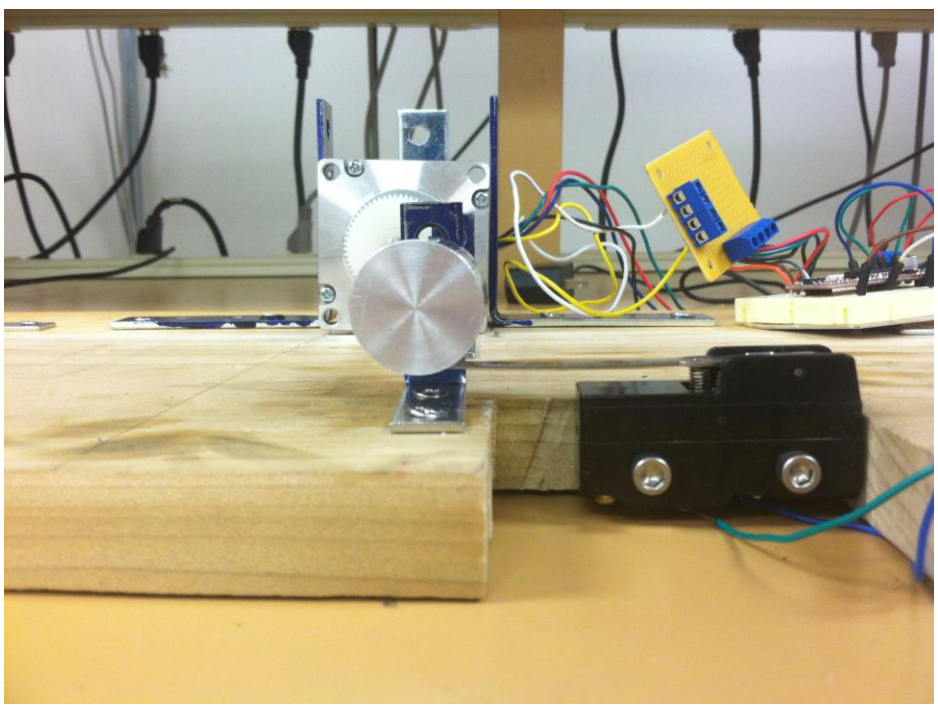


Figure #13 – Testing Apparatus: Cam & Switch Side View

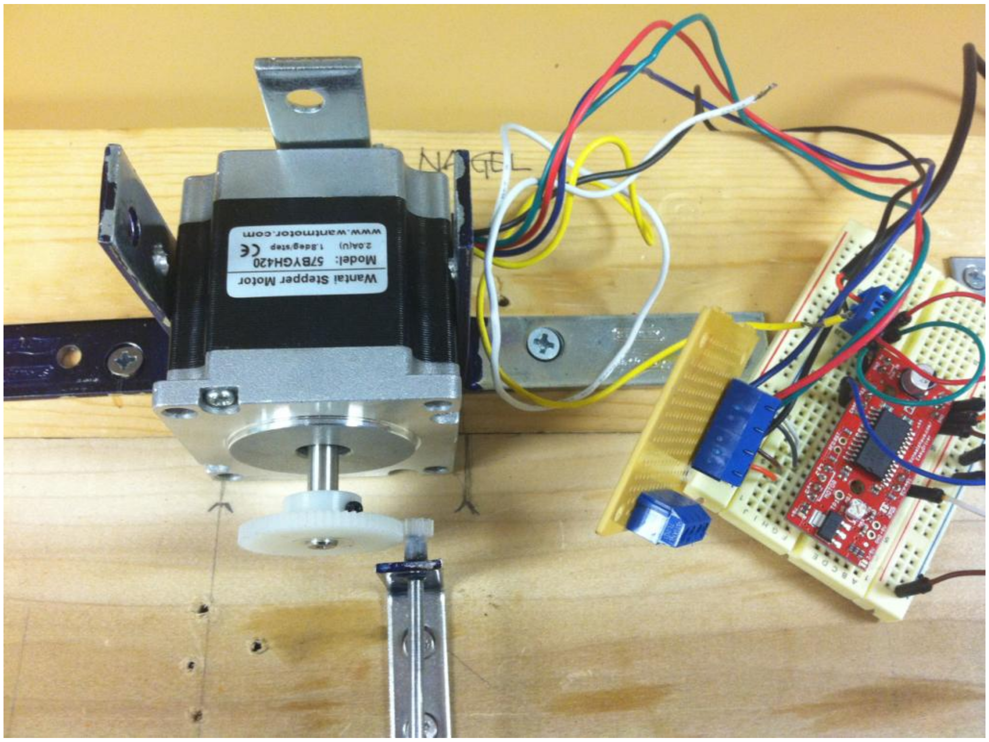


Figure #14 – Testing Apparatus: Motor Setup

As can be seen in the above pictures, the testing rig consists of the thin board connected to the base of the system with a hinge. Underneath the thin board, the shaft with the cam and small gear is mounted such that the cam is beneath the board and the small gear meshes with the motor gear. The motor with the gear on it is secured in place with brackets fastened to the base. The motor itself is powered and run by an EasyStepper Driver which itself is controlled through an Arduino microcontroller. This means that the speed of the motor is controlled through a computer attached to the Arduino and can easily be changed. The speed that is inputted into the Arduino is also verified by a switch that is attached beneath the cam which is pressed each time the cam rotates. When voltage is run through the switch, the switch creates a square wave formed at the frequency of the board's motion. This square wave is put into an oscilloscope and the peak of the first harmonic of the FFT taken represents the speed at which the cam is spinning.

As a verification of the speed inputted into the motor the graph on the next page was made by measuring the real speed of the cam rotating and the calculated speed from the Arduino as described above. The blue line in the middle represents the ideal 1:1 comparison of the measured versus the calculated frequency of the cam rotating. The circles are the scatter plot of the actual measured values against the calculated values.

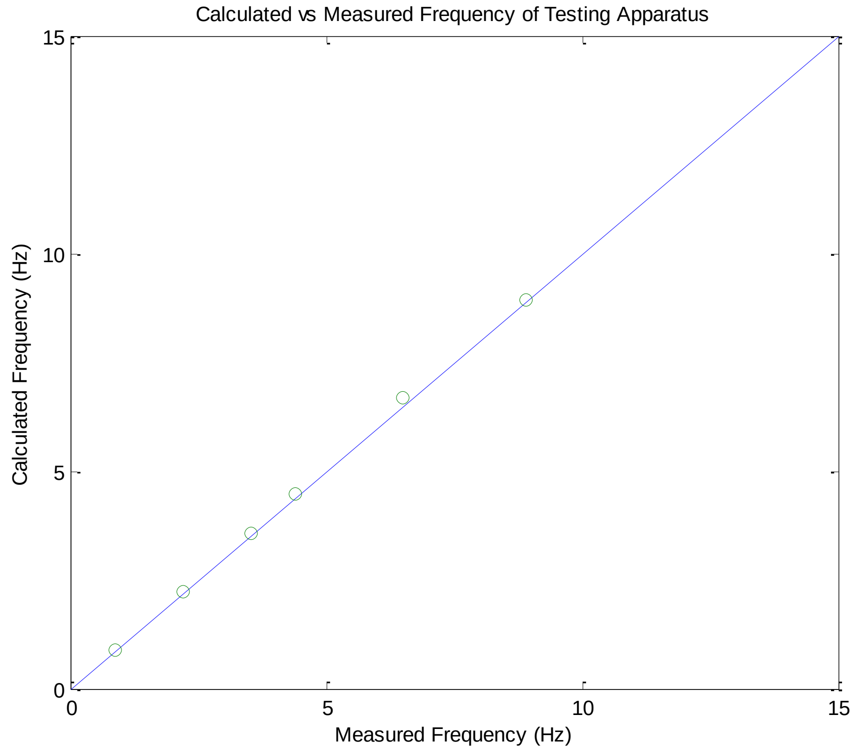


Figure #15 – Calculated vs. Measured Frequencies of Testing Apparatus

The following table simply summarizes the data in the graph along with percent difference between the two frequencies.

Measured Frequency (Hz)	Calculated Frequency (Hz)	Percent Difference
0.890	0.893	0.337%
2.21	2.232	0.995%
3.53	3.570	1.133%
4.39	4.464	1.686%
6.5	6.691	2.938%
8.9	8.929	0.326%

Table #9 – Calculated vs. Measured Frequency Results

The manners by which each of the subsystems and thereby the project as a whole will be tested before clinical testing are listed in the below sections.

Sensor and Optical Subsystem Testing

The testing of the two tremor detecting subsystems will occur on the testing apparatus that is described above. On the thin board there are locations for each subsystem to be attached to measure the periodic motion that the testing apparatus will create. The data taken from tests on the apparatus will be run through the data analysis system and the FFTs will be taken. The peaks of the FFT will correspond to the speed of the motor to prove that the two subsystems are accurate. This speed will come from both the speed that the Arduino will attempt to run the motor at and the speed that is measured using the FFT of the output of the physical speed of the switch opening and closing.

Some preliminary testing has been done using the optical subsystem on the testing apparatus. Similar to the test to confirm the speed of the testing apparatus, the optical subsystem was subjected to know speeds of periodic motion and the FFT of the resulting data was taken. The following is a graph of the results showing the known frequency that the board is moving at versus the peak of the resulting FFT from the optical subsystem. The line through the middle is the ideal 1:1 relationship while the circles represent the actual values.

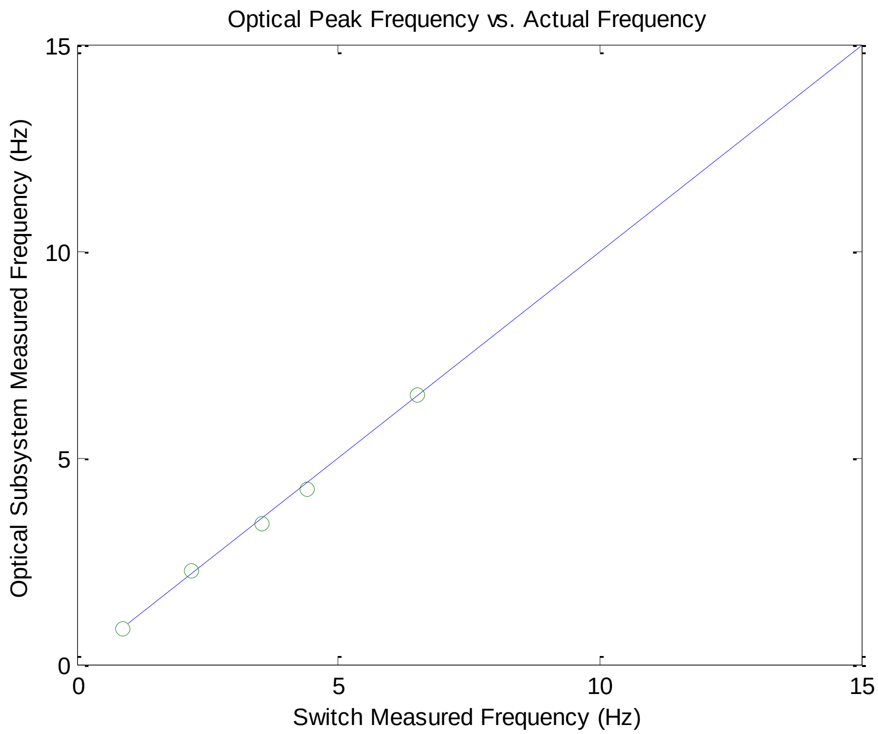


Figure #16 – Actual Frequency versus Optical Subsystem Frequencies

The following table simply summarizes the results of the graph and gives a percent difference between the two readings.

Actual Frequency (Hz)	**Optical Frequency (Hz)**	**Percent Difference**
0.890	0.86	3.37%
2.21	2.26	2.26%
3.53	3.38	4.25%
4.39	4.23	3.64%
6.5	6.504	0.062%

Table #10 – Actual Frequency versus Optical Subsystem Frequency Results

Verifying many of the specifications for the optical subsystem comes down to simply buying components that fit within specified ranges. The camera needs to capture at least 30 fps.

The maximum displacement of the LED strap from the webcam can be determined through the data analysis system.

Data Analysis Module Testing

Parts of the testing for this module have been completed in both the proof-of-principle and the subsystem demonstration projects. The difficulty of having a fully integrated test for this subsystem is that it requires the functionality of the other two subsystems, especially for the final correlation step. The positional plots can be verified by examining the periodicity of the plot. The frequency plots can also be verified easily by determining the periods of each positional and angular plot. To test the data analysis subsystem, data needs to be collected from the two prior subsystems using the testing apparatus. The quotient between the compared data will be visually analyzed. In addition, the slope will be extracted and plotted. If it is linear or stays constant, then it passes the criteria. If not, then it does not pass the criteria.

Parts List

Part Description	Manufacturer	Man. Part #	Supplier	Supplier Catalog #	Unit Cost	Total Cost
Arduino Uno - R3	Arduino	UNO R3	Sparkfun	DEV-11021	$29.95	$29.95
IMU Fusion Board	Sparkfun	SEN-10252	Sparkfun	same as previous	$59.95	$59.95
LED	Lite-On Inc	LTST-C191KFKT	Digikey	160-1445-2-ND	$0.29	$0.58
60 fps Camera	Sport Camera	WYTGRVRTCJGI	DH Gate	135461819	$74.10	$74.10
1k Resistor	Radio Shack	271-1321	Radio Shack	271-1321	$0.24	$0.48
1.5 V Battery	Sony	192-LR41	MicroBattery	same as previous	$1.25	$1.25
Battery Holder	MicroBattery	BH-CLIP20MM-THM	MicroBattery	BH-CLIP20MM-THM	$1.95	$1.95
Sensor Enclosure	Teko	L15.9	Teko USA	same as previous	$0.97	$0.97
Arduino Enclosure	Sparkfun	PRT-10088	Sparkfun	same as previous	$11.95	$11.95
Velcro Strap	Lynx Heli	LYX0124	A Main Hobbies	same as previous	$3.25	$3.25
USB cable	Dynex	9695523	Best Buy	DX-C114194	$24.95	$24.95
Ribbon Cable	BG Micro	CAB2184	BG Micro	same as previous	$4.99	$4.99
Slide Switch	Sparkfun	LilyPad	Sparkfun	DEV - 09350	$3.95	$3.95

Table #11- Parts List

Timeline Estimation and Milestones

The following image is a Gantt chart of the tremor project. A larger, more detailed one can be found in the Appendix 3 as fig. #A.3.a-A.3.d:

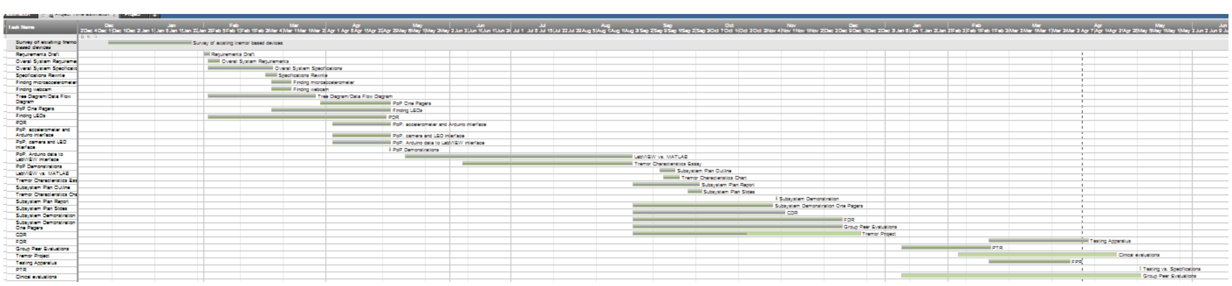


Figure #17 – Gantt Chart

On the Gantt chart are all of the assignments given to the tremor analysis team, from the inception of the project to the projected final requirements and specifications verification demonstrations. The timeline extends from December 2011 to May 2013, covering the full extent of the three semesters allowed to work on this project. Many of the milestones are the deliverables and demonstrations. They include the PDR, the CDR, the FDR, the PoP, the subsystem demonstrations, the PTR and FPR assignments. In addition, the Gantt chart also details unique assignments such as the LabVIEW vs. MATLAB paper and the tremor research.

Economic Analysis

To estimate the total cost of the project and eventually the unit price of the device should it eventually be sold, the first step is to estimate the cost of the prototype that is being built right now. The following table contains the costs of the parts that are being used for this project to build the prototype.

Part	**Cost**
IMU Fusion Breakout Board	$59.95
2 LEDs	$0.29 (each)
Arduino Uno	$29.95
60 fps Camera	$75
LabVIEW Student Edition	$75
Misc other items (wires, straps, housings, batteries)	$50
Total:	$290.48

Table #12 – Cost of Prototype Parts

As shown above the total price of all the parts of the prototype comes to $195.30. Factoring in the 5% pass-through fee, the total amount for parts comes to $305.00. The next step in costing the prototype is to consider labor costs. After consideration the following table was put together to estimate the total hours spent at particular positions with the corresponding wage displayed.

Role	**Hours**	**Salary**
Software Engineer (2x)	40 and 10 respectively	40 $/hr
Hardware Engineer (2x)	20 and 30 respectively	48 $/hr
Testing Engineer (3x)	20 (each)	36 $/hr
Technical Writer (3x)	10 (each)	30 $/hr
Totals	190 hours	$ 7460

Table #13 – Estimated Labor Hours and Salaries for Prototype

As shown in the table the total estimated number of hours for building the prototype is 190 hours and the total estimated salary earned for the roles in building the prototype is $7460. This number for total salary earned loaded by the factor 2.8 to cover the indirect costs of hiring for such positions. This brings the total labor price to $20,944 for the prototype. Adding to that the price of parts gives a total price for making the prototype of $21,249.

The next aspect to be considered in the economic analysis is the production costs. The device in this project is not a directly commercial project. It is hoped that it will have significant clinical applicability. Should the project have clinical applicability, it is estimated that approximately 1000 units could be sold to hospitals or other medical practices for use in diagnosis of tremor. Hence, the estimations for the production costs of this device are calculated for 1000 units. After researching the costs of the parts in bulk the following table was made of parts costs for the production of the device.

Part	**Cost**
ADXL 345 Accelerometer	$3.04
IMU 3000 Angular Rate Sensor	$12.00
Printed Circuit Board Fabrication	$0.39
PCB Assembly	$3.36
2 LEDs	$0.10 (each)
Camera	$57.47
Program (created from LabVIEW)	$10.00
Arduino Uno	$23.96
Misc other items	$20
Total:	$130.32

Table #14 – Estimated Cost of Production of Device per Unit

As shown in the table the total price per unit of the produced device would cost $130.32. This puts the price of 1000 units at $130,320.00. The next estimate was for printing and packaging. It is estimated that to print a manual for use of the device as well as proper documentation of the device it would cost $3.00 per unit. It is estimated that to package each device properly such that it would be protected during shipping it would cost $5.00 per unit. This puts the price for printing and packaging of the device at $8.00 per unit or $8,000 for 1000 units.

The final consideration in costing the production of 1000 devices is the cost of labor. It is estimated that there would be needed 250 hours of manufacturing verification at 20 $/hr and 100 hours of software verification at 15 $/hr to make 1000 units of the device. This puts the total hours for production at 350 hours and the total salary at $6,500. This salary is loaded with a factor of 2.0 for indirect costs to give a total cost of labor of $13,000.

To finish costing, the production of the device the next step is to sum the cost of parts, labor and printing and packaging of the device. This comes out to $151,320. Next this total has 40% added for overhead costs and 20% added for profit. The total cost of production comes out to $254,217.60 or $254.22 per unit.

The total cost of the product is the sum of the production costs and the prototype costs. This comes out to $275,466.60. Therefore the cost per unit would come out to $275.47. For the wholesale cost, one adds 20% per unit for a price of $330.56. For the retail cost, one adds 50% per unit for a price of $413.21.

As there is no comparable product on the market today, it is difficult to estimate the total number of units that might be sold. This means that the best indicator of how many units might sell of this device is completely dependent on the clinical significance of it which will be determined over the course of the project. Should it become clear that the device provides a large amount of useful clinical data then it is very possible that as much as 5000 units or more could be sold. On the lower end, it is possible that the device provides good clinical data but is limited in scope, as such it could only sell 500 or fewer as the applications of the device are more limited.

Another important factor to consider in this economic analysis is that one of the main objectives of this project is to analyze the effectiveness of each of the sensors and the optical system in recording tremor movement. Should it become apparent in the course of testing that one of the sensors or the optical system does not give useful or gives completely redundant information then the resulting product may not include that aspect and the costing of the overall product might change significantly.

Labor Costs Graph

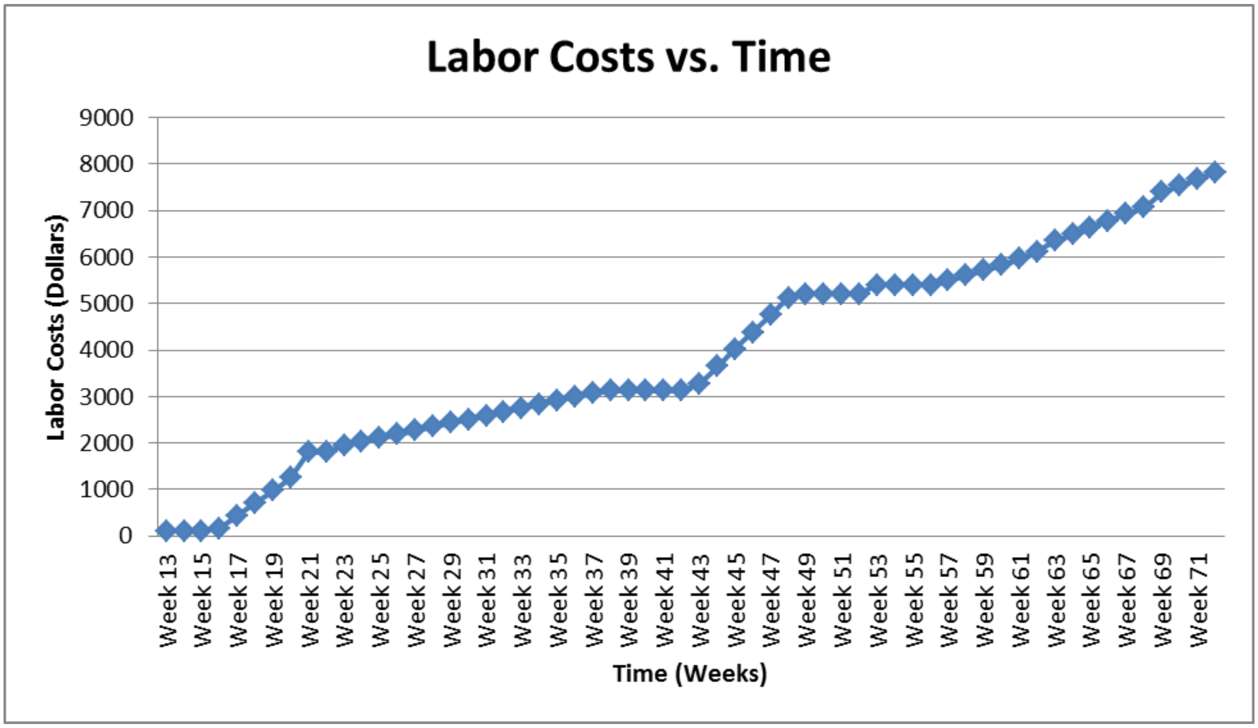


Figure #18 – Labor Costs vs. Time Chart of Entire Duration of Project

Though the project begins on Week 0 (December 4, 2011,) labor cost is not incorporated into the project until Week 13 (March 4, 2012.) The numbers for the labor costs graph are taken from the salaries shown in Table 11 in the Economic Analysis for labor costs to produce the device. These salaries and hours were divided up over the duration of the project to represent how money would be spent over the development of the prototype.

Applicable Standards if Commercialized

If commercialized, the software would need to incorporate include software development and maintenance standards for medical software as outlined in ANSI 62304:2006 – Medical

Device Software – Software Life Cycle Processes. Those include ANSI 62304:2006 5.2 – Software requirements analysis, ANSI 62304:2006 5.5 – Software unit implementation and verification, ANSI 62304:2006 5.7 – Software system testing, ANSI 62304:2006 6.1 – Establish a software maintenance plan, ANSI 62304:2006 6.2 – Problem and modification analysis, and ANSI 62304:2006 6.3 – Modification implementation. The development process standards ensure that the process can be followed by different software engineers. The maintenance process standards ensure that the quality of the product is continuously kept at a high level and all issues that consumers have with the product are addressed. In addition the previously mentioned standards pertaining to the hand-worn device also apply here.

Qualifications of Key Personnel

Hailey Cunningham, the group member responsible for the sensor subsystem, has not had any experience with MEMS in the past. Hence, this is the subject on which she is focusing personal studies so that she can further work with and understand the sensor for the inertial subsystem. She has had the standard exposure to C programming for any biomedical engineering student that is key to successfully interfacing the sensor with a computer to program the sensor settings and read the data from the sensors.

Anne Myung's primary responsibilities for the project involve the use of the webcam and a wearable sensor system. It is imperative that she has a solid understanding of optics, circuit theory and the application of electronic circuits. Courses she has taken as part of her biomedical engineering major requirements, such as Introduction to Circuit Theory and Electronic Engineering, provide her the knowledge she needs to be able to build the circuits required for the optical subsystem. She also has the standard exposure to C programming and understanding of LabVIEW, also obtained from major requirement coursework, in order to understand and help other group members with their parts of the project when necessary.

The signal analysis and processing module required many of the skills reinforced by classes and projects that all three design members have experienced in the past. LabVIEW skills were acquired from the electrocardiograph project during Principles and Practices of Biomedical Engineering. That project also instructed the project members how to collect physical data using a DAQ system in order to be manipulated digitally by LabVIEW. The fundamentals of frequency spectra and filter design necessary in order to process the data were taught in Introduction to Digital Signal Processing. This included Fourier analysis, a concept taking the form of the Fast Fourier Transform in this project. Justin Lee has also had experience using LabVIEW to collect and process data from force transducers on an instrumented chair. That experience taught him how to calibrate physical data from a transducer using LabVIEW. In addition, Justin Lee has also participated in a workshop on Arduino basics. All three members are studying to obtain bachelor of sciences in biomedical engineering.

The resumes of all three members are attached in Appendix 4 for reference.

Intellectual Contribution

Hailey Cunningham will be responsible for the sensor subsystem of the overall system. This subsystem mainly includes the three axis accelerometer and three axis angular rate sensor. Hailey will be responsible for providing sensor power and interfacing the sensors with the computer. This will involve writing code for the Arduino microcontroller that will allow the microcontroller to communicate with the sensor to adjust the settings of the sensors and read and interpret the returned digital data.

Anne is responsible for the optical subsystem portion of the project. It involves the use of the webcam and a pair of LEDs. The LED circuit will be designed and built on an adjustable wrist strap so that it can be worn on a finger or hand. The webcam will record the motion of the LED lights as the hand moves. Anne will be responsible for designing and testing a wearable LED and accelerometer circuit that can be used flexibly around any part of the body, without impeding the physical tremor's motion. She will also be required for an efficient webcam/LED interface; such that the turning on of the webcam will activate the LED circuit. The webcam must also provide usable data that can be evaluated by Justin's program.

Justin Lee will be working on the third module, the signal analysis and processing part of the project. He will take the signals from the webcam and the inertial sensor board generated by the other group members and import them into LabVIEW. From there, he will determine the spatial position of the limb wearing the device based on both the LED position and the accelerometer and angular rate sensor data. Having generated a positional graph of the spatial location of the limb, Justin will then compute and plot a Fast Fourier Transform of each of the six degrees of freedom in order to determine tremors based on the frequency of movement in each degree of freedom. The entire LabVIEW program will be developed by Justin, including the process for comparing the signals between the webcam and the inertial sensor board. Justin will also be in charge of designing an efficient, but aesthetically pleasing GUI that clinicians will be able to use intuitively.

Teaming Arrangements

Hailey will be creating the sensor subsystem consisting of the accelerometer and angular rate sensor. She will be responsible for interfacing the sensors with the computer first with an Arduino and then getting the data in the Arduino to output into LabVIEW so that Justin can use it in the data analysis subsystem. She will be responsible for writing the code that will program the settings of the sensors and reading the data from them in addition to adding any other later desired functionality from the sensors.

Anne Myung will be designing and creating the wearable LED hand strap, in addition to experimenting with the webcam. The optical interface will be under scrutiny as she continues to modify the LED sensor circuitry and research optimal parameters at which the LED is best seen on the webcam. Pictures and videos will be taken throughout the tests as she imitates a physiological tremor over the webcam while wearing the LED sensor system. She will also make the strap so that the sensor subsystem can be easily integrated into the overall system design.

Justin Lee will be working on the signal analysis and processing part of the project. He will work by acquiring data from the sensor subsystem and optical subsystem. He will attempt to detect centers of points of light on an image and extracting positional and angular information from those points of lights for the optical portion. He will also be building positional and frequency graphs from the sensor subsystem data. He will be performing the statistical coding in order to compare the waveforms from both systems. Justin will be using both NI Vision and NI Arduino Interface Toolkit to achieve his aims.

Summary and Conclusions

Since the completion of the Final Design Report much has been accomplished towards finishing the project. The sensor subsystem functions well within the whole system and the issues of integrating the sensors with LabVIEW have been solved. The optical subsystem has become easier to track even under the presence of background light and this stability has allowed for better results to be taken. The data analysis system can now effectively get FFTs from all of the different parts of each subsystem and the FFTs effectively filter out the DC offset to more clearly show the relevant frequency range. Integration between the three subsystems is all but complete. The two tremor detecting subsystems can now send their data through to the same .vi in LabVIEW in the data analysis subsystem. In addition headway on the comparisons between the different tremor detecting methods is being made. The comparisons in the data analysis subsystem are the main issues left to be finished. While connection issues occasionally arise in the sensor subsystem and the optical subsystem, these are small issues that are easy to deal with and prevent from occurring again.

With this system very nearly finished and capable of taking and analyzing raw data, it will be possible to move forward on the testing phase of the project. Now that the testing apparatus is built, information of known frequencies can be extracted for all aspects of each subsystem. This will allow for controlled confirmation of requirements and specifications as well as easy demonstration of the capabilities of the system. In addition as stated before, the group anticipates to work with the Exercise Science Department to get real clinical data to analyze with the system as well. As the group moves forward on this opportunity it will be necessary to standardize how testing is done and come up with a procedure to get the most out of the real-life testing.

The opportunities in testing out the system in such a way that could be applicable to real life is an exciting proposition that the group is eager to pursue. Through the course of this project it has been quite fortunate that the overall concept of the system has remained mostly constant. While some aspects of how to best get data have changed, the goal of the project has remained constant and attainable. While it was expected that the accelerometer would take data that appears valuable in analysis, the angular rate sensor and the optical system were not as certain. While the quality of each type of data has not been quantified, it is clear that the data from the other two methods has promise. This is due to the fact that the FFTs for all of the data taken clearly show periodicity when the subsystem undergoes such motion. It remains to be seen how useful this functionality is for real life application but the team is hopeful that this question can be answered over the course of testing in the final stretch of this design process.

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Appendices

Appendix 1:

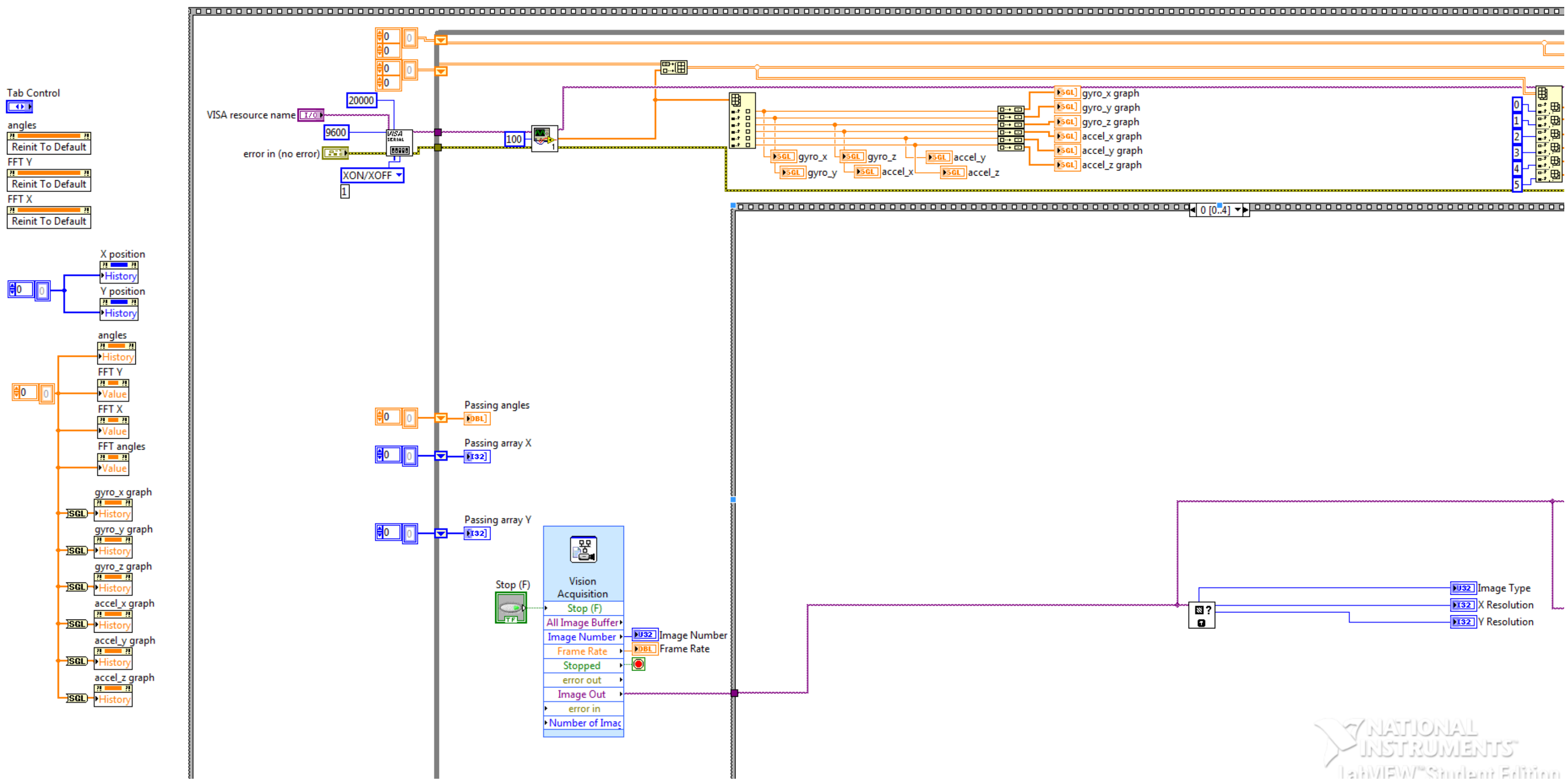

Figure #A.1.a – LabVIEW Block Diagram (left side)

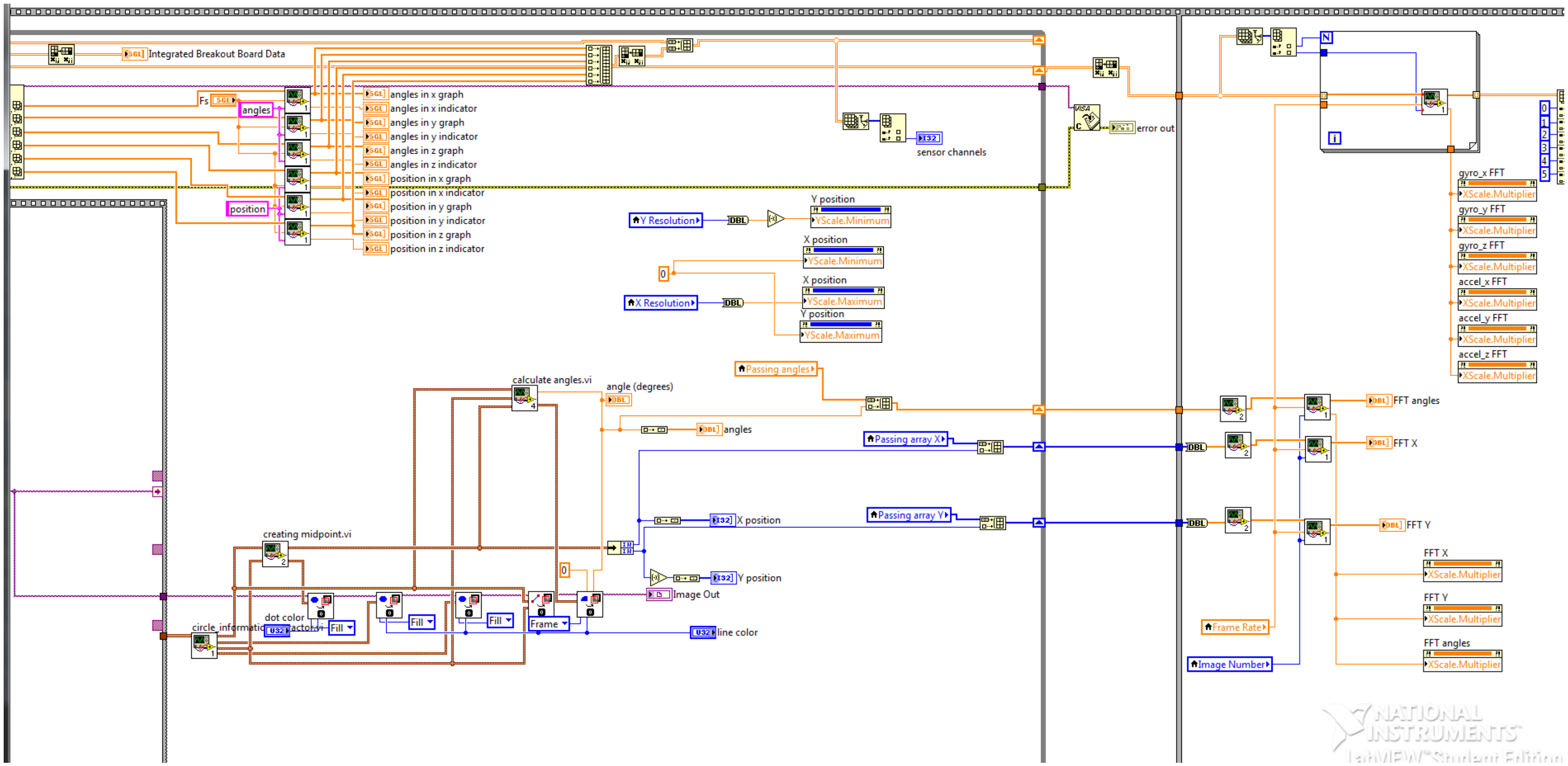

Figure #A.1.b – LabVIEW Block Diagram (middle side)

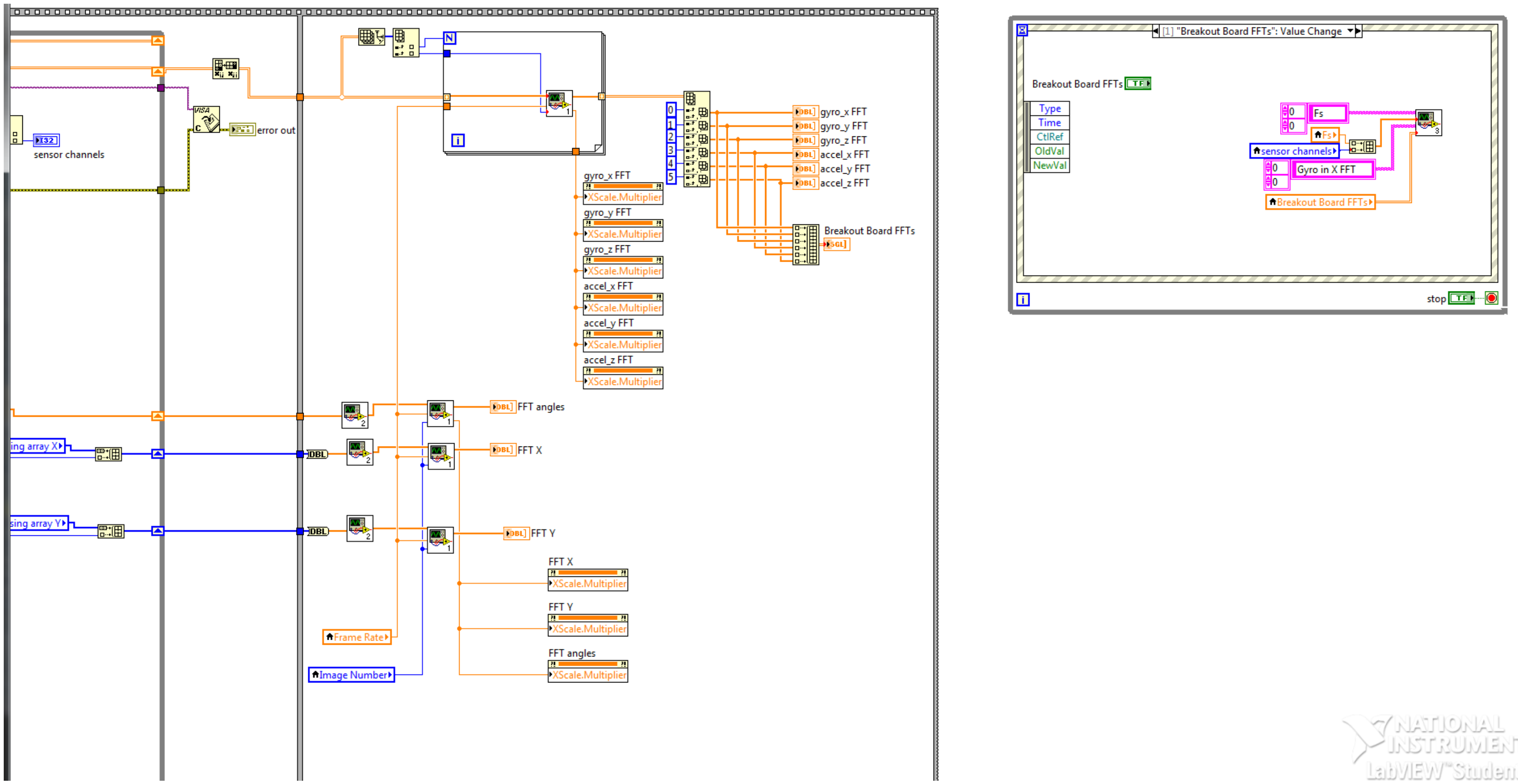

Figure #A.1.c – LabVIEW Block Diagram (right side)

Appendix 2:

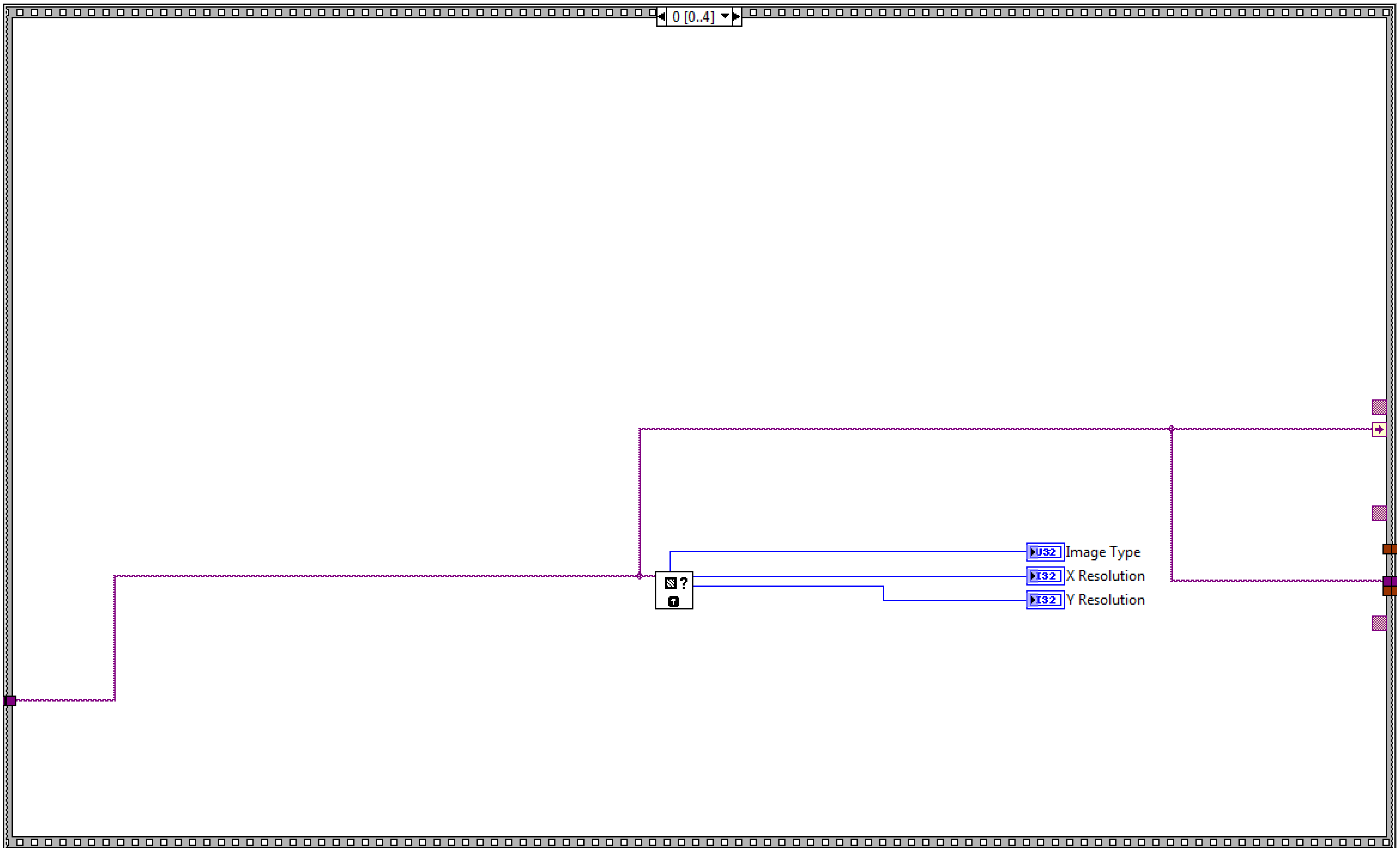

Figure #A.2.a – Stacked Sequence Structure (Frame 0)

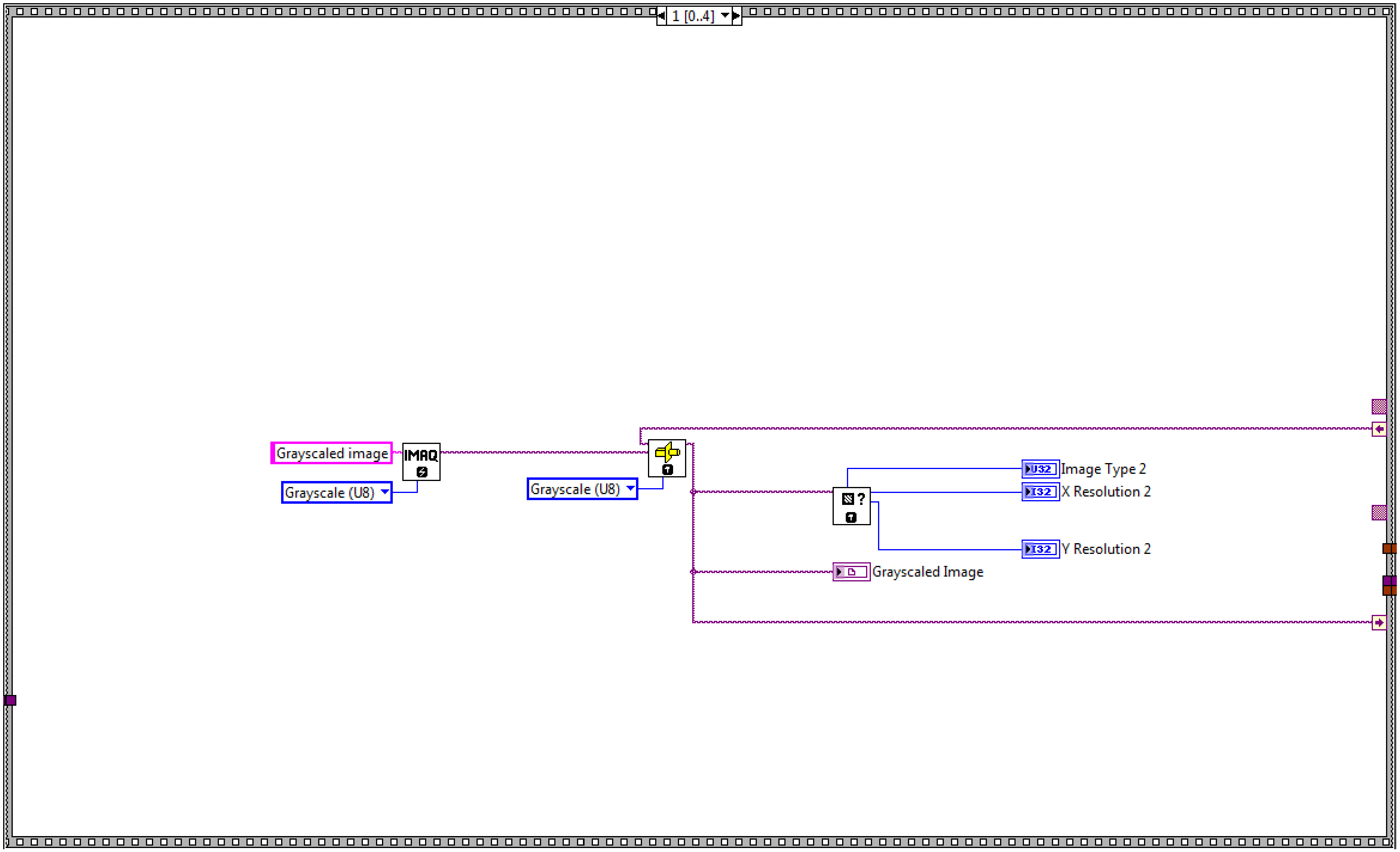

Figure #A.2.b – Stacked Sequence Structure (Frame 1)

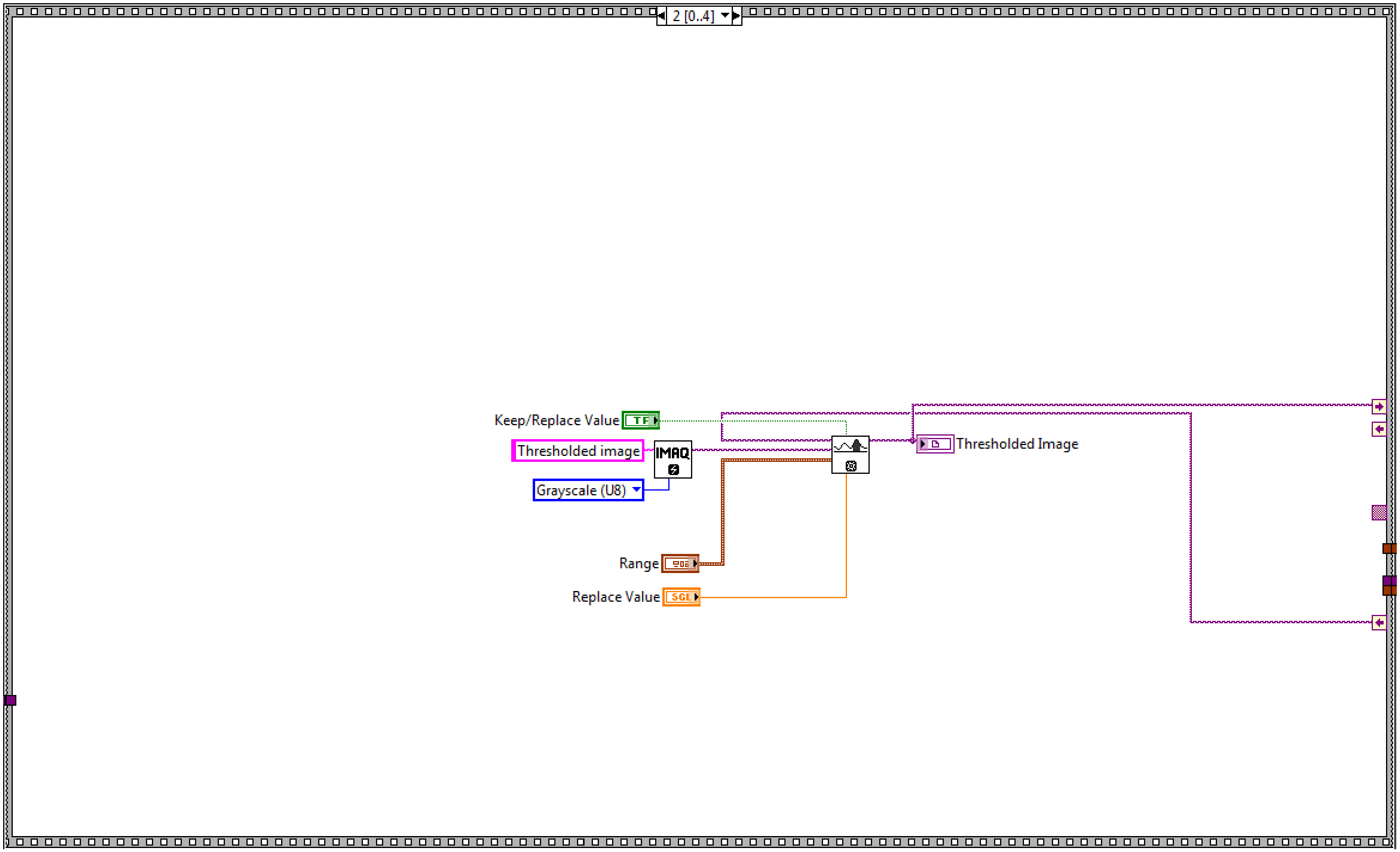

Figure #A.2.c – Stacked Sequence Structure (Frame 2)

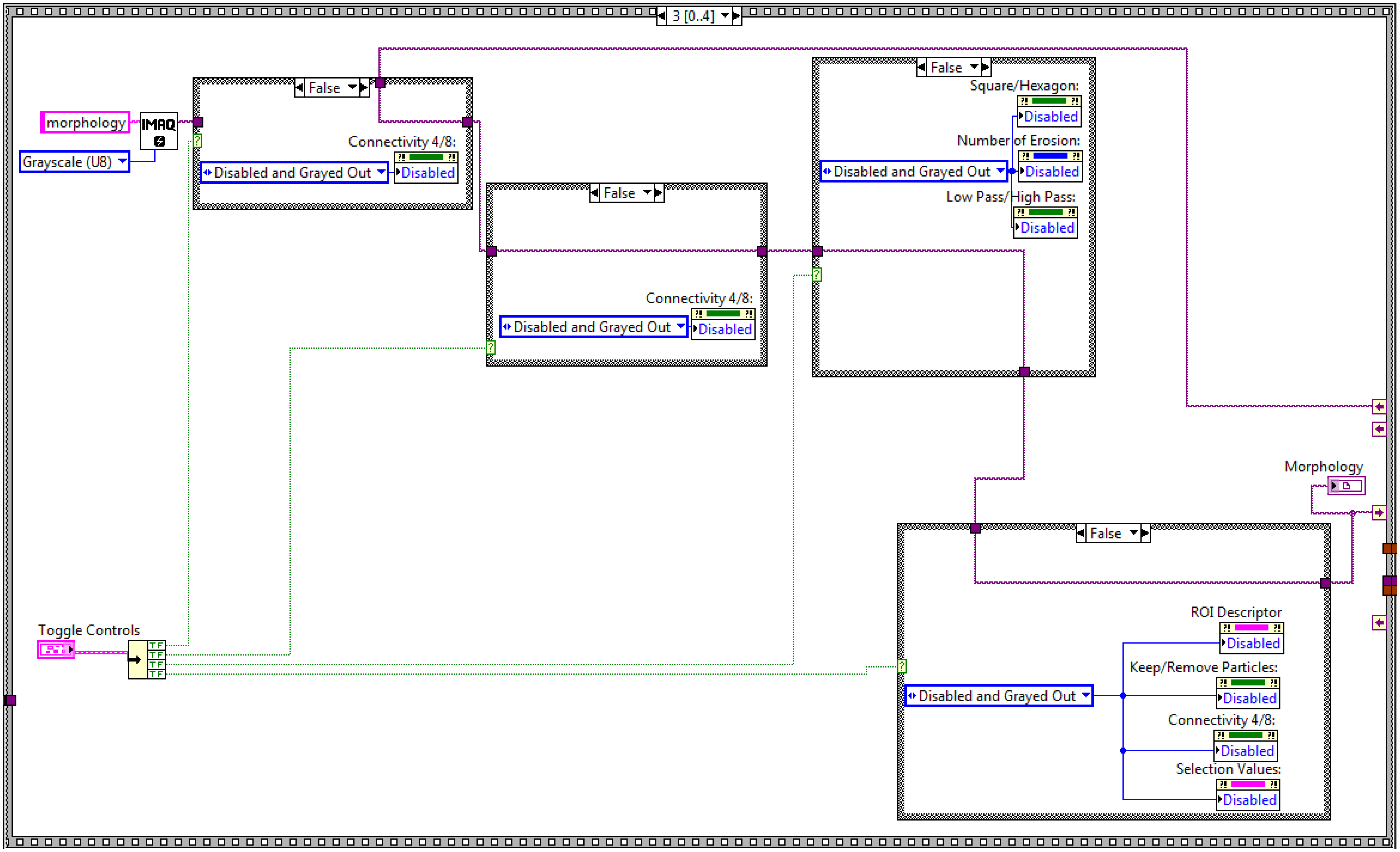

Figure #A.2.d – Stacked Sequence Structure (Frame 3)

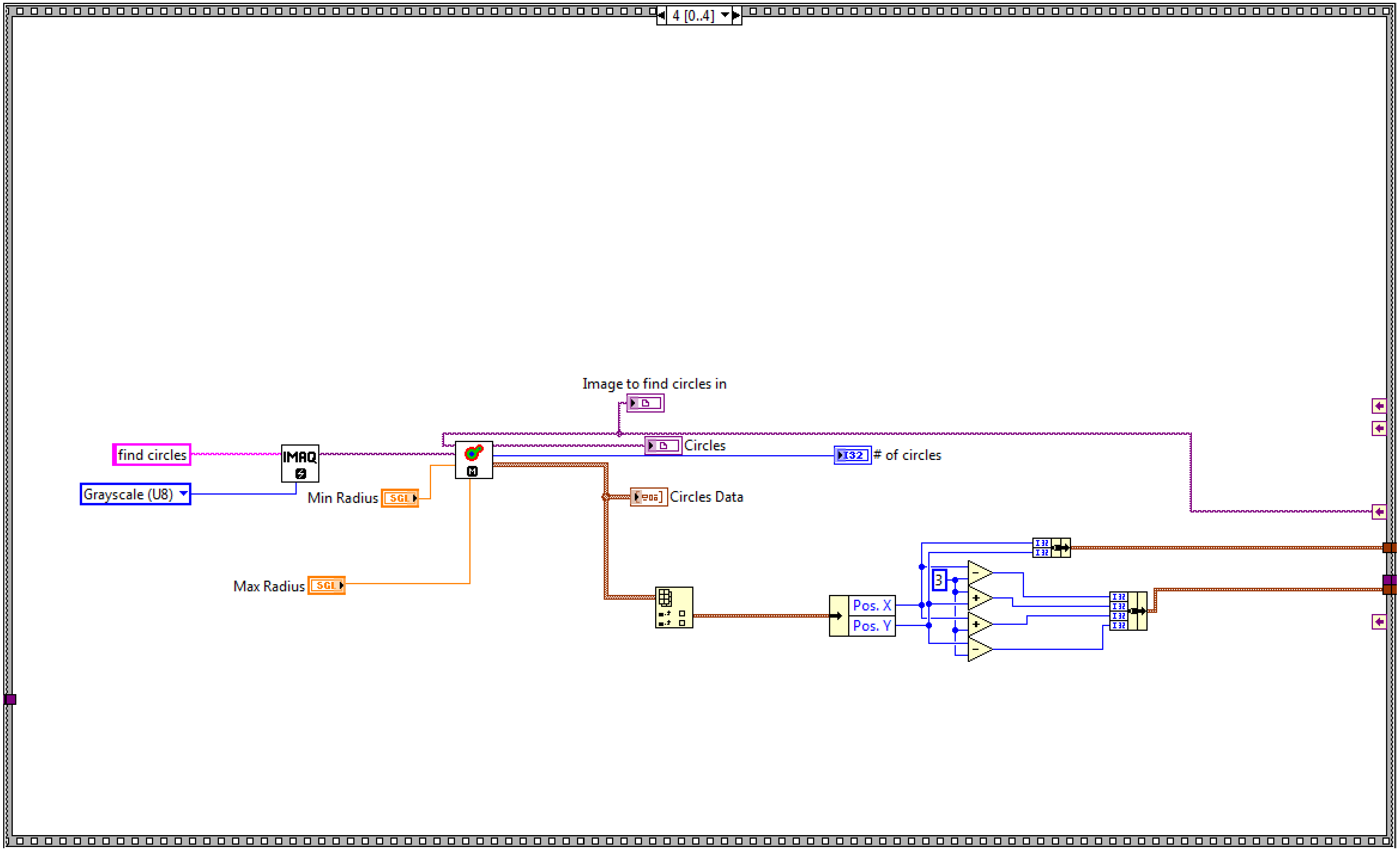

Figure #A.2.e – Stacked Sequence Structure (Frame 4)

Appendix 3:

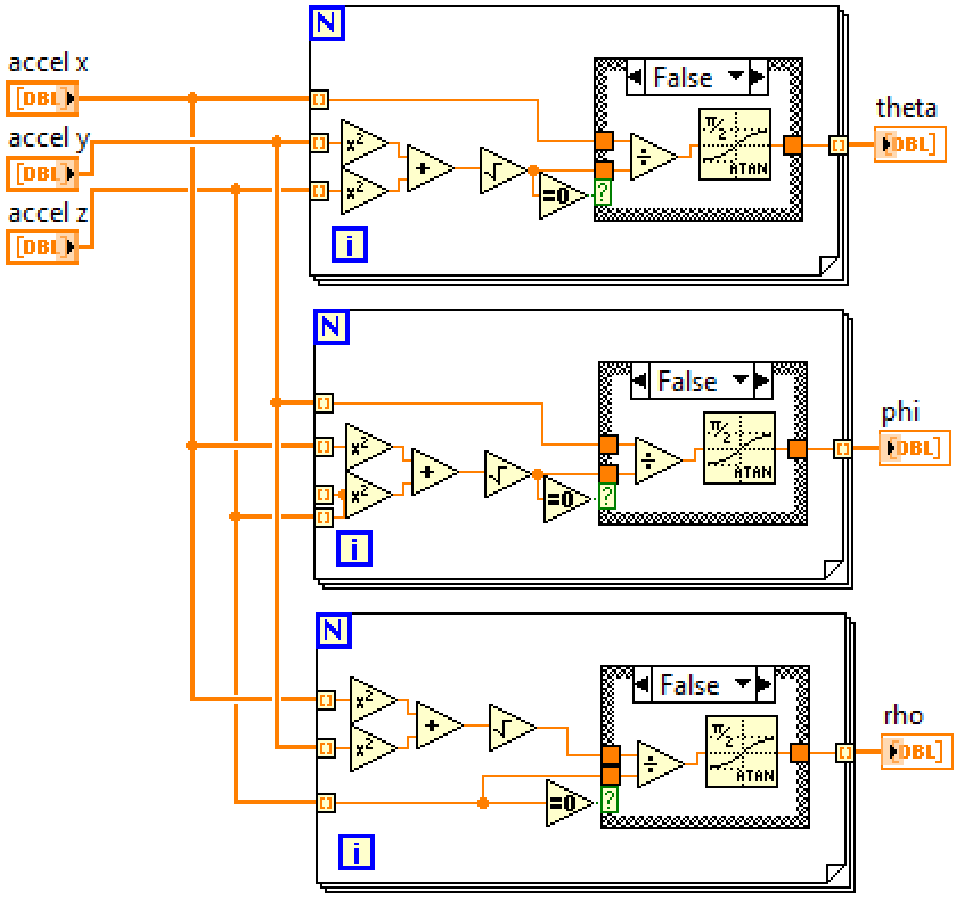

Figure #A.3.a – AN-1057 Method for Accel to Angles.vi

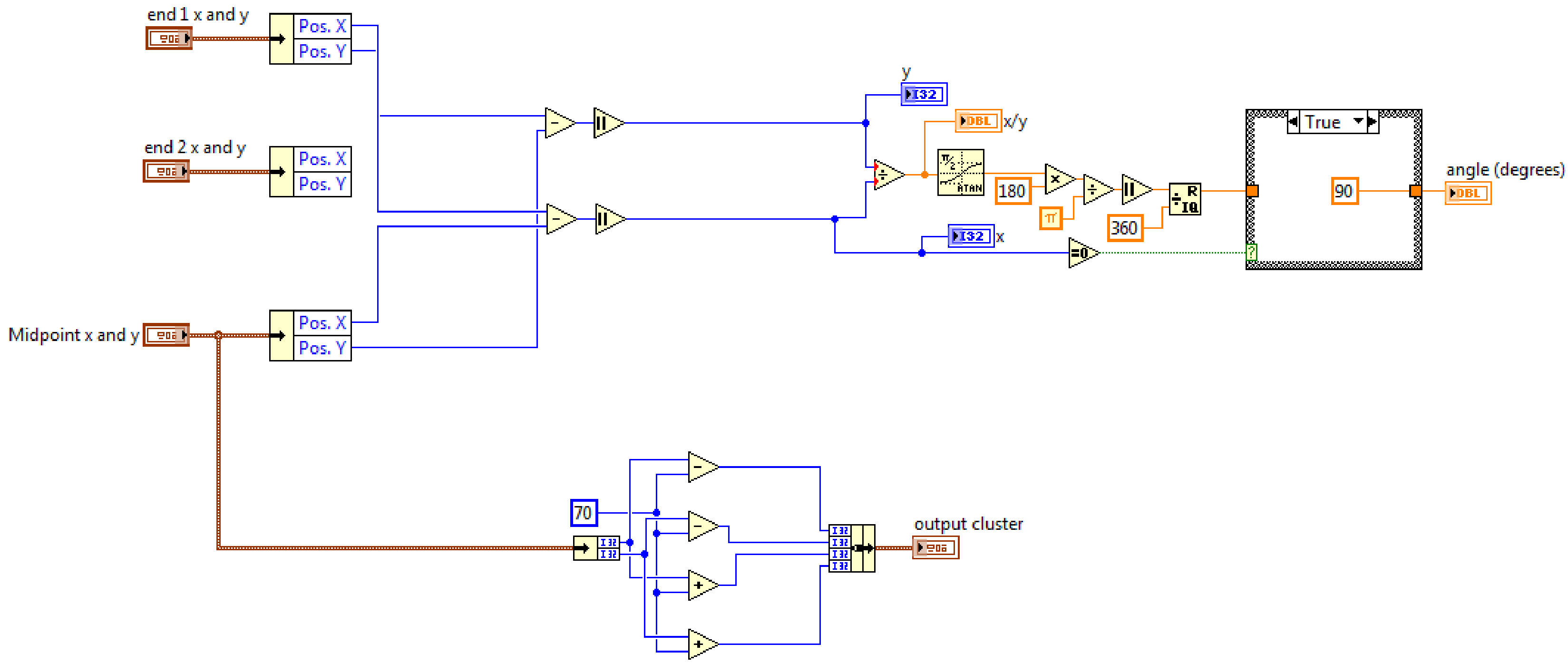

Figure #A.3.b – calculate angles.vi

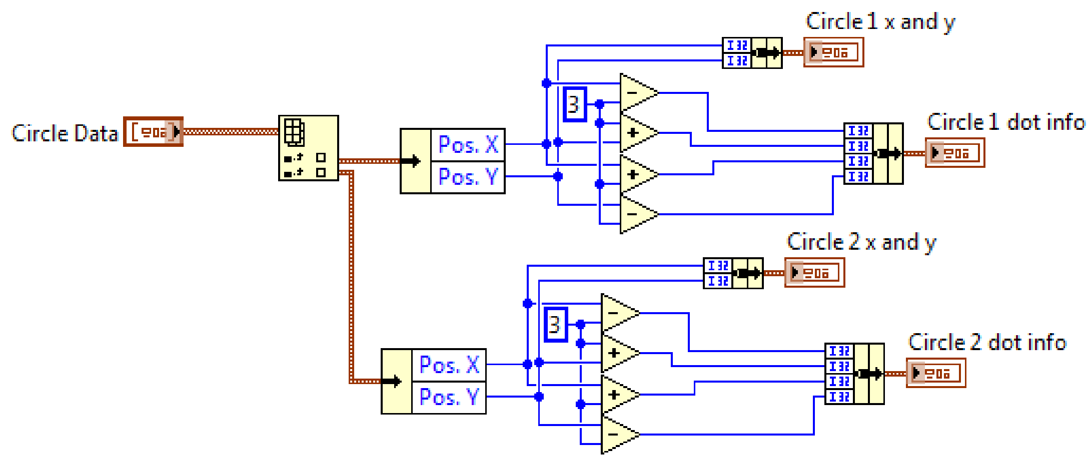

Figure #A.3.c – circle_information_extractor.vi

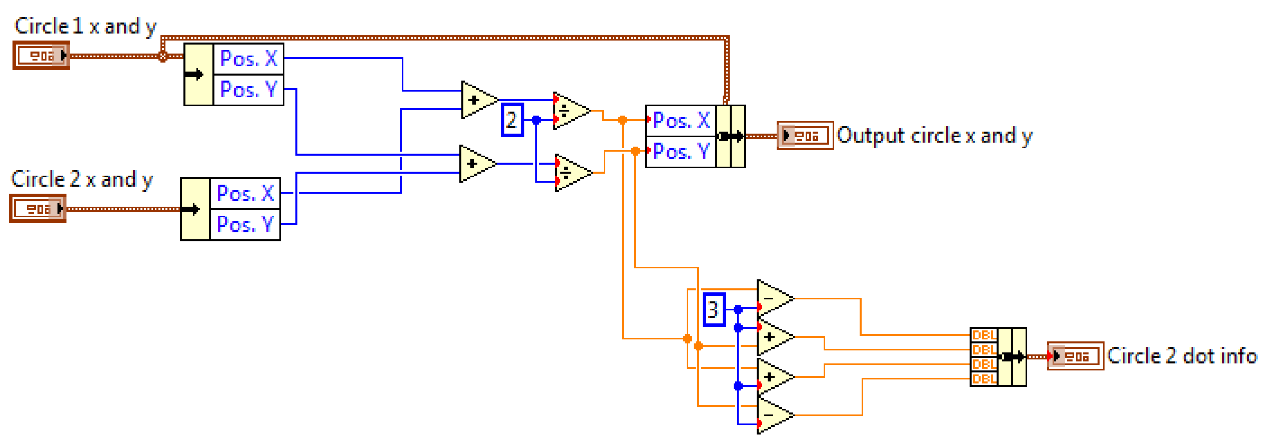

Figure #A.3.d – creating midpoint.vi

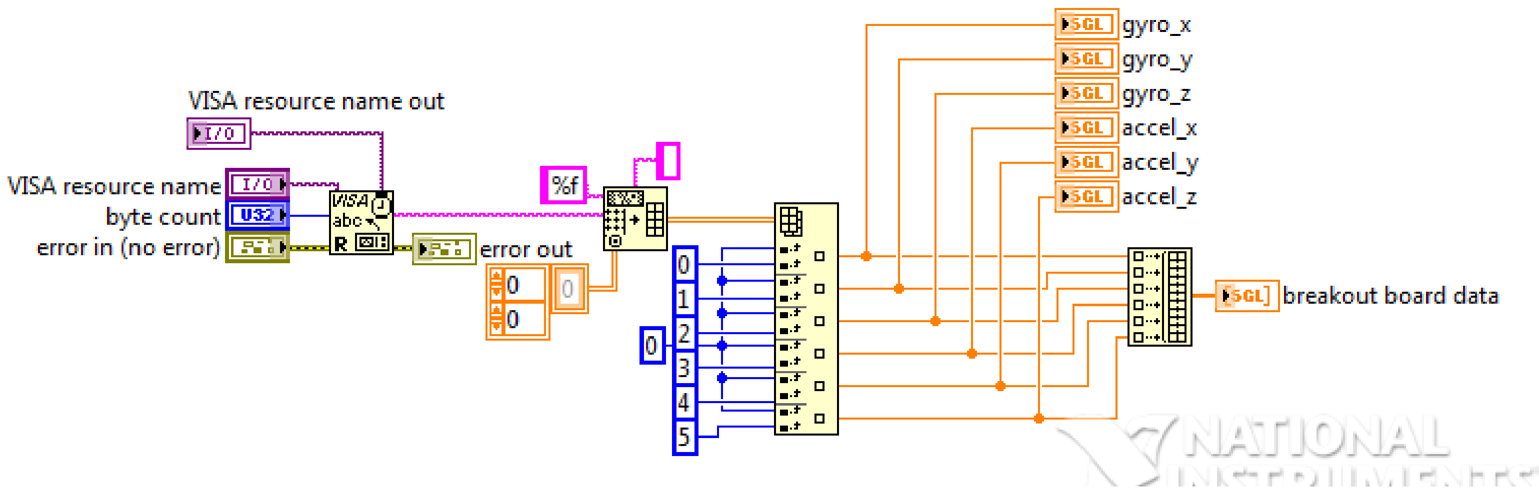

Figure #A.3.e – Data Reading from Breakout Board.vi

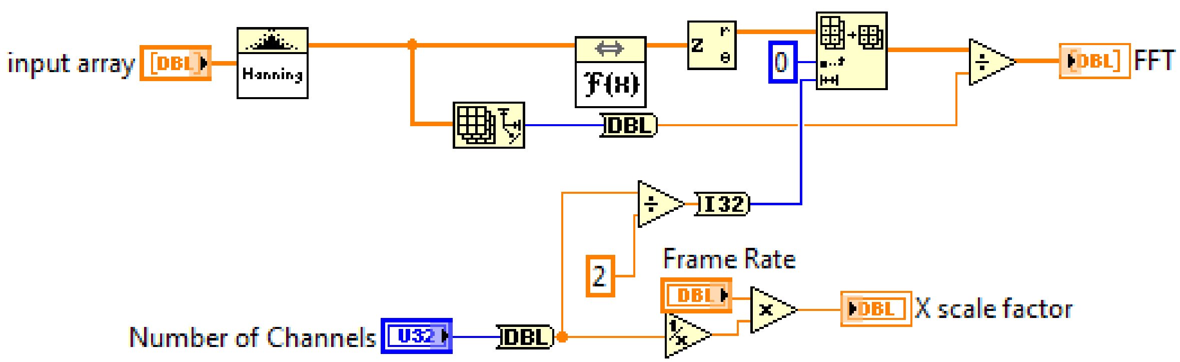

Figure #A.3.f – FFT Conversion.vi

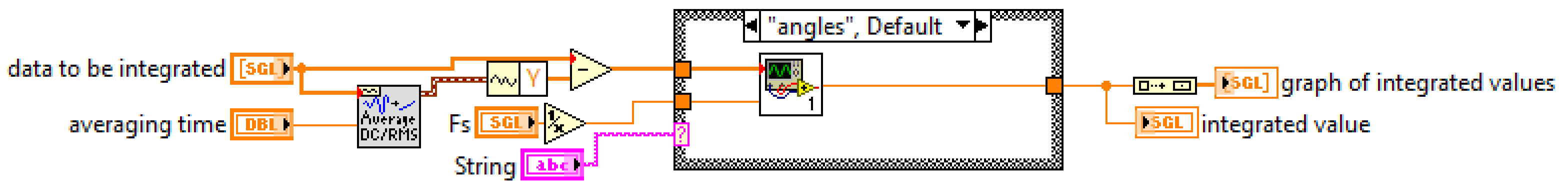

Figure #A.3.g – Integrating Breakout Board Data.vi

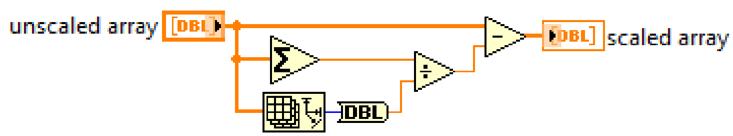

Figure #A.3.h – Remove DC Offset through Scaling.vi

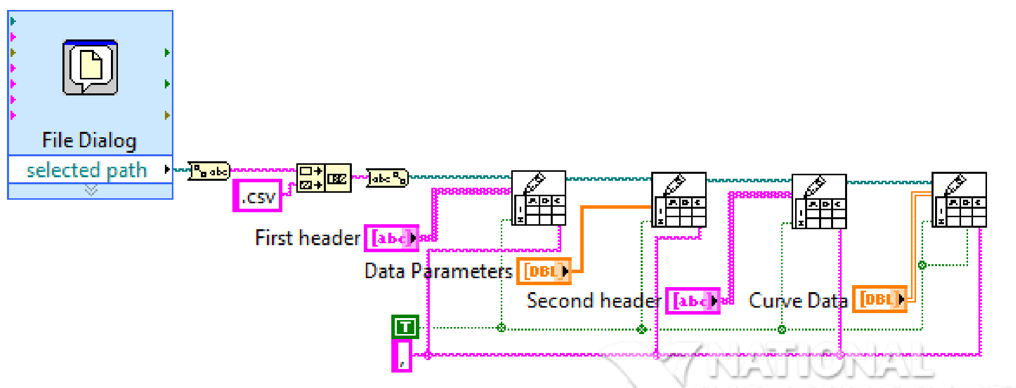

Figure #A.3.i – Saving as CSV files.vi

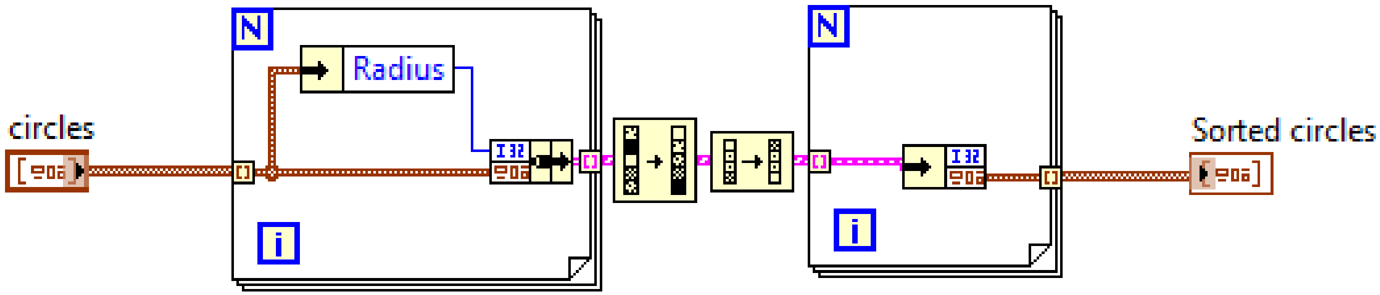

Figure #A.3.j – Sort circles.vi

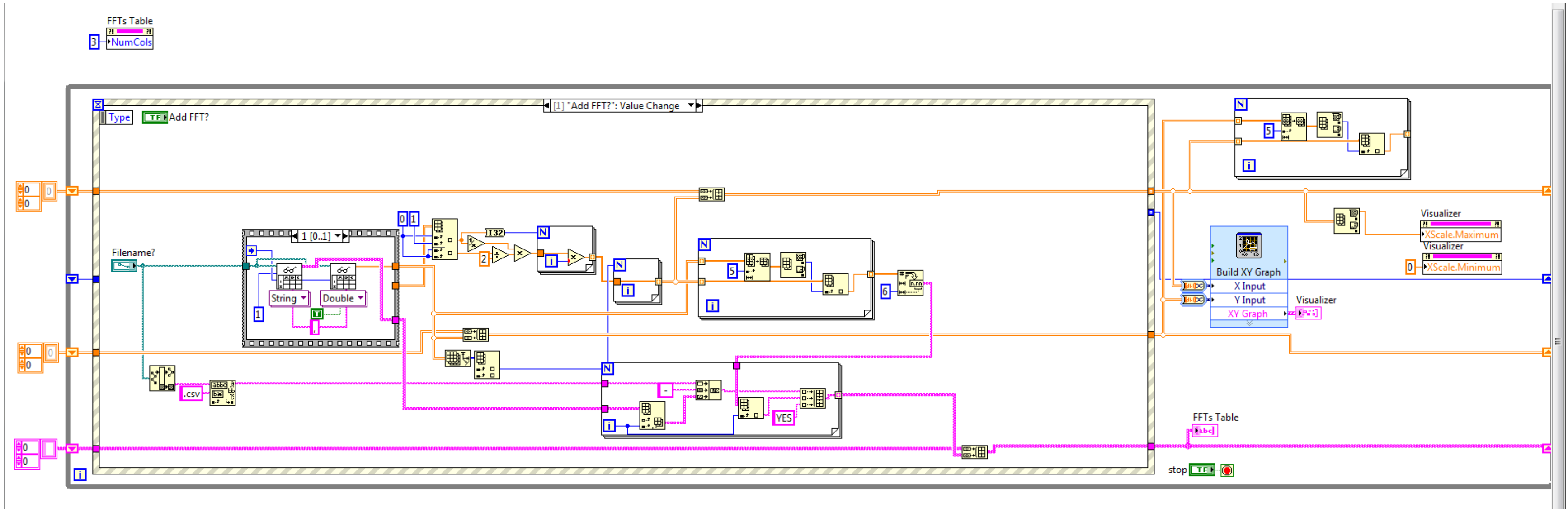

Figure #A.3.k – Waveform visualizer screen (Add FFT?).vi

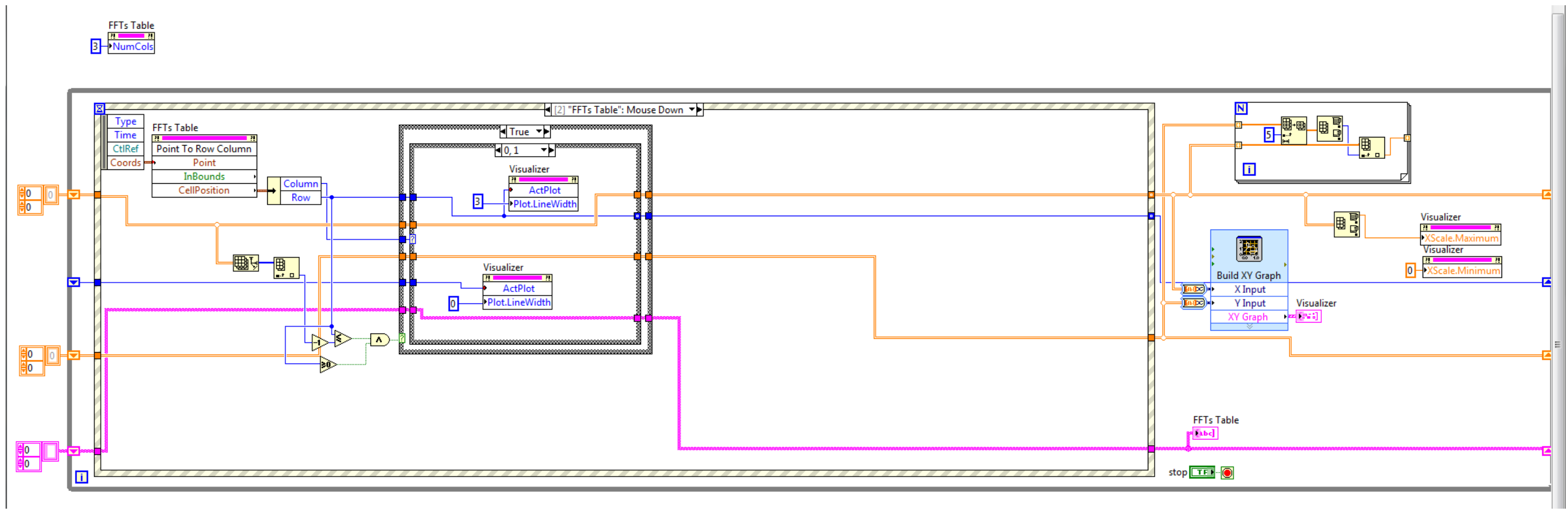

Figure #A.3.l – Waveform visualizer screen (FFTs Table - Highlight).vi

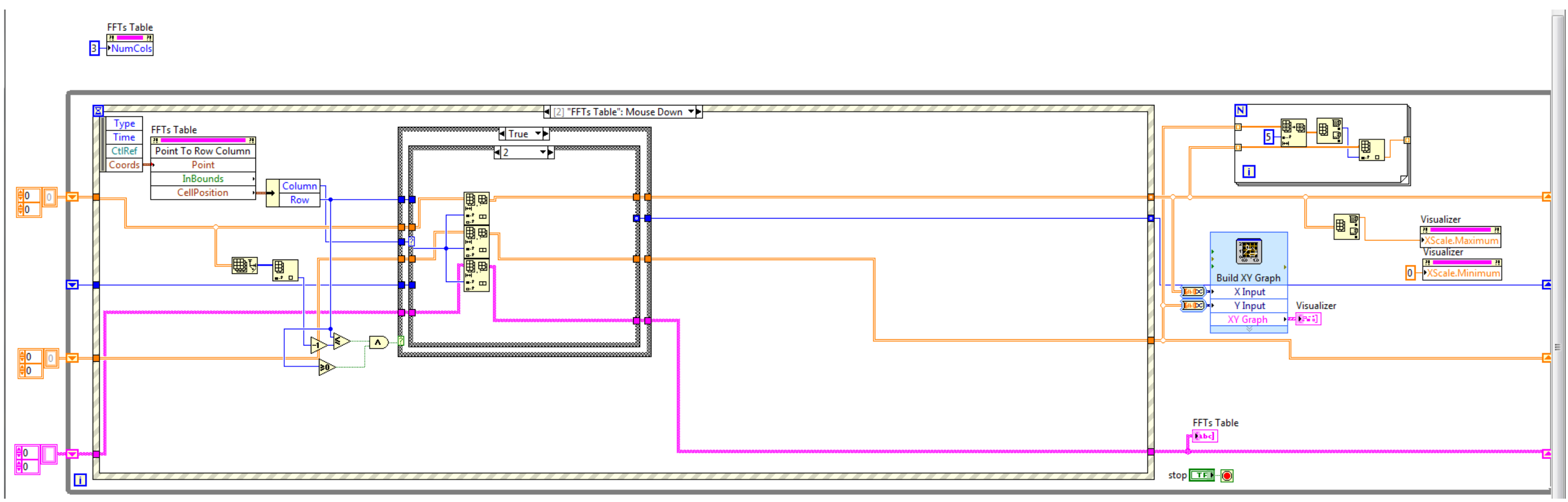

Figure #A.3.m – Waveform visualizer screen (FFTs Table - Delete).vi

Appendix 4:

Project Time Estimation

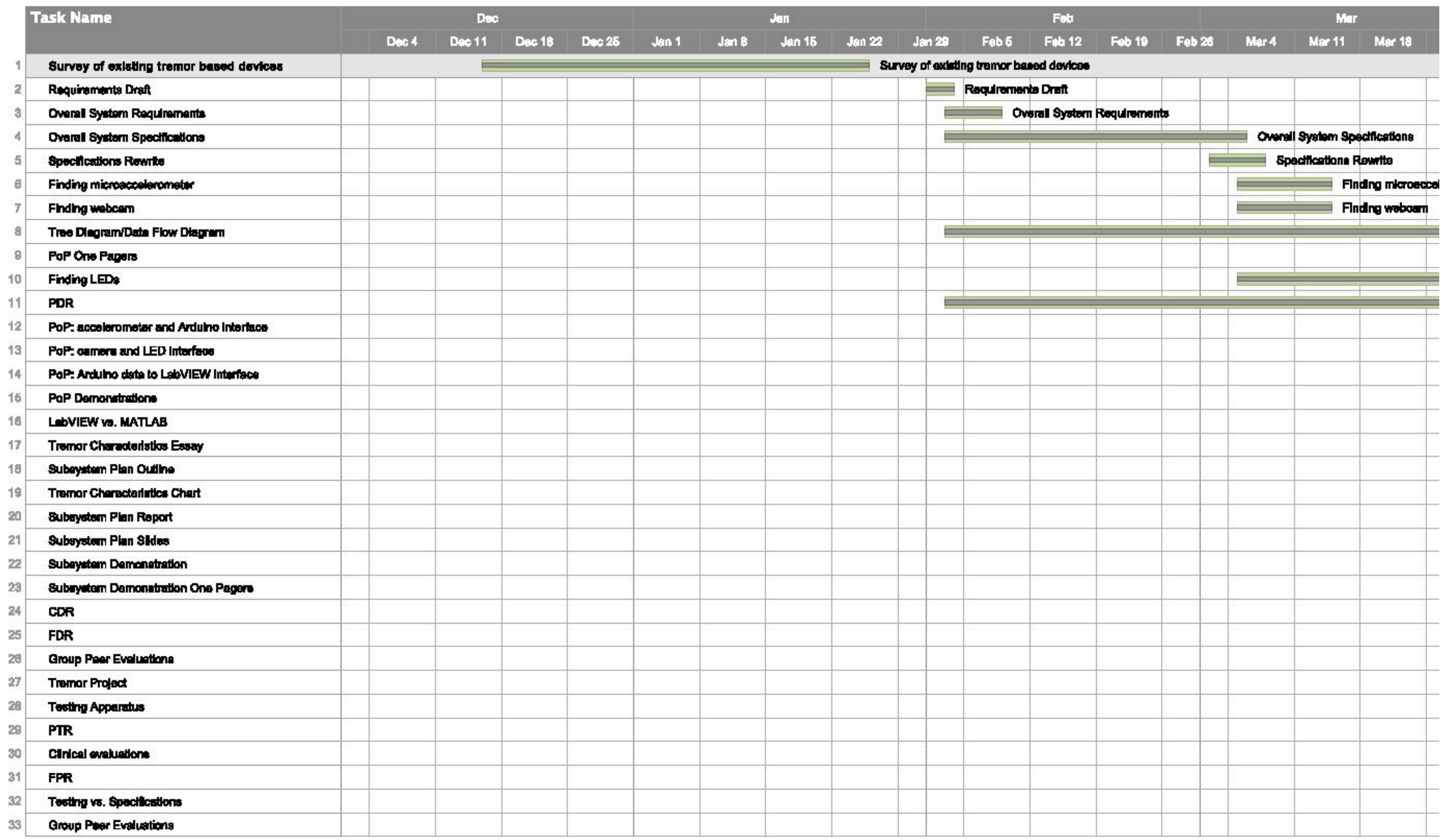

Figure #A.4.a – Gantt Chart (part 1)

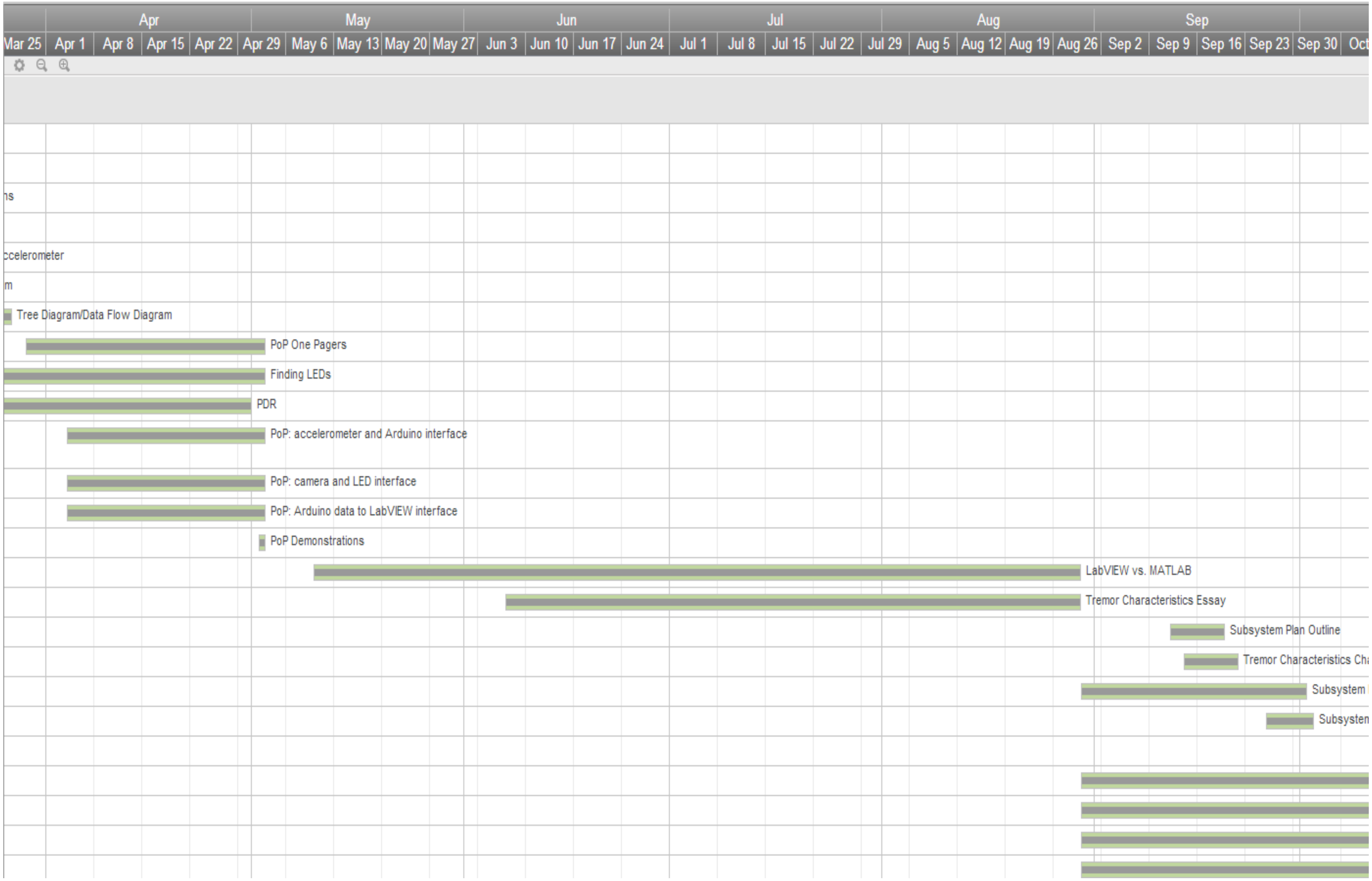

Figure #A.4.b – Gantt Chart (part 2)

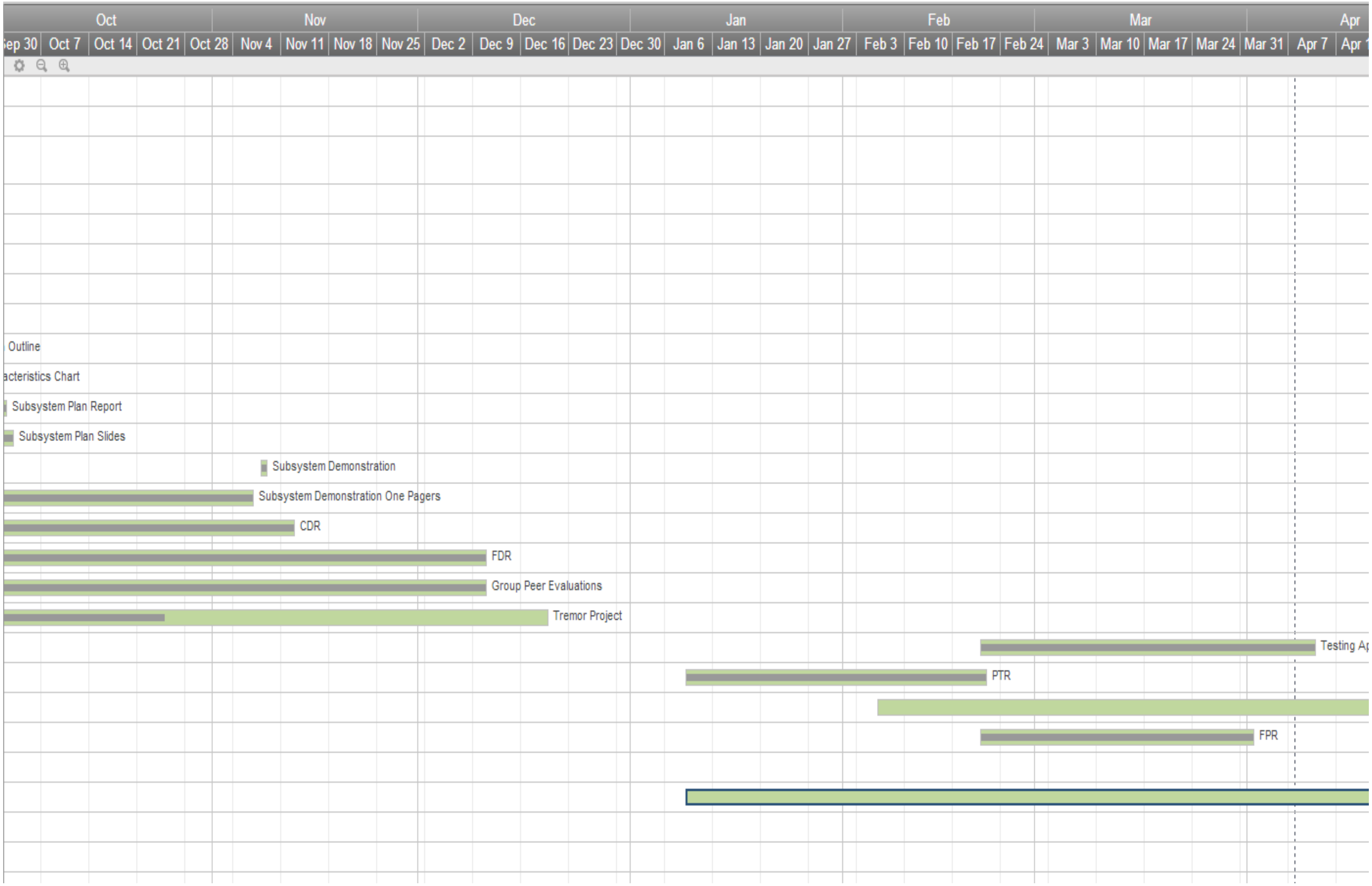

Figure #A.4.c – Gantt Chart (part 3)

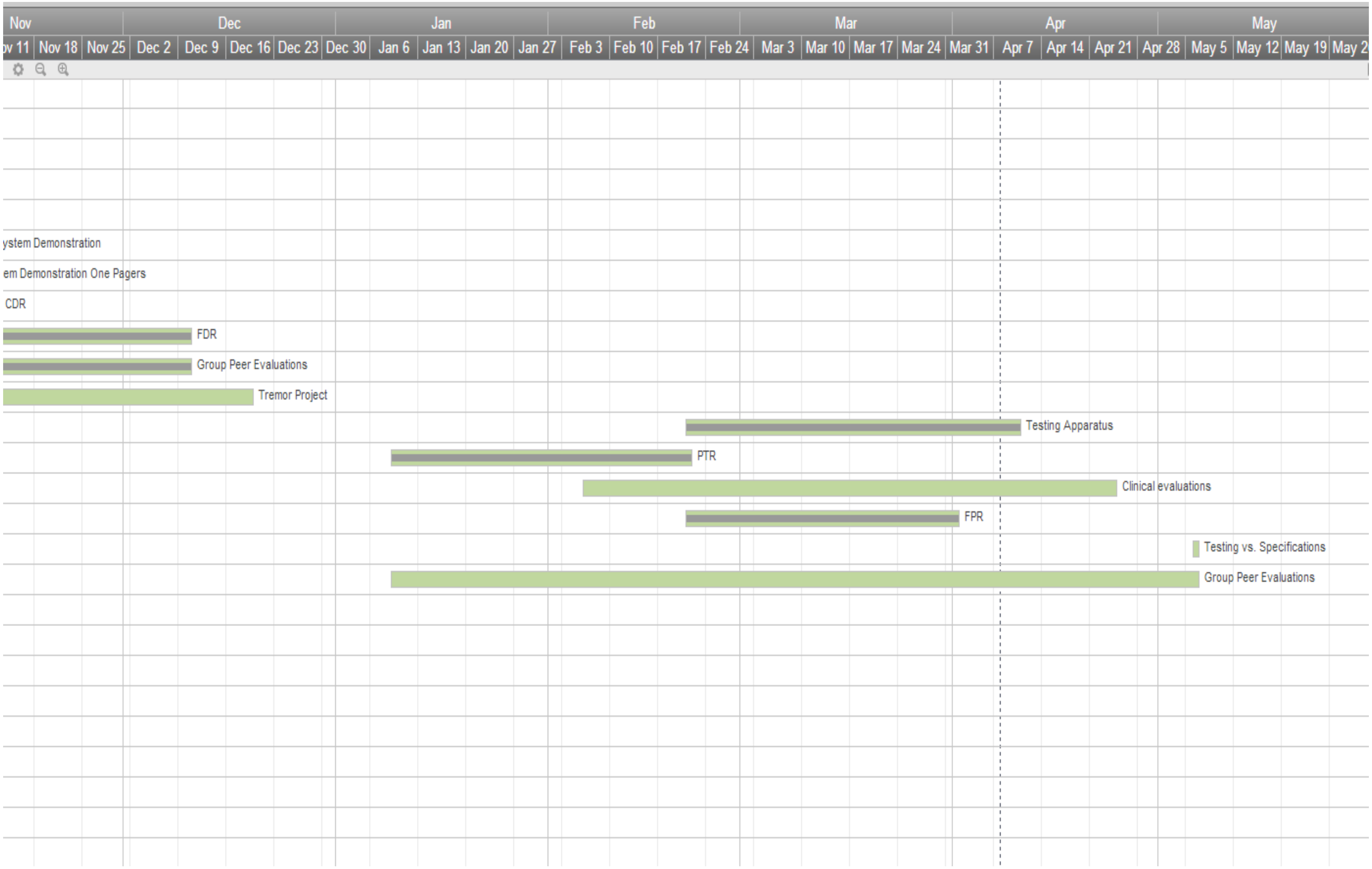

Figure #A.4.d – Gantt Chart (part 4)

Appendix 5:

Hailey Cunningham
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Cell: (619) 913-8710

Education

- The George Washington University School of Engineering and Applied Science Class of 2013
  - BS in Biomedical Engineering to be finished in May 2013
  - Dean's List: Fall 2009, Fall 2010, Spring & Fall 2011, Fall 2012
  - Dean's Commendation List: Spring 2010, Spring 2012
  - Received the SEAS Merit Scholarship
- Graduate of Scripps Ranch High School, San Diego CA in June of 2009.
  - Graduated with academic distinction (top 5% of the class)

Distinctions

- Tau Beta Pi Member: 2012 onwards
- National Honors Society Member: 2009 onwards

Projects

- Senior Design Project: Tremor Analysis System – Fall 2011-Spring 2013
  - Tremor Analysis system using two methods of analysis, an accelerometer & gyroscope sensor combination and an LED light tracking system for purposes of determining which system gives more relevant clinical information.
  -

Employment History

- Internship at the NIST Physical Measurement Lab: May-August 2011:
  - Researched the use of visible light spectroscopy to measure hemoglobin oxygenation levels in tissue as proof of concept for the use of hyperspectral imaging to noninvasively image tissue oxygenation levels during surgery.
- Internship at Biocom in the public policy department: July- August 2010:
  - BIOCOM is the largest regional life science association in the world, representing more than 550 member companies in Southern California.
  - Assisted in organizing member attendance at upcoming legislative and policy events, updated online event registration, communicated with membership on issues of interest.
- Internship at the City of San Diego Council President Scott Peter's office : August 2008
  - Answered constituent calls, wrote responses to letters from members of the community and scanned and filed memos.
  -

Volunteering Activities

- Scarves for Seniors Organizer: September 2008 – February 2009
  - Taught high school students to knit scarves for low income senior citizens. Delivered the scarves to the San Diego Senior Community Center.

SOOHYUN A. MYUNG

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Washington, DC, 20052
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EDUCATION

***The George Washington University (GWU)*, Washington, D.C.**
B.S. in Biomedical Engineering, expected 2013
***Korea University*, Seoul, Republic of Korea**
Abroad Programs in Korean, Spring 2011

LEADERSHIP

President, Institute of Electrical and Electronics Engineers (IEEE) at GWU 2011 –Present

- Amended the GWU IEEE Constitution to create a more proactive Executive Board with closer ties to the Department of Electrical and Computer Engineering faculty.

Vice President, IEEE GWU chapter, 2010-2011
Freshman Representative, IEEE GWU chapter, 2009-2010

UNDERGRADUATE RESEARCH EXPERIENCE

Biomedical Engineering Senior Capstone Project **Spring 2012 – Spring 2013**
Department of Electrical and Computer Engineering, The George Washington University,
Principal Investigator: Professor David Nagel)

Summer Clinical Research Assistant **Summer 2011**
Department of Anesthesiology and Pain Medicine, Korea University Hospital, Republic of Korea
Principal Investigator: Dr. Choon Hak Lim

Summer Scientific Research Assistant **Summer 2010**
National Institute of Standards and Technology Summer Undergraduate Research Fellowship
Biophysics Group, Radiation and Biomolecular Physics Division, Physical Measurements Lab
Principal Investigator: Dr. Maritoni Litorja

LABORATORY EXPERIENCE

Lab Assistant (Federal Work Study Job) **Fall 2009**
Department of Biological Sciences, The George Washington University
Principal Investigator: Dr. Diana Johnson.

PUBLICATIONS, TALKS AND PRESENTATIONS

Myung, Soohyun A., Kim, Y.H., Chung, H.G., Rha, J.H., Yang, S., Nam, M.H., Shin, S.H., & Lim, C.H. (2012). In vitro effect of clinical propofol concentrations on red blood cell aggregation and deformability, *Clinical Hemorheology & Microcirculation*. (in press).

In vitro effect of clinical propofol concentrations on platelet aggregration (under review for publication).

Justin Lee

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Education:

The George Washington University, Washington DC

Bachelor of Science in Biomedical Engineering, anticipated Spring 2013

Completed three years

Minor in biophysics and mathematics

GPA: 3.62 out of 4.00

Special Honors:

Tau Beta Pi – DC Gamma Chapter

Initiated Fall 2011

Research:

National Institutes of Health – Summer 2012

NLHBI SIP Intern

Wrote software in LabVIEW that that took FLIM images and extracted the theoretical multiexponential model for the fluorescence decay of each pixel to be used in intensity and time-correlated analysis

Food and Drug Administration – Summer 2011

Lab. of Functional Performance and Device Use Intern

Worked on the design and evaluation of an instrumented chair, including building the in-amp panel and computer-chair interface, the calibrating of the chair, and the design of the GUI using LabView.

Leadership Organizations:

GWU IEEE - Junior Co-Representative

- Participated in regional conferences, competitions and leadership seminars
- Helped coordinate and run events, including developing advertisements
- Recruited new members

GW Tech Collective - Financial Board Member

- Raised and allocated funds for the organizations
- Helped implement ideas for workshops and projects, including a pumpkin smashing event for charity

GWU ASME - Student Member

- Helped plan for and participated in fundraising events
- Participated in field trips, including visits to the Air and Space Museum and Langley

Technical Skills:

Languages: C, Python

Applications: Microsoft Word, Microsoft Excel, Microsoft PowerPoint, Cadence PSPICE, MATLAB, LabVIEW