Wentworth Institute of Technology

Department of Electrical Engineering and Technology

Research Proposal

Feasibility of Pulse Oximetry Implementation through FPGA Technology

Date of Submission: February 18, 2014

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Abstract

Hard processors such as microcontrollers and digital signal processors are traditionally used in the design of pulse oximetry systems. We propose a soft processor system implemented through field-programmable gate array (FPGA) to enhance the performance of near real-time patient oxygen saturation measurements. An investigation to a FPGA-based pulse oximeter will be conducted with a focal analysis of the advantages that such a system has over traditional ones, evaluating for design flexibility, real-time performance, and system longevity. A pulse oximeter model will be constructed on a FPGA development board for this feasibility research. The evaluation will use industry systems as benchmarks: Microcontroller and digital signal processor-based pulse oximeters that are deployed within Boston, MA's Longwood Medical Area hospitals.

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1 Introduction

Pulse oximetry is a non-invasive medical device that uses photosensors to monitor a persons oxygen levels. The sensor, comprised of light-emitting diodes (LEDs) and a photosensor, is attached to a translucent body part, typically a finger, to capture wavelength absorption changes. These light absorption changes can be used to measure oxygen saturation and heart rate of the individual through their arterial blood, which pulsates with each heartbeat. Pulse oximeters can be found within hospitals as part of a patient vital signs monitoring system.

1.1 Justification of a FPGA System

The current pulse oximetry systems, such as the Masimo SET found within Brigham and Women's Hospital and Boston Children's Hospital, are realized on digital signal processors (DSP) [1, 2]. Other similar systems, such as Covidien's Nellcor, utilize a microcontroller (μC) platform [3, p. 150-151] in their pulse oximeter designs. This proposed study will examine the feasibility of developing a pulse oximeter system on a field-programmable gate array (FPGA) platform, which will allow for a system that is flexible, easily updated post-production, and will have a longer lifecycle than the current μC and DSP pulse oximeters.

1.1.1 Performance

Many devices that require scanning or image processing in the medical field are now moving over to FPGA due to their greater parallel processing capability. This is especially true for medical imaging, which requires a high level of performance during real-time operation. One notable example is Optical Coherence Tomography (OCT), an imaging system which uses light coursing through a patient to create an extremely detailed image reconstruction with a resolution that is higher than the ones that magnetic resonance imaging MRI devices produce [4]. In combination with a quad-core computer processor, these OCTs are used to create a real-time 3-D model.

1.1.2 Regulation Compliance and Minimizing Obsolescence

Besides performance benefits, FPGA offers the ability to perform upgrades during the lifecycle of the system. An oft-mentioned challenge in the medical device industry is Food and Drug Administration (FDA) compliance: The FDA's method of software validation does not include a line-by-line analysis of a medical devices source code [5]. The software code for medical devices typically receives testing that is limited by time. This limitation to thorough testing can become problematic post-shipment. If the FDA decides to implement an adjustment to a regulation that affects a device's compliance, companies are responsible for upgrading their product. On traditional rigid systems, this becomes a burden of cost. By migrating over to a FPGA platform, these adjustments can be accommodated in-field with minimal engineering and manufacturing impact.

1.1.3 Shortening the Design Cycle

A FPGA platform will decrease the time-to-market of a product by reducing reliance on external components. By de-emphasizing individual component integration, designers can focus on developing a device without compromises stemming from any issues with a singular component [6]. Late changes to a devices design can be readily addressed without the need to reconsider the entire system, allowing for an overall faster design cycle.

2 Objectives

The primary focus of this proposed research is to investigate the advantages that a FPGA-based pulse oximeter has over μC and DSP-based systems. The process will include constructing a pulse oximeter on a FPGA development board and evaluating the system by measuring the peripheral capillary oxygen saturation of the researchers. This FPGA-based pulse oximeter will be compared against μC-based systems currently used within Longwood Medical Area hospitals as well as pulse oximeters in possession of Wentworth Institute of Technology's Department of Biomedical Engineering.

1. Investigation of the merits of implementing a pulse oximetry FPGA systems, including:
   (a) Cost-saving benefits.
   (b) Power-consumption reduction.
   (c) Longevity and upgradability.
   (d) Real-time performance.
2. Device will display an accurate numerical percentage of oxygen saturation when the sensor is correctly attached to an individuals finger.
3. Device will perform near real-time analysis of oxygen saturation.
4. Device will include a user interface that will indicate a saturation percentage below a defined threshold.

2.1 Course Requirements

As this research proposal was originally a sophomore-level design project proposal for a 200-level and a 300-level course, the objectives will also incorporate those course's project requirements as secondary objectives. While the constraints for ELEC306 Integrated Circuits with Apps, including op-amps and filters, can be accomplished through standard sensor signal extraction, the constraint for ELEC296 Digital Applications presents a new challenge: Utilization of FPGA technology using VHDL. This constraint will afford the opportunity to investigate the merits of FPGA usage for medical devices.

ELEC296 Digital Applications Project must utilize FPGA, programmed in VHDL.

ELEC306 Integrated Circuits with Apps Project must contain IC components relevant to the course, e.g. op-amps and filters.

2.2 Preliminary Literature Review

The preliminary literature review that was conducted focused on expanding the team's understanding of the principles of pulse oximetry and FPGA technology in the medical industry.

2.2.1 Principles of Pulse Oximetry

Oxygen saturation measurement is a method of determining oxygenation percentage, that is, the measurement of oxygen found within a human's bloodstream based on hemoglobin. Hemoglobin, a protein that transports oxygen, can come in oxygenated (HbO_2) and deoxygenated (Hb) forms. Oxygen saturation is measured as a percentage of HbO_2 in the bloodstream, with 95%-100% values clinically accepted as a healthy patient's normal oxygenation range [7, p. 77]. The arterial saturation, also known as peripheral oxygen (SpO_2), is typically achieved through a medical device known as a pulse oximeter. This is calculated by [8, p. 46],

$$SpO_2 = \frac{HbO_2}{HbO_2 + Hb} \tag{1}$$

Pulse Oximetry: Pulse oximetry is a non-invasive method of monitoring oxygen saturation in arterial blood. This type of medical device utilizes optical sensors containing a grouped pair of light emitting diodes LEDs and a photosensor situated on opposing ends of a patient's thin, translucent appendage [9, p. 2]. This transmission method, shown in Figure 1, allows light to pass through the measurement site before being absorbed by the photosensor.

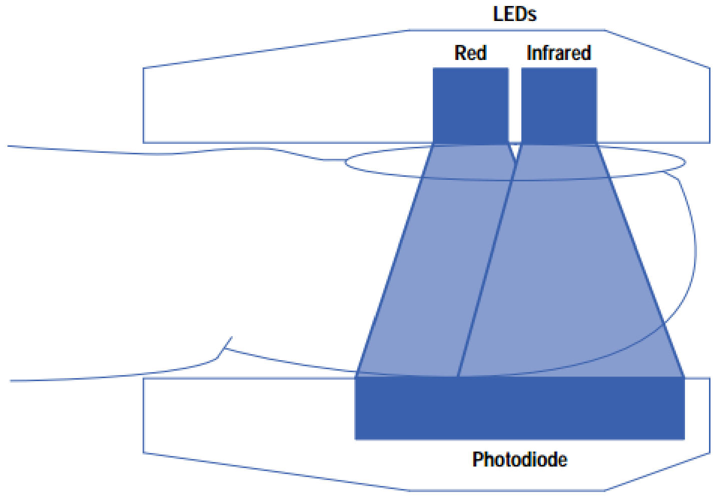

Figure 1: Side view of a finger sensor, from Hewlett-Packard Journal, 1997.

The two LEDs are chosen with wavelength values that absorb HbO_2 and Hb differently: HbO_2 absorbs more infrared (IR) light, and Hb absorbs more red light. A red LED at 660 nm wavelength and an IR LED at 940 nm wavelength are thus chosen.

Beer-Lamberts Law and the Absorbance Ratio: It is necessary to understand Beer-Lambert's law in order to grasp the principle of pulse oximetry. Beer-Lambert's law states that the absorbance of light is proportional to the concentration of the substance which it passes through [10, p. 33]. As long as proportional values are known, this formula can be utilized (see Appendix B for mathematical deductions) in order to find the absorbance of red and IR wavelengths. Once we obtain the red and IR signals, a ratio between the two, R, can be calculated [11, p. 887-888] using,

$$R = \frac{AC_R/DC_R}{AC_{IR}/DC_{IR}} \tag{2}$$

Where:
AC_R is the AC amplitude of the red signal
DC_R is the DC component of the red signal
AC_{IR} is the AC amplitude of the IR signal
DC_{IR} is the DC component of the IR signal
AC and DC is the alternating and direct values of the signals

This ratio is finally matched against a table of empirical formulas, which will return a SpO_2 percentage.

2.2.2 Current Systems

The majority of the pulse oximeters in use around the Longwood Medical Area are designed with μC platforms, along with a few designed with DSP platforms. Solutions such as the Masimo SET and the Philips FASTSpO$_2$ are found within the inpatient rooms of Longwood hospitals, including Boston Children's Hospital and Brigham and Women's Hospital. A typical block diagram of a μC or DSP-based system is shown in Figure 2:

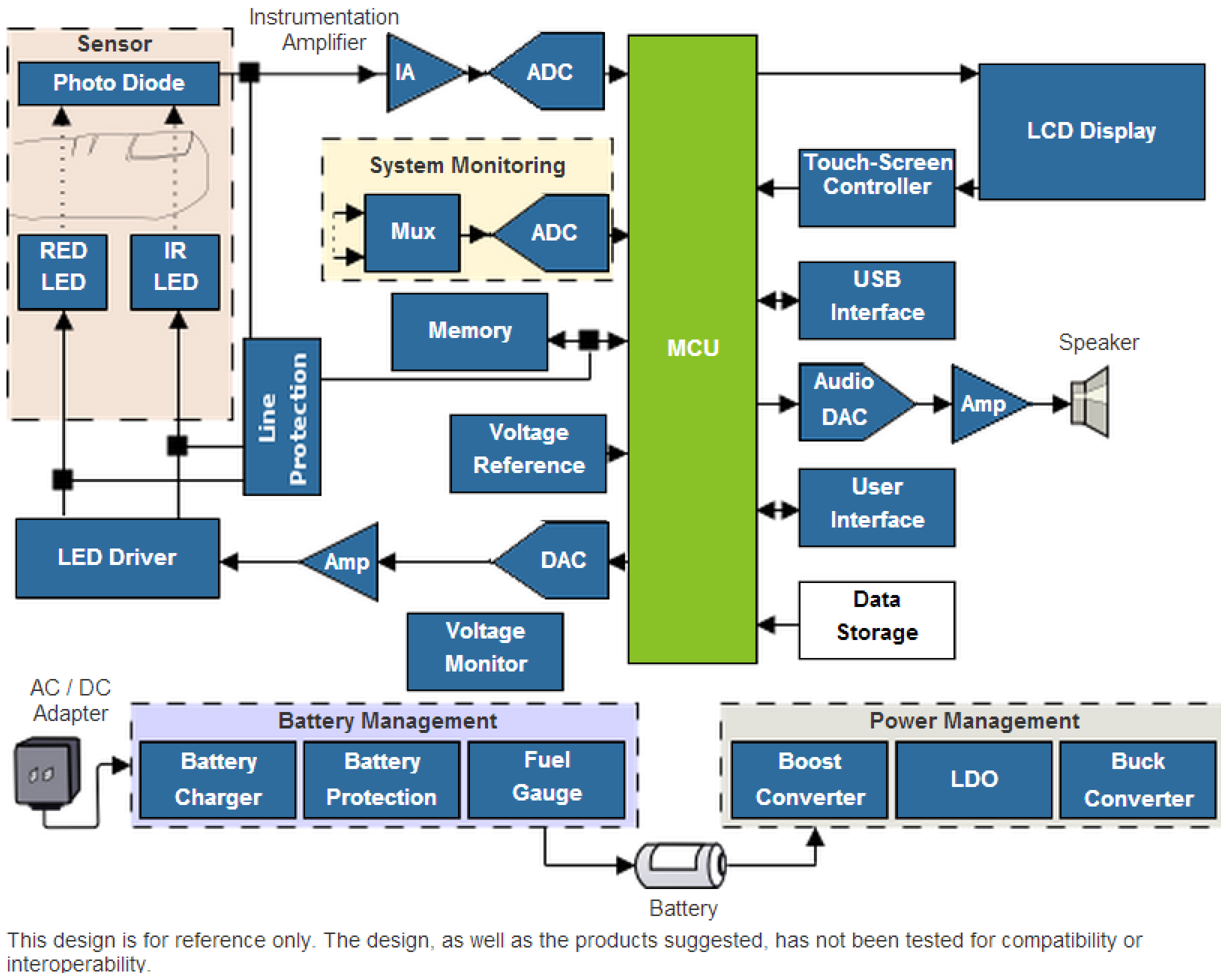

Figure 2: A reference block diagram of a μC or DSP-based pulse oximeter, by Mouser Electronics Medical Applications.

2.2.3 FPGA

FPGA are programmable semiconductor devices that are connected through configurable logic blocks that can be reprogrammed at any instance, including modification of a design after the product has shipped. One interesting factor about FPGA is that they are typically superior over Application Specific Integrated Circuit (ASIC), because no matter how far a design is into the development stage, adjustments can still be executed without a significant increase to the cost. Using FPGA allows the designer to configure digital functions through a Hardware Description Language (HDL).

3 Proposed Concept Overview

The chosen concept, shown in Figure 3 will utilize a commercial Masimo pulse oximeter disposable sensor that will be connected to a custom signal conditioning board. This board will then be connected to an Altera DE2-115 board, where the FPGA implementation will occur.

3.1 Functional Block Diagram

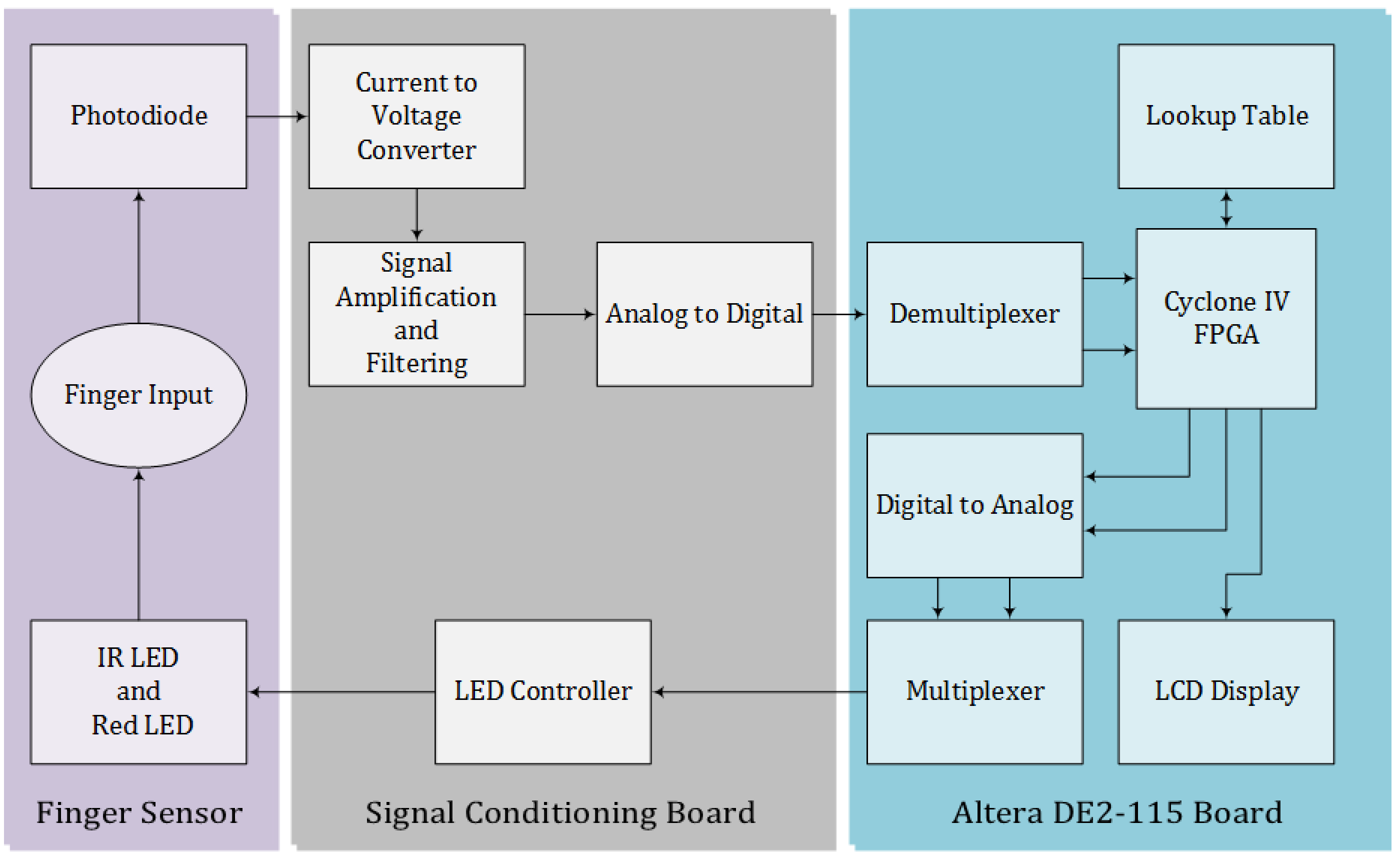

Figure 3: Functional block diagram of the proposed system.

3.1.1 Finger Sensor

The process of selecting a finger sensor was narrowed down to the selection shown in Table 1,

Table 1: Selection for a finger sensor.

Source	Advantages	Disadvantages
Custom built	Cheapest route	Time to build required, greater errors
Masimo disposable	Researcher familiarity	Pinout documentation unavailable
Nonin reusable	Durability is better then others	Expensive
Philips disposable	Newly released to market	Difficulty in obtaining individual units
Nellcor disposable	Faculty familiarity	Limited student familiarity

A review of pulse oximetry studies that compares company technologies largely showed that, although each company's technology has their own advantages, the technology from Masimo, Nellcor, and Philips have similar clinical performance, with no strong and convincing evidence of one technology's individual superiority over the others [12]. Based on these findings and the advantages and disadvantages of our available selection, a choice was made to use a Masimo disposable sensor.

The finger sensor that will be used for this study will be a Masimo LNCS-L Adhesive Sensor, shown in Figure 4. These disposable sensors contain red and IR LEDs, and a photodiode encased in a copper shield. The copper shield protects against electromagnetic interference (EMI), and has a screen to permit light to enter the photodiode. A cable shield begins at the copper shield, wrapping around the wires and terminates at a DB-9 connector.

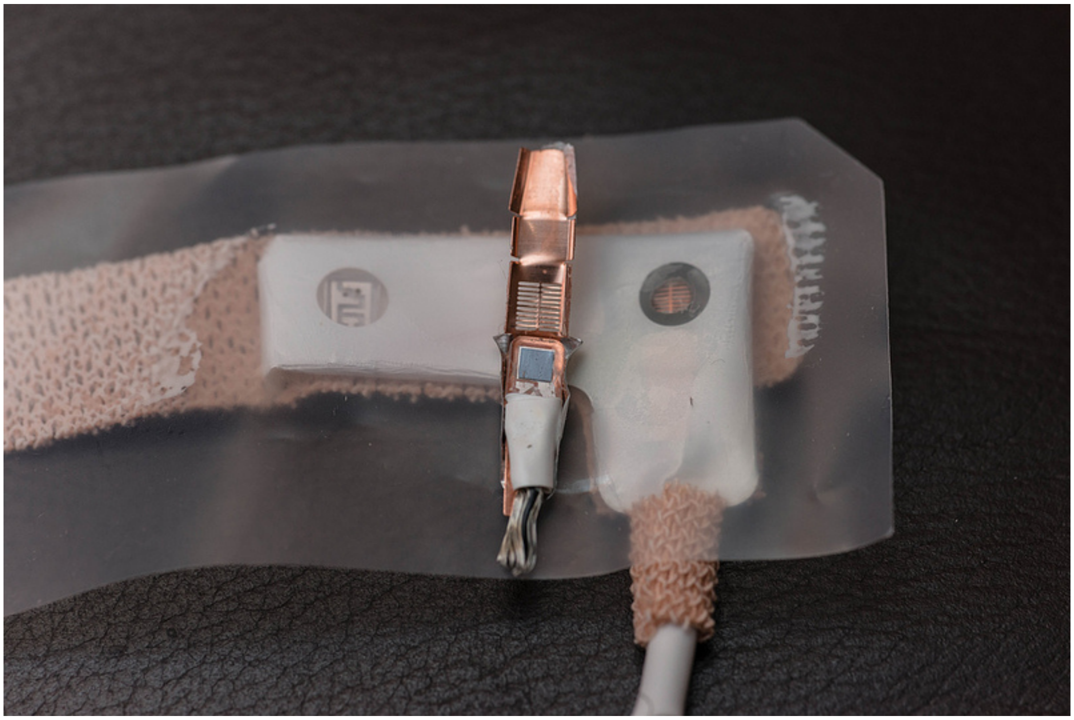

Figure 4: Masimo LNCS-L Adhesive Sensor, overlaid with a duplicate sensors photodiode and copper shield. Photograph by Sze Chau, 2013.

The original plan was to construct a sensor, but this was ultimately abandoned in favor of using a commercial sensor. Inclusion of a commercial sensor will eliminate the amount of time required for the prototyping phase, allowing the team to focus on the challenging aspects of the design. Furthermore, it was discovered during our background research that several faculty members within Wentworth's Department of Electrical Engineering and Technology have experience with interfacing with a Nellcor sensor [13, p. 1] which also terminates with a DB-9 plug. This offers us a strong resources in working with our similar Masimo sensor.

Red and IR LEDs: The LEDs will be chosen by wavelengths based on well-established research: one red spectrum (660 nm), and one IR spectrum (940 nm). These LEDs provide a high wavelength and a low voltage drop. The light absorption through a thin, translucent appendage of a human's body are affected by the concentration of HbO_2 and Hb, and their absorption coefficients will be measured using the two wavelengths of a red LED and an infrared LED.

Photodiode A photodiode is the optimal choice for a photosensor due to their sensitivity to light. In the diode, a transparent window allows light to pass through the package to the diode's pn junction. The more light seen through the junction, the larger the reserve current is in the diode. This current will be picked up by the signal conditioning board.

3.1.2 Signal Conditioning Board

The signal conditioning board will be designed within MultiSim, tested on breadboard, and finally realized on perfboard. A discussion into designing a custom printed circuit board PCB will be initiated during the evaluation phase.

Current to Voltage Conversion: A current-to-voltage converter, also known as a transimpedance amplifier, is one of many applications of an operational amplifier (op-amp). This resistor-feedback transimpedance configuration accepts current rather than voltage at the input terminals. Since photodiodes output a current, this converter take that as an input, and output a proportional voltage. Final selection of the IC op-amp will be made during the literature review phase.

Signal Amplification: At the current stage, the current-equivalent voltage signal, typically in the range of several hundred microvolts, will require amplification in order to detect miniscule changes. This will also be accomplished with an op-amp.

Filtering: Although the Masimo sensor contains shielding properties, the signal will still retain noise stemming from various sources, e.g. EMI from mains power and nearby medical devices. The amplified signal will require multi-stage filtration for elimination of noises with different frequency ranges. The filtering process will include a low-pass filter with the purpose of eliminating high frequency noise. Other stages of the filtering block will be identified during the literature review phase.

Analog to Digital Conversion: An analog to digital converter (ADC) is a component that converts analog data, such as current and voltage signals, into digital data. This conversion will be required before the data can be introduced to the FPGA development board.

LED Controller: A pulse train waveform will be necessary, allowing each LED to be separately switched on in an alternating fashion. This block will drive the LEDs, controlling their intensity. The LED controller block will either remain on the custom board (as shown in Figure 3), or migrate to the FPGA board, to be determined during the literature review phase.

3.1.3 Altera DE2-115 board

The Altera DE2-115 board was chosen as the FPGA platform that forms the basis of the pulse oximeter. This board contains a newer generation Cyclone IV over Wentworth's standard DE2, which contains a Cyclone II [14]. This decision was made to remove the limitation of access to the Altera boards during lab opening hours. In addition, Altera offers more support for their newer generation equipment.

Multiplexer and Demultiplexer: A multiplexer receives multiple input signals and outputs a single signal, whereas a demultiplexer does the exact opposite. Since there is only one photodiode and two LEDs, a demultiplexer will be required to separate the wavelengths. The multiplexer will be used in combination with the LED controller block as a method to input a pulse train to the LEDs. Details of the timing signal multiplexing can be found further below, within the LED Timing Diagram.

Digital to Analog Conversion: A digital to analog converter (DAC) is a component that will convert the FPGA digital data back to an analog signal. The Altera DE2-115 board can perform this task.

Cyclone IV: Cyclone IV provides a low-power and low-cost FPGA functionality. Cyclone IV architecture targets high-volume, cost-sensitive applications, and contains embedded memory and clock management circuitry. Furthermore, the official support for Cyclone IV is stronger than the Cyclone II.

Lookup Table: Once the red and IR signals pass through the demultiplexer block, the development board will then calculate the ratio between the signals. This ratio will then be analyzed against a lookup table of empirical formulas based on clinical studies, and select a oxygen saturation percentage to return.

LCD Display: Liquid crystal displays (LCD) are a flat panel display, consisting of an array of pixels that can be manipulated to present information. These are used for user interfaces to present relevant data from a system. The LCD display on the Altera DE2-115 board will be initially used to display the SpO_2 percentage to the user.

3.2 Software Flowchart

The current software algorithms are broken down into two portions, shown in Figure 5: The main program, and the sensor's sampling flow.

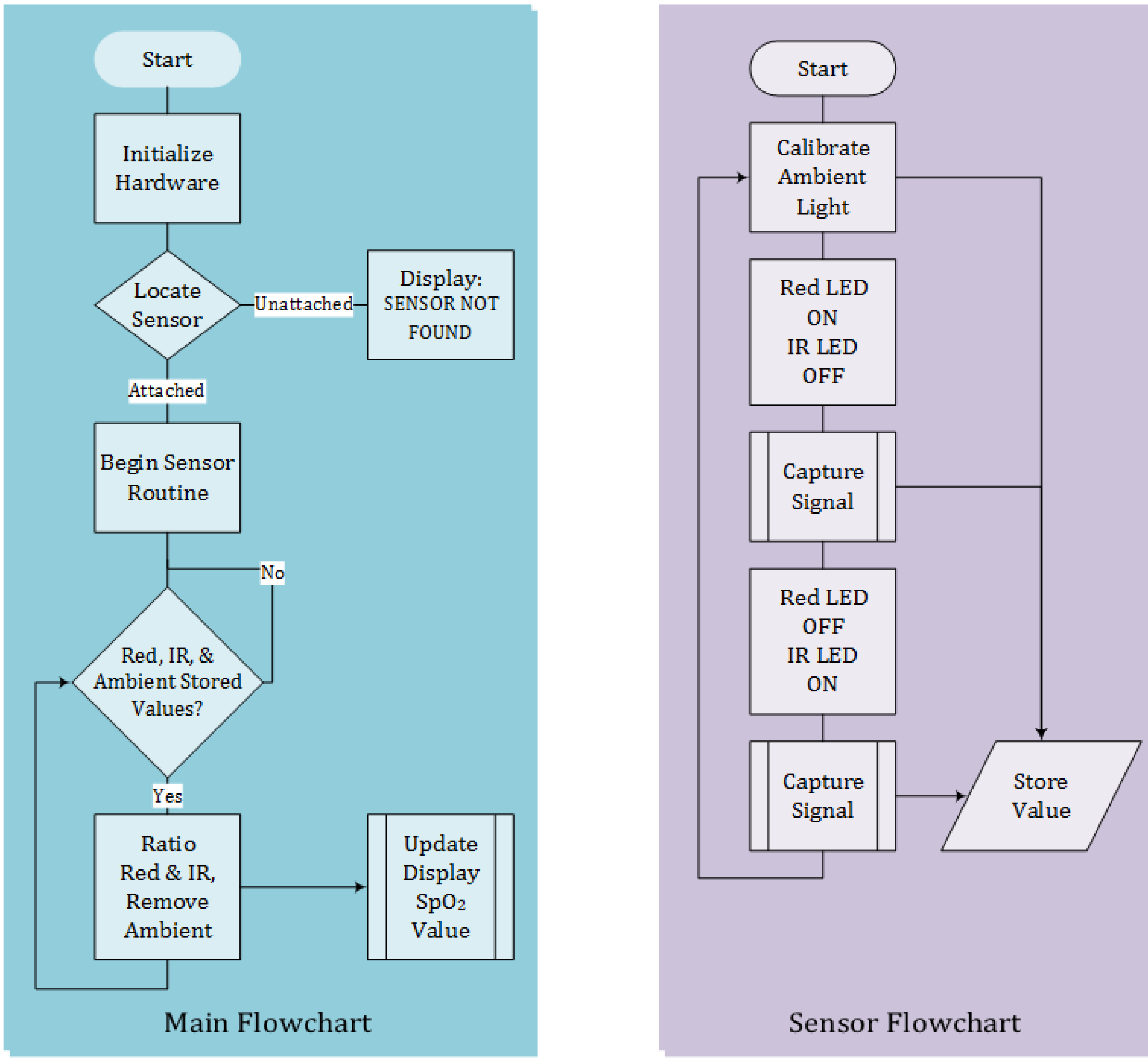

Figure 5: Main and Sensor flowcharts.

3.2.1 Main Flowchart

The beginning of system cycle starts with the hardware initializing. Once this is complete, the system will attempt to locate the sensor. If there is no sensor connected, it will display a message reading, "sensor not found." If a sensor is detected, it begins the signal sampling cycle shown in the sensor flowchart. Once an entire sampling cycle has been completed, the system detects if there is a stored value from ambient and each LED. Once everything is in place, calculations for a ratio between the signals will happen, including the removal of the ambient light sample. This ratio will then be matched up against a SpO_2 percentage, and returned to the user interface. The process is thus repeated, constantly creating new ratios between the red and IR signals until a system shutdown is initiated.

3.2.2 Sensor Flowchart

At the start of the sensor's cycle, a sample of ambient light is first calibrated through the photodiode. This value gets stored in order to be subtracted from the final signal. Once ambient light is captured, the red LED will emit light, repeating the signal extraction process. The red LED will then be turned off, and IR LED will emit light. As with the red LED, a sample will be taken and stored. These samples will then transfer to the main flowchart. The extracted signals are analyzed against a lookup table of empirical formulas that are paired against the ratio of the samples, and the SpO_2 percentage is given to the user interface.

3.3 LED Timing Diagram

Each LED must alternatively emit light at a separate time from each other, with a window of time between one LED turning off and the next LED turning on. This window of time where both LEDs are off is important, as this gap is necessary for separating the ambient light that is seen by the photodiode. Commercial pulse oximeters utilize a timing with shorter ON duration to limit ambient noise. As this type of timing configuration increases the complexity of the signal extraction, the initial timing diagram that was selected evenly portions out the pulses: Each LED will remain ON for 250μS, separated by 750μS in order to allow a 250μS ambient light reading in between each pulse. The result is the timing diagrams in Figure 6.

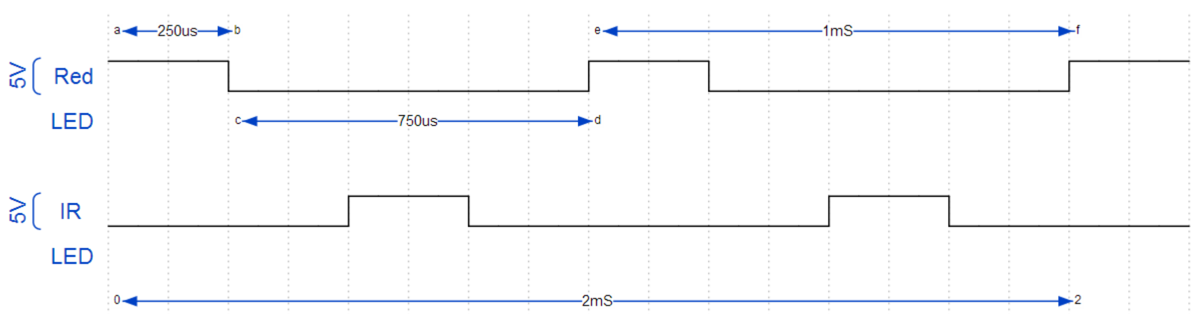

Figure 6: Timing diagram for the LED controller, with a 25% duty cycle at 1kHz for the red and IR LED signals.

3.3.1 Timing Signal Multiplexing

The finger sensor contains two LED signals that needs to be read, but only one photodiode that will receive these signals. In order to sample both signals, multiplexing will need to occur. Multiplexing the signals, as explained in [15, p. 3], will allow a transmission of both LED pulses at the desired timing, interleaving both signals into one. After the photodiode's sampling passes through the signal conditioning board, demultiplexing will occur, separating the red and IR LED samples from each other.

4 Management Plan

The progress of this research will initially be seperated into two distinct iterations based on two major milestones,

1. Semester iteration, ending with the submission of ELEC306's course project final report.

2. Polytechnic iteration, ending with a presentation at Polytechnic Summit 2014.

Currently, only Iteration 1 is scheduled. Iteration 2 will be discussed at the end of the Spring 2014 semester.

4.1 Methodology and Deliverables

ID	Task	Start	Finish	Duration
1	Preliminary Research	1/24/2014	2/14/2014	22d
2	Technical Writing: Proposal	2/9/2014	2/17/2014	9d
3	Proposal Submission	2/18/2014	2/18/2014	0d
4	Literature Review	2/19/2014	3/1/2014	11d
5	Equipment Acquisition	2/10/2014	3/1/2014	20d
6	Empirical Data Formulation	2/20/2014	2/28/2014	9d
7	Prototyping	2/20/2014	3/23/2014	32d
8	Debugging and Troubleshooting	3/1/2014	3/20/2014	20d
9	Evaluation	3/17/2014	3/27/2014	11d
10	Data Analysis	3/20/2014	3/27/2014	8d
11	Presentation Preparation	3/23/2014	3/30/2014	8d
12	Soft Presentation	3/31/2014	3/31/2014	0d
13	Technical Writing: Report	3/27/2014	4/13/2014	18d
14	Iteration 2 Formulation	4/10/2014	4/13/2014	4d
15	Course Report Submission	4/14/2014	4/14/2014	0d

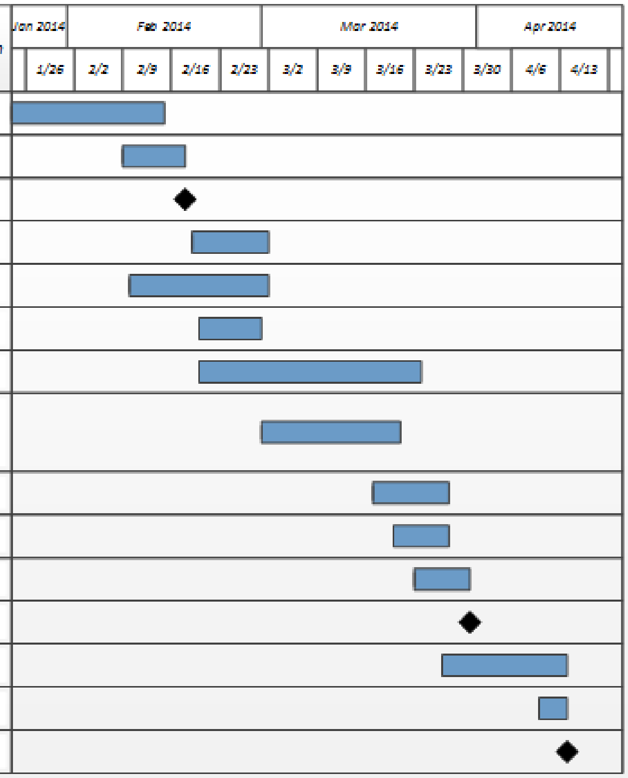

Figure 7: Gantt chart timetable of Iteration 1's phases and milestones.

At the start of the Iteration 1, the team will schedule a weekly meeting to discuss progress and collaborate in tasks. A more thorough literature review will be conducted to ensure the feasibility of our proposed design. This will identify the relevant publications to peruse as well as resources to approach. Component selection will be conducted within this phase. We will also determine the initial algorithms to use for the prototyping process. Once this research process ends, the prototyping phase will begin in earnest. The majority of our team's focus will be on working with the FPGA development board through Altera's Quartus II software. Secondary tasks includes adapting the Masimo pulse sensor for use with the development board. As the team gets comfortable with the syntax and semantics of VHDL, focus will be split between programming and construction of the signal conditioning board. These tasks will continue until a rudimentary prototype is realized.

Once the team builds a rudimentary prototype, the troubleshooting and debugging phase will take over. The algorithms will be streamlined, and the signal conditioning board modified to decrease ambient and movement-related noise. The VHDL code will also be modified within this phase. At the end of this phase, the signal conditioning board will migrate from breadboard to perfboard.

The evaluation phase will utilize μC and DSP-based pulse oximeters that are currently deployed within the Longwood Medical Area hospitals. Specific identification and selection of the benchmark pulse oximeter systems will be conducted during the literature review phase. This phase will provide the majority of the research's objective data.

The final phases will focus on organizing our documentation for review by the supervising professors. Modifications will be made based on the advisement of the supervising professors. After the completion of the presentation and report in Iteration 1, the team will then shift over to Iteration 2, where an increased effort to troubleshooting and evaluation will occur. Iteration 2 will be constrained by the Polytechnic Summit 2014. Iteration 3 will continue Iteration 2's work on the system, including a stronger emphasis on patentability and possible publication of our findings. Another factor of Iteration 3 to consider is developing a novel approach to the signal extraction algorithm.

The initial list of deliverable items that will be generated over the course of this research, shown in Table 2, has only been identified up to Iteration 2.

Table 2: Initially identified deliverables, seperated by Iteration.

Item	Type	Iteration
Soft presentation	Powerpoint	1
Course final report	Written report	1
Proof-of-concept	Physical	1
Polytechnic presentation	Poster	2

4.2 Cost Analysis

The current cost analysis contains a rough initial estimate of most components. The actual cost, however, is expected to remain ± \$50.00 within the estimated total cost for Iterations 1 and 2.

Table 3: Bill of Materials

Component					
Name	Source	ID	Cost $	Qty.	Total $
Board, DE2-115 Cyclone IV	Terasic	P0059	300.00	1	300.00
Book, Design of Pulse Oximeters	Amazon	0750304677	164.49	1	164.49
Breadboard, Solderable	Sparkfun	PRT-12070	5.00	1	5.00
Connector, 2x5 Breadboard	Sparkfun	PRT-10965	0.95	3	2.85
Capacitor, 0.1μF	Mouser	581-SA105E104M	0.10	15	1.50
Capacitor, 10μF	Mouser	74-173D106X9020WWE3	1.88	10	18.80
DB9 Connector, Female	Sparkfun	PRT-11157	2.00	3	6.00
HDL Coder	MATLAB	-	-	1	-
Op-Amp, 0.05μV	Mouser	595-OPA335AIDBVT	3.05	6	18.30
Op-Amp, 2μV	Mouser	595-OPA333AIDBVT	3.16	3	9.48
Op-Amp, ADC	Mouser	700-MAX11628EEE+	4.36	2	8.72
Op-Amp, Transimpedance	Newark	75C52222	7.09	2	14.18
Resistor Kit	Sparkfun	COM-10969	7.95	1	7.95
Sensor, Pulse Oximeter	Masimo	LNCS Neo-L	10.00	3	30.00
Ribbon Cable, 10 Wire	Sparkfun	CAB-10649	1.00	2	2.00
			Total Cost $		589.27

4.3 Qualifications and Responsibilities

This project will be carried out by a team of 3 students under the guidance of Professor Decegama and Professor Zaman within the Department of Electrical Engineering and Technology. While every team member are expected to contribute towards all portions of the project, ownership of specific sections will be assigned to individual members to ensure success.

4.3.1 Sze "Ron" Chau

Ron has over half a decade's worth of healthcare experience in direct patient care, and he brings that perspective to this project. In addition to his coursework, Rons experience in the electronics field includes projects realized on Arduino, Atmel μCs, LabVIEW, and the Raspberry Pi development board. Ron is also the Co-Founder of Modular Branch System, a medical device startup that began with funding from Wentworth's Accelerate program. He is currently studying for his Bachelor of Science in Electronic Engineering Technology.

Ron's individual contribution:

1. Team leader and point-of-contact to coordinate with all involved parties

2. Analog circuitry
3. FPGA development
4. Signal conditioning

4.3.2 Connor Marks

Connor's experience through his undergraduate engineering courses has given him an understanding of Altera FPGA technology, with familiarity in block diagram and VHDL. He has also worked on design projects using MATLAB and analog circuitry, knowledge which will be utilized for the research ahead. The Secretary for Wentworth's IEEE chapter executive board, Connor is committed to his work and leadership responsibilities. He is currently studying for his Bachelor of Science in Electronic Engineering Technology.

Connor's individual contribution:

1. Budget management
2. Algorithm design
3. MATLAB simulation
4. VHDL implementation

4.3.3 Jenny Tran

Jenny's experience includes work on FPGA development boards, in block diagram and VHDL programming, through Altera's Quartus II environment. Some of her projects includes working with Arduino, display interfaces, op-amp configuration, and various measurement sensors. Of note, her freshman-year design project, "Electronically Assisted Remote Height Measurement", was presented at the 2013 Polytechnic Summit Conference. Jenny serves on the executive board of Wentworth's IEEE chapter as the Advertising and Marketing Officer, and leads their VEX Robotics Team. She is currently studying for her Bachelor of Science in Electronic Engineering Technology.

Jenny's individual contribution:

1. Timeline management
2. Hardware-software integration
3. Test and debugging
4. User interface experience

4.4 Communication and Coordination

The main files for this research will be located within a solid state drive on Ron's Wentworth-issued laptop under 'D:\WIT Docs\Sophomore'. The master copies of the reports will be typesetted within LaTeX and saved as a Portable Document Format (.PDF), and the on-going drafts will be shared on Google Drive. Dropbox will also be utilized for storing and distributing large files, and GitHub for managing VHDL code.

The undergraduate participants will meet at minimum once a week in relation to research topics. Skype video conference will be used for additional meetings. Wentworth e-mail will be used for circulating agendas and memos.

Communication with the supervising professors will consist of a weekly meeting and progress memos circulated through Wentworth e-mail.

5 Risk Assessment

This feasibility study is not without potential risks that are technical in nature. These are highlighted within this section along with a plan of addressing each risk.

5.1 Identification

1. VHDL: Although every team member has a passive familiarity with programming in this language through their coursework, the level of knowledge that will be required for implementing a pulse oximetry system is substantially complex.

2. Signal Conditioning: The benchmark systems that the study plans on using during the evaluation phase are commercial pulse oximeters with proprietary algorithms. This means that any algorithm that is used will be different from the benchmark systems.

3. Lookup Table: The lookup tables of the benchmark systems contain empirical formulas based on the manufacturing company's clinical studies.

5.2 Mitigation

1. VHDL: During the literature review phase, each team member will devote time to peruse texts on this subject in order to gain a better understanding of the language. Tools such as MATLAB's HDL Coder will also be considered for use to minimize the complexity of implementing the FPGA portions of the system. We will also utilize the faculty members within the Department of Electrical Engineering and Technology that has worked extensively with the Altera development platforms.

2. Signal Conditioning: The evaluation phase will be organized by limiting the comparison to healthy human volunteers during low-ambient, motionless measurements. By

isolating it with these constraints, the evaluation will remove focus from noise-related comparisons.

3. Lookup Table: Our system's lookup table will use Beer-Lambert's law to obtain SpO_2 percentages, based on the measurements of the team members. By utilizing a lookup table that only uses the data obtained from the teammates, we will ensure minimal discrepancies during the evaluation phase. As we arrive to Iteration 2-3, a new plan of attack will be formulated, with an emphasis of improving the algorithms involved.

A
Supervision Agreement and Résumés

This appendix contains the signed research supervision agreement form between the overseeing professors and researchers. Included after the agreement form are the résumés of the undergraduate students that are involved in this research project.

Wentworth Institute of Technology

Department of Electrical Engineering and Technology

Proposal for Undergraduate Research in Partial Fulfillment

of the Requirements for the Degree of Bachelor of Science in Electronic Engineering Technology

Title: Feasibility of Pulse Oximetry Implementation through FPGA Technology

Submitted By:

Sze Chau
[redacted]

3/6/14
S. Chau, BEET '16
(Signature and Date)

Connor Marks
[redacted]

3/6/14
C. Marks, BEET '16
(Signature and Date)

Jenny Tran
[redacted]

3/6/14
J. Tran, BEET '16
(Signature and Date)

Hard processors such as microcontrollers and digital signal processors are traditionally used in the design of pulse oximetry systems. We propose a soft processor system implemented through field-programmable gate array (FPGA) to enhance the performance of near real-time patient oxygen saturation measurements. An investigation to a FPGA-based pulse oximeter will be conducted with a focal analysis of the advantages that such a system has over traditional ones, evaluating for design flexibility, real-time performance, and system longevity. A pulse oximeter model will be constructed on a FPGA development board for this feasibility research. The evaluation will use industry systems as benchmarks: Microcontroller and digital signal processor-based pulse oximeters that are deployed within Boston, MA's Longwood Medical Area hospitals.

Preliminary Keywords: *Biosensors, FPGA, Patient monitoring, Pulse oximetry, Real time systems*

Supervision Agreement:

The program outlined in this proposal is adequate for an Undergraduate-level research project. The supplies and facilities required are available, and I am willing to oversee the research, advise the participants, and evaluate the project.

03-06-14
A. Dedegama, Asst. Prof. of Elec. Eng. and Tech.
(Signature and Date)

3/6/2014
H. Zaman, Asst. Prof. of Elec. Eng. and Tech.
(Signature and Date)

Sze "Ron" Chau

[redacted]

Education

Expected Graduation August 2016 **Wentworth Institute of Technology**, *Boston, MA*,
Bachelor of Science in Electronic Engineering Technology.

Skills

Programming Arduino, C, LaTeX, MATLAB, Python: SimpleCV Framework, VHDL

Software AVRDude, LabVIEW, Multisim, Notepad++, PSpice, Quartus II, SolidWorks, Visual Studio

Laboratory Soldering, Oscilloscope, Function Generator, Digital Multimeter, Logic Probe

Language Conversationally Fluent: Cantonese Chinese, Mandarin Chinese

Healthcare Cerner PowerChart, Philips IntelliVue Monitoring Network

Projects

Spring 2013 **Freshman Project Leader**, KIWI OBSERVATION SYSTEM, Wentworth Institute of Technology.
- Designed a field-use device that autonomously identifies, weighs, and photographs Little Spotted Kiwi birds.
- A first-year Electronic Design course project that utilized the Arduino platform; the Raspberry Pi development board; and SimpleCV, a computer vision framework for Python.

Fall 2013 **Personal Project**, SUNRISE ALARM CLOCK, Newton, MA.
- Modification of an alarm clock by adding LED strips that ramps up in brightness prior to the audible alarm.
- Adjustments to brightness intensity is accomplished by using an ATmega328 microcontroller for pulse width modulation of the LED strips.

Leadership

2013-Present **Co-Founder**, MODULAR BRANCH SYSTEM, Boston, MA.
- Invented a medical device that minimizes mechanical obstructions occurring in intravenous and enteral lines.
- Successfully pitched for funding at Wentworth's innovation and entrepreneurship program, and currently in the proof of concept prototype phase.

Professional

2010–Present **Clinical Assistant II**, BOSTON CHILDREN'S HOSPITAL, Boston, MA.
- Provide patient care under the delegation of the Clinical Care Team on an Inpatient Medicine Unit (gastro/pulmonary) and the Intermediate Care Program (acute care, step-down ICU).
- Assist Staff Nurses during bedside interventions, and Physicians and Technicians during medical and minimally invasive procedures within various departments, e.g. Fluoroscopy, Interventional Radiology, and Ultrasound.

Detailed Achievements:
- Promoted during the first year due to an ability to acquire and instruct new skills to peers, a capability to triage tasks on fast-paced units, and for having an aptitude for "seeing the big picture."
- Preceptor for 40+ staff members, some with no prior clinical experience, to an intensive, multidisciplinary, inpatient environment.
- Assist Unit Nurse Managers with transforming care at bedside by advocating for the Clinical Assistant's role within Inpatient Medicine Units.

Military

2004–2006 **Infantryman**, UNITED STATES ARMY, JFK Special Warfare Center & 82nd Airborne Division.

Connor G. Marks

[redacted] E-mail: marksc2@wit.edu Phone: (603) 370-9759

EDUCATION:

Wentworth Institute of Technology, Boston, MA — Exp. Graduation August 2016
Bachelor of Science in Electronic Engineering Technology
GPA 3.55/4.0
Merit Scholarship Recipient

TECHNICAL SKILLS:

Engineering: Analog and Digital Circuit Design, Building and Testing Circuits, Robotics
Software: Multisim, PSpice, Quartus II, MATLAB Simulink, SolidWorks, C Programming Language, Windows XP/Vista/7, Microsoft Office (Word, Excel, PowerPoint, Outlook, Visual Studio), RobotC
Hardware: Oscilloscope, Function Generator, Digital Multimeter, Power Supply, Altera's Cyclone II

COURSE WORK:

Integrated Circuits	Digital Applications	Computer Science I/C
Calculus II	Electronic Design	Circuit Theory II

ENGINEERING WORK:

Electronic Design: Created and implemented camera based system using MATLAB and computer vision to calculate weight of an object from an image
Semiconductor Devices: Designed and created an AC to DC converter using discrete components
Personal: Repair Xbox 360 Red Ring of Death, and PlayStation 3 Yellow Light of Death

LEADERSHIP EXPERIENCE:

Secretary for Wentworth Institute of Technology IEEE Chapter — December 2013 - Present
Wentworth Admissions Office Campus Tour Guide — April 2013 - Present
Wentworth Leadership Institute Phase I and II — February 2013 - Present

WORK EXPERIENCE:

Tip Tap Room | Boston, MA — January 2014 - Present
Bar Back

- Retrieve alcohol for bartenders
- Set up bar before night shift then clean at the end of the night

Wentworth Learning Center | Boston, MA — September 2013 - Present
Tutor

- Assist students with the understanding of Circuit Theory (I, II), Calculus I, Physics I, and other lower level math courses

Levasseur Electrical Contractors | Manchester, NH — June 2012 - Present
NH Licensed Electrical Apprentice

- Drive stock
- Wire both residential and industrial jobs
- Install electrical equipment

VOLUNTEER SERVICE:

Assisted with VEX middle school competition — January 2014

- Assembled and set up VEX fields
- Checked in middle school students and created competition bracket

Assist with annual town Historical Association "Duck Race" — September 2010 - Present

- Set up tents and tables
- Assist with concession sales

JENNY TRAN

[redacted]

[redacted] | Email: Tranj5@wit.edu

Website: http://sites.google.com/site/witjennytran/ | Linkedin: www.linkedin.com/in/tranj5/

EDUCATION

Wentworth Institute of Technology, Boston MA — Expected Graduation: August 2016

Bachelor Science, Electronic Engineering Technology — Dean's List: 1/3 semester

Overall GPA: 3.43/4.0

COURSE WORK

Electronic Design, Circuit Theory II, Semiconductor Device, Digital Applications, Integrated Circuit with Application, Logic Circuit, Introduction to Engineering and Technology, Computer Science using C, Calculus II and Physics II

SKILLS

Electronic: MultiSim, Circuit Board, Pspice, Quartus, MatLab, Soldering, Digital Multimeter**,** Minty-Boost (Battery charger), Altera D32 Board

Robotics: Vex Robotics, NXT Lego Mindstorm Robotics, Programming, Building prototypes, Dremeling

Design: SolidWorks, Web Design, Logo making, Adobe illustrator , Window Movie Maker

Languages: C, HTML/CSS, RobotC, Easy C, English, Vietnamese

Computer: Window 7/XP/Vista, Microsoft Office Suite (Word, Excel, PowerPoint, Publisher, Visio, Outlook, OneNote), and Microsoft Visual Studio

Other: Project management, Costumer Services, Advertising

PROJECTS/COMPETITIONS

VEX U Robotics Competition (WIT IEEE) – ***WIT IEEE VEX Team Leader & Liaison*** — January 2014

- Won VEX U competition with the highest score in the University Division; Qualified for the World Championship in Anaheim, CA
- Utilizing Vex Parts and Easy C programming to build two VEX robots for the VEX U Toss up competition.

NXT Mindstorm Robot Competition (WIT IEEE) — November 2012

- Built and programmed NXT robot using RobotC and competed against other IEEE member's teams on a track.

LAB EXPERIENCES/PROJECTS

AC to DC Power Supply — Fall 2013

- Consist of semiconductor components (a bridge rectifier, capacitor input filter, step-down transformer, silicon and zener diodes)

Electronically Assisted Remote Height Measurement Device (Freshman Design) - *Polytechnic Summit Conference (Wentworth)* — June 2013

- Presented an informative poster on a group design project on Electronically Assisted Remote Height Measurement at the poster session of the conference. (http://www.polytechnicsummit.org/Polytechnic-Summit-2013.pdf)
- Using an Arduino, Ultrasonic sensor, potentiometer and more. Through the use of this device multiple measurements taken by the ultrasonic sensor were converted by the Arduino and displayed on an LCD.

WORK EXPERIENCES

Information Hub Manager *(*Wentworth Institute of Technology's Flanagan Campus Center – Campus Life) — January 2014 - Present

Provide information regarding campus, events, information and resources to Wentworth students, being a resource to Info Hub Attendants, do condition reports, and manage info hub customer service.

Information Hub Attendant (Wentworth Institute of Technology's Flanagan Campus Center – Campus Life) — September 2013 – December 2013

Provide information about the campus, sales, events, and costumer services to Wentworth students, families, and staff. Make tickets orders; manage pool room materials and campus material available to students.

Worcester Trial Court's District Attorney Intern (Worcester Community Action Council) — July 2012 - August 2012

Created summons, duplicate files, retrieve and file paperwork while learning about law enforcement.

VOLUNTEER EXPERIENCES

VEX Tournament Volunteer (Worcester, MA) – ***Vex Referee and Head Referee*** — November 2013- February 2014

Assist Vex Coordinator of Worcester and the REC Foundation run the VEX Robotics Competitions.

ACTIVITIES/INVOLVEMENTS

Wentworth's Institute for Electrical and Electronic Engineers (Wentworth IEEE) - (http://wit.orgsync.com/org/witieee) — September 2012 - Present

- ***Executive - Board Position: Marketing and Advertising Person*** — September 2013 – Present

  Update and designed Wentworth's IEEE website and logo and design posters and flyers about WIT IEEE, club events, and fundraising events.
- ***Leader and the Liaison of WIT IEEE VEX Robotics Team*** — September 2013 - Present

B
Mathematics

Beer-Lambert's law states that the absorbance of light is proportional to the concentration of the substance which it passes through [10, p. 33], given as,

$$I_o = I_{Ne^{-\epsilon c L}} \tag{3}$$

where:
I_o is the intensity of the light transmitted through the substance
I_N is the intensity of light entering the substance
ϵ is the absorption coefficient
c is the concentration of the substance
L is the optical path length

Absorbance, A, can be defined as,

$$A = \ln(\frac{I_o}{I_N}) \tag{4}$$

furthermore implying that absorbance is linear with concentration,

$$A = -\epsilon c L \tag{5}$$

thus,

$$A = \ln(\frac{I_o}{I_N}) = -\epsilon c L \tag{6}$$

which tells us that Beer-Lambert's law can be utilized to calculate an unknown concentration, provided that A is measured, and ϵ and L are known.

References

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