Indocyanine Green Fluorescence Intensity Sensor Array

GROUP E

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1 Executive Summary

This project is meant to design a biomedical sensor to read the fluorescence of indocyanine green in a patient. The sensor will emit a certain wavelength to react with the indocyanine in the bloodstream, collect the fluorescence at a different wavelength, and interpret the data to display on a graph. The sensor portion of the project itself will consist of an LED as the emitter and a photodiode as the collector. A filter will be placed on the collector in order to avoid as much unnecessary noise as possible. The signal from the photodiode will be sent to a microcontroller’s analog input to be analyzed. The output of the microcontroller will go to a LCD screen to be displayed as an intensity versus time graph so the user can easily read the information presented by the sensor.

The primary motivation for the design and implementation of this biomedical sensor is to help people. Helping advance society and keeping life easier and safer is an integral part of being an engineer. There could come a point in the future where this sensor is used in surgery to give important information to the surgeon. Another possibility is that it joins in with the pulse oximeter as a piece of equipment that remains with most all patients in their rooms at a hospital. The potential for this project is unknown yet vast. All members wanted to do something that could eventually be used to help society while also teaching each member an important lesson in the ordering and use of various pieces of hardware and the programming and application of software. The project itself has been quite a gamble due to the unknown nature of what purpose it will serve in the future. A dive into this mysterious abyss has also served as an integral part of the group's desire to continue on and figure out how to make the sensor work properly.

One of the most time consuming portions of this project came in the research portion. Figuring out the wavelengths necessary to get a fluorescing dye along with understanding the properties of indocyanine green itself took a substantial amount of time to realize. The sources for this research came primarily from two places: the first are various websites and the second is the sponsor of the project, Dr. Looke. The websites consisted of various data sheets, schematics, user manuals, and documentation from prior senior design projects.

It is important to note that the software portion of this design project appears to be more intense and extensive than originally anticipated. An understanding of how to interact an LCD screen with the chosen microcontroller, the MSP-EXP430G2, must be known along with a program that understands how to interpret the data being sent from the collector. The software is going to give a magnitude of the dye being read, along with updating points at consistent intervals to be displayed on a graph. Also, depending on what information is most important, the microcontroller is going to have to find the area under the curve of the constantly updating graph or find the slope of recent points being analyzed, whichever is found to be more important.

2 Project Description

2.1 Project Motivation and Goals

The motivation for creating a biomedical sensor lies in an innate drive to help people if at all possible and it will prove as a good project to add to a resume. The group began with one member having talked to a man named Doctor Looke who is both a medical doctor and electrical engineering PhD. In discussions with this doctor it was made known that he was interested in UCF electrical engineering students who were beginning Senior Design I. Two offers were made to the group; one offer was to create a waistband for surgeons to know if something was wrong with the patient during surgery without having to look at the monitors, and the second was a biomedical sensor idea for reading indocyanine green.

A key factor in choosing this project is intrigue into the unknown. While it is known that the fluorescence of indocyanine green can be used to find healthy tissue which can then be used to replace removed or unhealthy tissue in plastic surgery, it is unknown what exactly the amplitude, or rather intensity, of the fluorescence might actually mean. Typically the dye is used for imaging rather than as a numerical magnitude or time vs. amplitude graph. The main motivation and goals for individual parts of the project are as follows:

Positioning – interestingly enough, this sensor could eventually be proved useful in hospital environments and give important information out to doctors and nurses. In order to have a higher possibility of such a future, it would likely have to be piggybacked onto an existing device or sensor. The pulse oximeter, which is very commonly used and goes on the finger, is the device/sensor which this is intended to be piggybacked onto. This is why the finger is one possibility of where the sensor might be placed. Due to possible complications with sharing of power, interference of signals, and the challenge of creating a reasonably sized sensor, this sensor's focus will not currently be on compatibility with the pulse oximeter. Rather, the sensor will be focused more on being placed somewhere flat on the body.

Casing – since the senior design group working on this project consists entirely of electrical and computer engineers the casing will be plain and simple. What is important with the creation of this case is that no light will be able to come in from the sides. The allowance of light from the outside into the sensor area could easily cause erroneous results. There is some lenience here since during the application and reading of this dye currently, doctors and nurses already know to dim the lights in the room in order to avoid interference with sensor readings. Another important point to mention is that this sensor will be tested on synthetic skin, muscle, and blood. Setting up a case that lies on a flat surface would make testing of the sensor much simpler to do. Also, to keep light from entering around the edges where the case touches the skin of the patient, electrical or medical tape should be applied to keep light out and avoid these inaccurate readings.

Powering – for the sake of being convenient and possibly used in future circumstances in hospitals, the sensor, microcontroller, and LCD screen will all be powered by a rechargeable battery. Currently, almost all equipment in an operating room is powered via batteries. So long as the battery can be recharged in a charger connected to a wall socket, the device will be considered practical and easy enough to be used in hospitals.

Filtering – being harmful or a threat in any way to anyone is by no means a goal in this project. In order to avoid causing any harm to the patient, filtering is necessary in this project. As it turns out, applying ultraviolet light to indocyanine green actually causes the dye to split into quite literally unknown substances which may or may not be considered harmful to the body. The filtering of ultraviolet light is of utmost importance in this project so as to avoid causing any kind of harm to anyone and to avoid lawsuits. By choosing an LED with a narrow band wavelength, the dangers of working in the ultraviolet range of been eliminated. The collector must be filtered so that only the fluorescence of the indocyanine green is read and not the light coming from the emitter.

Microcontroller – being electrical and computer engineering students, embedded systems was a class the entire senior design group had to take. The MSP430FG4618 was the microcontroller used in labs that the group had experiment with using. For practice at home the MSP-EXP430G2 was bought by numerous students and is easily accessible and found on the UCF campus. Due to the convenience of the part, already having practiced with the device, the more than enough computing power of the microcontroller, and its ability to communicate with a photodiode, the MSP-EXP430G2 was chosen as the best microcontroller for the job.

Monitor – the project is not of much use without some method for displaying reading received from the dye. If this truly is to be used by doctors and nurses in hospitals, the information should be easy to read and understand. Little is simpler than a monitor which merely displays a number representing the amplitude of the fluorescence. This is why the display will show a number on the top right corner. Once again, it is not known whether the magnitude of the dye is important or not, but if it is then the display is already set up to show it. The main feature of the LCD is going to be a graph. The data points will be shown graphically on an intensity versus time graph. It is unknown which aspect of the curve will be most important, however it is speculated that the area under the curve or the slope of it at various points may in fact be the most important aspects of the sensor's readings.

In conclusion, this device may one day pose as an important addition to any operating room during surgery. Due to the unknown potential of this project and the possibility of one day helping people, the senior design group unanimously agreed upon taking on this endeavor. While the waist-band idea was also possible, other universities and senior design groups have already begun research and work in the area, so the feeling of true innovation would have been lost. Due to the complexity of programming and testing the device, the idea of feedback from the output of the sensor has been dropped. In the future it is possible that feedback and a device that increments or decrements respectively the injection of indocyanine green into a patient's body based on that feedback may be created, however that will not be the focus of this project.

2.2 Objectives

The sensor will have a number of objectives that are going to have to be accomplished. Fortunately, through the objectives process money will not be an issue; the sponsor of this project will be more than capable of covering any costs this project might require. The main objective for this project is to simply attain a reading that alters based on whether or not there is indocyanine green present. This objective can only be obtained if the following criteria are met:

Limited Range Emitter – the LED must be working in the proper wavelengths necessary to cause a fluorescing reaction from the dye. Also, the LED cannot be emitting at the ultraviolet wavelength range in order to maintain safety for the use of the ICG (indocyanine green).

Accurate Collector – all values from the photodiode must be accurate and sensitive enough to note changes in the fluorescence of the dye. Along with the collector comes the filter. Any unnecessary signals coming from other wavelengths must be filtered out so that the information gathered is as accurate as possible. The output will be altering in the form of current which can then be transferred into voltage with the use of a resistor. This output will be what this entire project is based around.

Simple Casing – in order to help keep the input accurate, the case needs to be able to keep out as much light in the near infrared range as possible. Using medical tape around the edges of the casing where the sensor is placed on the patient, for example, might be enough to keeping readings from being interfered with. The case itself will have to be completely solid and opaque to keep all unwanted light out as well. Simplicity is necessary since the group has very limited knowledge in the realm of mechanical engineering.

Battery Powered – operating rooms in hospitals are generally filled with nothing but equipment which is quite unanimously battery powered. Keeping an environment that the doctors and nurses are well acquainted with could be very important to maintain a comfortable atmosphere and bypass any learning curve having to do with using this new sensor. The battery must last long enough to be able to power the entire sensor setup throughout the length of a whole surgery or at least for the duration that the indocyanine green is in use. The battery must provide sufficient power to turn on the LED, microcontroller, and LCD screen. Being rechargeable from a wall socket is also important since that is how other equipment is recharged in operating rooms.

MSP-EXP430G2 – the microcontroller must have enough computing power to output a number onto a magnitude versus time graph. There must be enough memory so that it can remember a minimum of a screen’s length worth of data points. The controller has to be small so it is not a problem space-wise in the operating room and could be fit wherever the doctors and nurses want. An analog to digital converter will also be needed in order to translate the output coming from the photodiode collector into digital data that the microcontroller can then compute and the LCD screen display.

LCD Screen – compatibility with the MSP-EXP430G2 is important along with being simple enough to look at and understand. The size must be large enough to be easily read and bright enough to be seen in a dim room. This is likely going to be the most expensive portion of the project, so it is important to keep the cost of the screen low.

Division of Responsibilities

Chris	Daniel	Steven	Tuyen
Power Systems	Microcontroller	Emitter	Microcontroller
Miscellaneous	Display	Collector	Display
Project Tracking	Software	ICG Research	Software
	Verification Testing		

Table 1: Division of Responsibilities

2.3 Project Requirements and Specifications

After the objectives and goals have been established for the biomedical sensor and accompanying equipment, hardware and software requirements and specifications were figured out as more information was gathered about the various parts. Having a general idea of how to organize the creation of this project is very important to figuring out what is necessary to make the sensor possible. Research is a key aspect for this section.

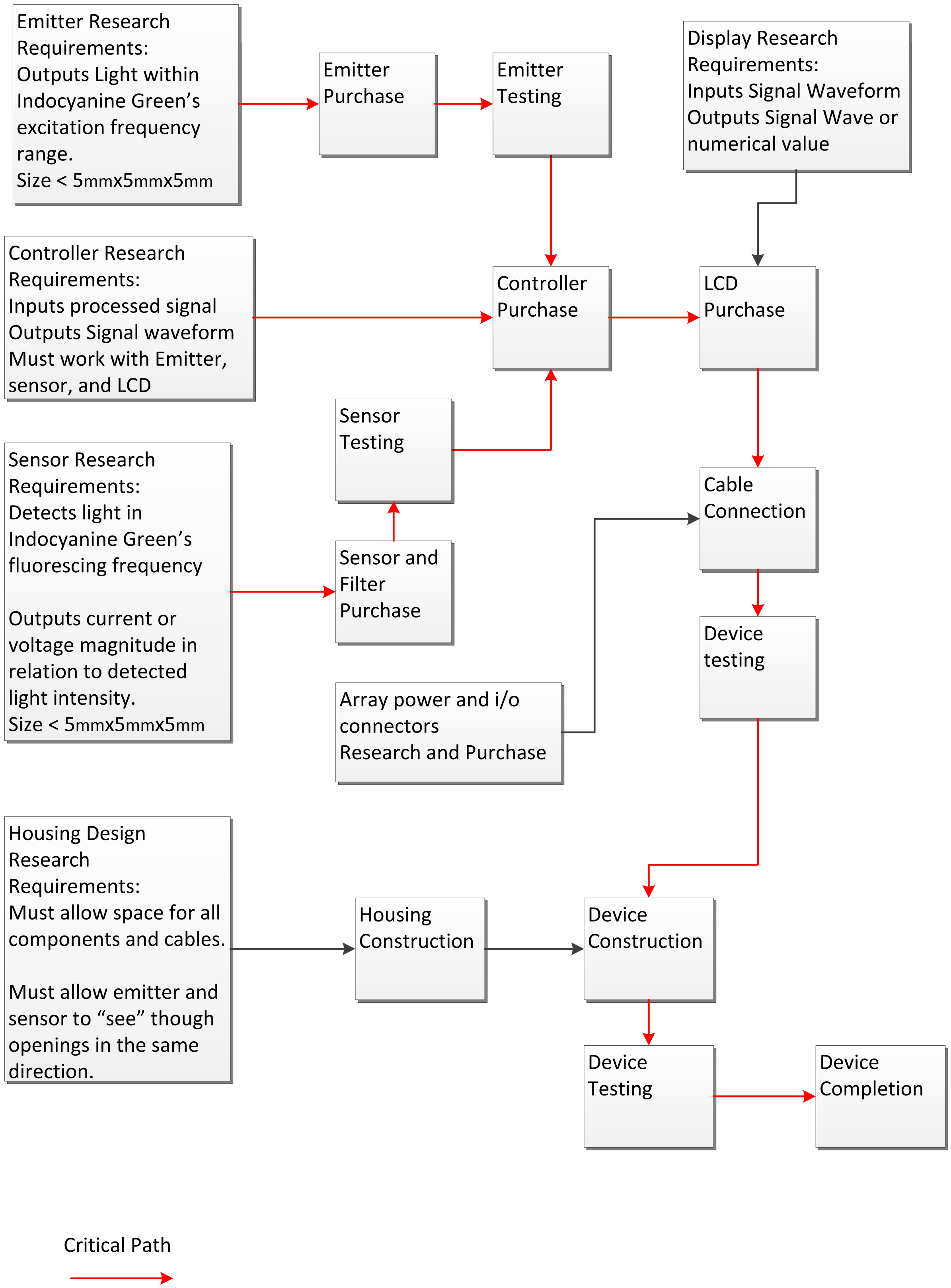


Figure 1: Project Steps Diagram

2.3.1 Emitter-Collector Specifications

The required parts for an effective emitter-collector subsystem are as follows:

- A Silicon photodiode inclusive of the 830 nm range.
- An optical filter of relatively narrow band pass centered at 830 nanometers.
- An LED emitting wavelengths centered around 780 nanometers with a medium bandwidth, but not overlapping with the optical filter's bandwidth.

With these parameters, it can be seen that parts can be found readily available to match these design criteria. The wavelength ranges, or filter bandwidths, will provide the necessary limiting criteria around which the other design parameters will be selected.

The most general parameter is the silicon photodiode. It must merely include the 830 nanometer wavelength of light within its current spectrum. Beyond it responding to 830 nanometers wavelength of light by producing current, there are no other essential requirements for its performance.

The criteria for the optical filter should pose no difficulty to match. It should be rather simple to locate an 830 nanometer, relatively narrow band pass filter that could provide the photodiode with the shielding from emitter light that it requires to not be fed directly from the emitter.

The LED criteria is general as well. Providing a range of light broad enough to fluoresce in a general range of Indocyanine Green should be a fairly generic task to achieve. By providing a medium bandwidth of light from around 30 nanometers below to 30 nanometers above the 780 nanometer mark, it should give ICG plenty of light to fluoresce at the chosen desired wavelength.

The figure below displays a flowchart of all of the separate pieces involved in the Emitter-Collector design. It can be clearly seen how these pieces interact with one another. It is important to understand how these optical components interact in order to capture a full understand of how light will be sensed in order to detect Indocyanine Green concentration levels within blood plasma in a given sample.

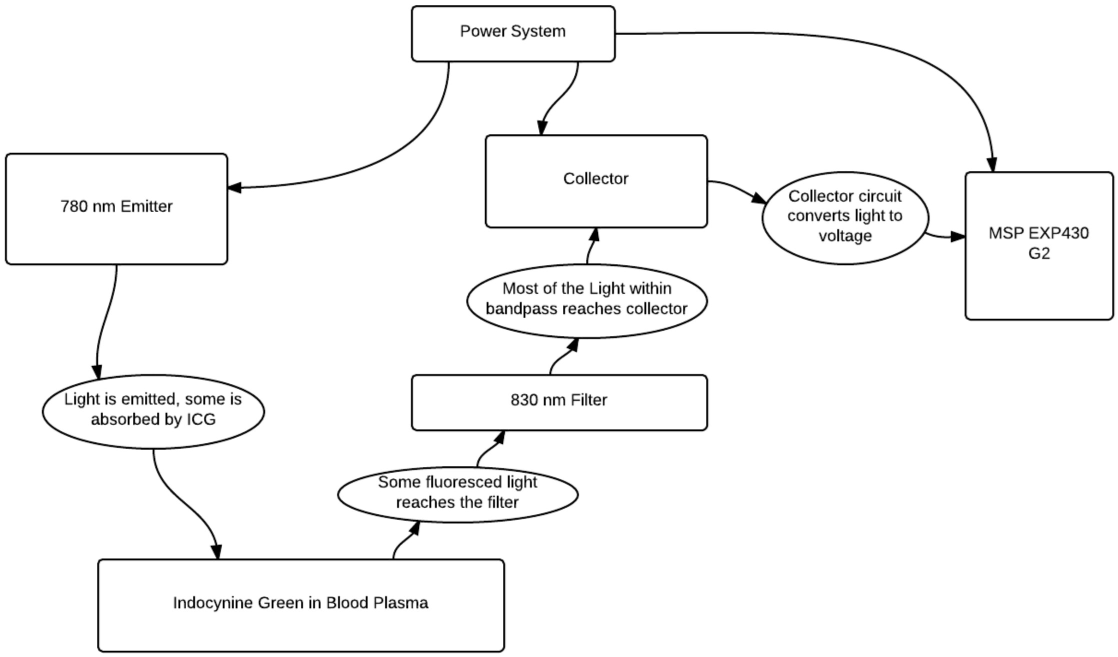


Figure 2: Emitter-Collector Design Flowchart

2.3.2 Controller Requirements and Specifications

Microcontroller Specifications

The microcontroller must...

- run on 3V to 5V maximum
- run at a minimum of 4 MHz
- have at least 16 available pins
- have at least 8 digital pins
- have at least 2 analog pins
- have at least of 16kB flash memory
- have at least of 512B RAM
- must be programmable by a higher level language

The controller is the heart of the device; the point at which all other subsystems will be connected and controlled. As such, the choice of a MCU is crucial to the success of the project. The controller must be powered from between 3V to 5V. These are fairly standard voltage ranges, which will allow a large selection of controllers. Running at these voltages will simplify the power subsystem and helps avoid adding unnecessary complexity to the design. Being able to perform four million operations a second is seen as the minimum acceptable speed for any microprocessor. The 4 MHz minimum frequency will provide the necessary processing power to drive the essential functions the software will require.

The controller will also need a large array of inputs and outputs. Digital and analog pins will take I/O from the sensor and display. A minimum of sixteen pins will be needed as the sensor requires one analog pin and a display will require anywhere from five to twelve pins. Having a board with sixteen will allow three spare pins for possible future design additions. The board must also have a minimum of 16kB of flash memory and 512B of RAM. More features, of course, require more computational power and more memory. These requirements ensure the functionality of the software and expandability of our device. Lastly, it must be programmable using a higher level language such as C or C++. The use of assembly would lengthen the code considerably and add an order of magnitude to the complexity of the software.

2.3.3 Display Requirements and Specifications

Display Specifications

The display must...

- run on 3V to 5V maximum
- have a minimum PPI (pixel per inch) of 30
- have a backlight for visibility
- use no more than 12 pins
- be able to be driven with 512B of RAM
- be able to interface with a microcontroller

Our requirements for the display have been set to ensure an adequate level of precision and clarity for any information conveyed to a medical professional. A PPI of 30 is needed to guarantee the display’s clarity. We will be drawing a time graph, so resolutions are an important consideration. The liquid crystals of an LCD also do not generate their own light; so a back light is required to allow use of the device in most lighting environments.

The device must also be able to be driven with a microcontroller. Since there are a limited number of pins available on microcontroller, the display can only account for at most 12 of these pins. The microcontroller is also memory limited with a maximum of 16kB flash and 512B of RAM. As such any software needed to drive the display will need to be streamlined to run with the available RAM. If the display’s logic contained its own memory to buffer the output, it would be a significant advantage. Again we wish to make certain any information being displayed is clear and concise. In a medical environment precision is key to making choices which can greatly affect the lives of others.

2.3.4 Software Requirements and Specifications

Software Specifications

The software designed for this project must...

- be able to adequately control the microcontroller and all its functions
- be stored in 16kB of flash memory
- use no more than 512B of RAM
- be able to write output to a display
- be able to draw a time graph of incoming data
- be able to draw simple shapes to the display
- be able to draw text to the display
- be able to rotate basic shapes and text
- be able take touch input
- be written in C or assembly

The software must interface with the microcontroller and all of its pins to properly display the correct output. All software must be able to run with a maximum of 16kB of ROM and half a kilobyte of RAM. 16kB is a moderate amount of memory for the actually binaries of the software. The limitations of the RAM are the main concern. The 512 bytes represents our available runtime memory. As of this moment it is unclear just how severe these memory constraints are.

The libraries will be written with these limitations in mind while implementing the necessary functionality. Such as the ability to write standard alphanumeric characters and punctuation from the English character set and support for drawing basic shapes such as lines, rectangles and circles. These figures may need to be rotated so functionality to turn the figure about a point will be written. And most important will be the ability to display and update a time-graph as the data samples come in. All software will preferably be written in the C programming language.

3 Research Related to Project Definition

3.2 Relevant Technology

3.2.1 Possible Applications

The exact use of the Indocyanine Green Fluorescence sensor is to determine the magnitude of the Indocyanine Green dye present in the blood circulating through the appendage on which the sensor is attached. The value read by the device can be applied to several uses and procedures in modern medicine.

1) The magnitude of fluorescence can be correlated to the amount of blood present in the body and the volume of blood circulating through the body part being measured. This can be used for Surgeries involving copious loss of blood. Such surgeries include Transplants, blood transfusions and Dialysis.

2) The fact that the measurements can be taken constantly or at set intervals can show the blood flow as a steady, rising, or declining curve, to monitor the blood flow to the appendage being monitored.

3) In emergency situations, EMT's may be able to use this device in conjunction with the heart monitor, to monitor blood volume and blood flow as well as pulse and blood pressure in emergency patients and respond accordingly.

4) In cases of internal hemorrhage, this device can be used to monitor reduction of blood flow over time to certain regions on the body.

3.2.2 Alternative Components

In the course of researching the necessary components, there are many alternatives to consider. Pros and cons must be weighed and sometimes sacrifices to performance must be made for a more feasible design. These are some alternatives that were considered for the components included in the design.

Device Alternatives	Positive features	Negative features
Emitter		
Full Spectrum Emitter	Full spectrum LEDs are fairly cheap and easy to find	An LED would require an optical filter to keep the emitted light within the Indocyanine Green dye's spectrum of excitation and not

		cross into the spectrum of fluorescing light, contaminating the readings of the Sensor.
Near-Infrared LED	NIR LEDs are LEDs designed specifically for emitting light in approximately the 700nm to 800 nm spectrum, and would require no filter.	These may be more costly. Compatibility with the possible sensors has yet to be determined
Sensor		
Photo Multiplier Tube	PMT's are designed specifically to detect trace amounts of light with high sensitivity using a vacuum within a glass tube surrounding metal electrodes	They are very complex and highly sensitive, however they are extremely delicate, prone to degradation over time, damage due to shocks and vibration, and damage due to over exposure of light. The delicacy, along with large, cumbersome design and high price tag renders it non-ideal for a small, relatively lightweight and cheap sensor device.
Photodiode	A component that reacts to light, these are relatively small and cheap components that can be operated in different modes and can be affixed with an optical filter for specific spectrum analysis. Assuming we can find a microcontroller that is compatible with voltaic input, a Photodiode may be the ideal selection for a sensor device.	
Microcontroller		
MSP430 Launchpad	Readily available, at no cost (already bought for class) and if needed, can be bought for cheap from TI. 16 bit data bus and 8 analog I/O channels	Less available support from TI in regards to use and programming. 16 kB Flash and only 512 B RAM Only 8 digital I/O channels
Arduino Uno	Great deal of support	Cost: $30 each

	online in forums and at Adafruit.com. A lot of user friendly documentation. Much more storage than MSP430 32 kB Flash and 2 kB RAM 14 channels of digital I/O	Uses an 8-bit data bus for half the rate of MSP430 Only 6 channels of analog I/O Not allowed for this project.
Display		
Oscilloscope	Small versions of oscilloscopes can be purchased and made to display a signal waveform given an input from a microcontroller.	An oscilloscope may be too expensive and is considered too complex and pre-constructed to be used in the final product design
LCD	A traditional LCD Display, this is cheap and, when used with a good microcontroller, can be used to display all necessary information. Some LCDs even come with extra bright backlights and touch screens.	This may need significant programming to display waveforms in the manner desired for the final product design
LED	An LED display is basically a LCD display with better contrast, lighting, and potentially better resolution.	They also have a higher cost. The shortcomings of an LCD versus an LED can largely be overcome by procuring an LCD with a backlight feature. This renders the LED a less favorable option when compared with price as the factor.

Table 2: Relevant Technology

	TI Launchpad	Arduino Uno
Microcontroller	TI M430G2553	ATMega328
Data Bus	16 bit	8 bit
Speed	16 MHz	16 MHz
Storage	16 KB	32 KB
RAM	512 B	2 KB
Digital I/O	8 channels	14 channels
Analog I/O	8 channels	6 channels
Kit cost	$4.30 @ TI.com	$29.95 @ Adafruit
MPU cost	$2.80/1 chip	$2.82/1chip

Table 3: Comparison of MSP430 Launchpad vs. Arduino Uno

Existing Similar Technology

The majority of devices whose traits we will be attempting reflect are medical center health monitoring devices. Most hospitals are hesitant to include or use new technology or devices and our sponsor we have come to the conclusion that a product that behaves and appears similar to the technology currently in use will be more readily accepted.

Pulse Oximeter

One of the major technologies existing in the medical field today is the pulse oximeter. This device, a small clamp on the patient's finger that takes readings from the patient's blood, is a similar idea to our intended product, at least in physical design. Our product will mimic the simplicity and size of this common medical device to make it accessible and useful, and more easily accepted and integrated into a medical center's inventory of devices. One goal for the future of our device is to combine the pulse oximeter and our ICG Fluorescence Intensity Detector into one device, which will increase the likelihood of our device's integration.

EKG

Another major technology in use in nearly all medical centers is the Electrocardiogram, a device that monitors heart rate. The manner in which the EKG's monitor refreshes left to right and, upon reaching the right edge of the monitor, begins anew on the left, overwriting the old data as the new data is measured is the way we will program our devices LCD to behave. As the device is turned on, the data measurements will display beginning in the left of the graph and moving right. When the rightmost edge of the graph is reached, the graph will begin writing from the left-most edge again. This similarity will, hopefully, make the device more desirable and have an easier transition to use for the hospital staff.

Sphygmomanometer

The Sphygmomanometer uses a tight fitting cuff to cut off blood flow and when used with a stethoscope, can measure blood pressure. The tight fitting cuff seems like it may be a good method to secure the Sensor-Emitter component of the project to a patient's arm, as it would keep the device from coming out of contact with the skin and letting in external light.

Rechargeable Battery Technology

Most devices in use in medical center rely on direct power from outlets. The devices generally have an attached cable to power themselves for a wall outlet. In the prototype of the project, a rechargeable battery will be used to maintain portability and easy of testing.

3.2.3 Indocyanine Green Fluorescent Imaging in Surgery

Taken from an International journal of Biomedical Engineering:

"Fluorescence Imaging (FI) is one of the most popular imaging modes in biomedical sciences for the visualization of cells and tissues both in vitro and in vivo [1]. The benefits of FI include

(i) High contrast, that is, signal to noise ratio (SNR): only the target, not background, is visible because separate wavelengths are used for illumination and recording (cf. Figure 4);

(ii) High sensitivity: extremely small concentrations can often be made visible;

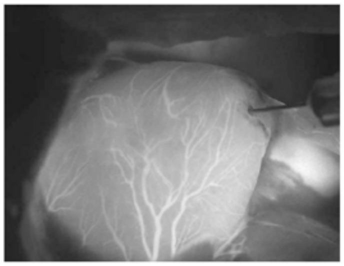
(iii) Gives molecular information: makes some (bio) chemistry spatially and temporally visible;

(iv) Great tools for research: several possible imaging modes, most of which are unique;

(v) Cheap: the optical instrumentation and computing needed are quite simple;

(vi) Easy to use: resembles classical staining."

This Journal section references the use of Fluorescence imaging using a large, specialized camera to view a patient's blood vessels through Indocyanine Green fluorescence illumination, as demonstrated in the following picture.



The blood vessels are clearly visible and can be avoided or interacted with easily. The quote above lists the benefits of FI, one of which is the separate wavelengths for illumination and recording, allowing for both the emitter and the sensor to be active in close proximity at the same time. This will allow a smaller housing, more efficiently using available space, with a same-sided setup of the sensor and emitter.

“Fluorescent imaging is a relatively recent imaging method and thus still developing in many ways. This is especially true for indocyanine green (ICG) imaging in its new clinical applications recently proposed in various branches of surgical medicine, although it has been used in some clinical applications routinely already for almost sixty years. Thus, ICG is well known in its established clinical applications, which greatly facilitates its introduction to new applications.” This product will be honing in on a smaller, more focused aspect of Fluorescence Imaging, focusing on magnitude readings to gather specific information about the subject’s body. Hopefully this branch of the FI field will yield useful, and maybe lifesaving information for the Doctors who utilize it.”

3.3 Emitter/Collector Subsystem Research

3.3.1 Influential Design Factors

There are many key components and design statistics to manage for the development of a sensor such as this. Developing an optics device by its very nature requires the consideration of many differing values and interferences. Light is a complicated phenomenon and attempting to read specific wavelengths of light can be challenging in real-world environments where light concentrations are not straight forward.

The designs of both the emitter and collector are intimately tied to the fluorescence spectra and molar extinction coefficient of the Indocyanine Green Dye. Put simply, the equipment must be tailored towards the statistics surrounding how ICG emits light after absorbing it. The following is a list of factors to consider:

- Fluorescence Spectra - Most obviously, determining what spectrum of light is absorbed by ICG, and what spectrum of light is emitted in response to the excitation light through the mechanism of fluorescence is important. The most interesting barrier to overcome in this area is that ICG fluorescence is a complicated principle, and depends on numerous factors, including, though not exclusively, the composition of the substance containing the sampled ICG, and the concentration of the sample. This is due to the fact that since the optical qualities of ICG are dependent on its chemical makeup, and since how ICG bonds with other elements is heavily influential on that makeup, the bonding patterns of ICG are essential in determining fluorescence.

- Transducer Sensitivity - The selected transducer (that is to say, whatever sensor and its corresponding circuit that is utilized as a collector for the emitter-collector subsystem) must be tailored to receive the signal. If the only feasibly accurate readings require a minimum input of light, this becomes a limiting factor, as it must then be made certain that the ICG fluorescence gives off at least that amount of measurable light. However, with appropriate selection and implementation of parts, this key factor should become insignificant, assuming the parts competently read signals.

- Difficulty of Transmission Through the Body - The most difficult factor to prepare for is how much factors like skin, plasma, etc. will impede light from reaching the ICG in order to fluoresce and from escaping the body after fluorescence to reach the transducer. If too much light is blocked by the body, the dye might not absorb enough to fluoresce enough to reach the sensor. This complication however is stopped short by the notable transparency of the body with respect to infrared light. ICG is so commonly used for body-imaging processes simply because at the infrared spectrum, where ICG fluoresces, the body possesses little to no interference.

- Prevention of UV Rays - ICG has been noted to deteriorate in potentially harmful ways under exposure to ultraviolet light. It must be ensured that whatever emitter is applied does not emit ultraviolet light. This task can be ensured in a number of different ways. One approach would be to choose a source of light that simply does not emit wavelengths in the ultraviolet spectrum, or perhaps that is generally limited to the near-infrared spectrum entirely.

- Ambient Interference - If the sensor is subject to ambient light from the environment, it must considered that there is the possibility of a portion of this light being of a wavelength with potential to be read by the transducer. This sort of noise when read by the collector could potentially distort or otherwise overpower the signal sought, rendering the device inaccurate. If this ambient light is significant in our sensor's wavelength range, we must consider methods of shielding it from ambient light, to prevent noise overpowering our readings. This includes any light given off by our emitter.

3.3.2 Efficiency as a Proportionality of Design Factors

It is helpful to approach the design with a sense of proportionality of various factors. If it is known how various statistics of a design interact to produce the desired effect, various factors can be selected for improvement towards the goal of honing the device with respect to accuracy or efficacy.

The efficacy of the Collector-Emitter subsystem can be said to be proportionate to the following ratio:

$$\text{Efficiency}\ \alpha\ R / (R + N)$$

Where R is the amount of light fluoresced by ICG that reaches the collector, and N is the noise that is registered by the collector due to ambient light, or any source of light within the collector's bandwidth. In short, this proportionality states that the efficiency of the Collector-Emitter subsystem is the true signal received as proportional to the total signal received, including noise interferences at the received bandwidth.

To investigate this proportionality further, it can be noted that the amount of fluoresced light registered by the collector can be loosely expressed as:

$$R\ \alpha\ F * (1 - I)$$

Where F is the amount of light fluoresced by the dye, and I is the fraction of that light lost due to interference from the body. This is simply stating that if R is the amount of light fluoresced by the ICG, then it is equivalent to the total fluoresced light after being decremented by the interference of the body.

These relationships can further be investigated by examining the amount of light the dye fluoresces:

$$F\ \alpha\ E * (1 - I) * C$$

Where E is the amount of light emitted by the emitter, and C is the proportion of absorbed light that ICG successfully emits. I is once again the factor of light lost due to interference from the body. This proportionality is equivalent to the one before it, save for the fact that instead of referring to the light coming from the ICG to the collector, it is the light coming to the ICG from the emitter.

When all above proportionalities are taken into consideration, these proportionalities yield the following:

$$\text{Efficiency } \alpha \ \frac{E*C*(1-I)^2}{E*C*(1-I)^2+N}$$

In other words, efficiency of the emitter collector subsystem is proportional to E, proportional to C, inversely proportional to I, and inversely proportional to N. Since this equation has been found, the particular factors able to be influenced to alter system efficiency are clear. Thus, to increase and ensure subsystem efficiency, the following possibilities must be considered:

- Increasing E: Increasing the light emitted by the emitter.
- Increasing C: Increasing the proportion of light ICG absorbs that it successfully fluoresces.
- Decreasing I: Decreasing the factor of light lost due to body interference.
- Decreasing N: Decreasing the amount of non-fluoresced light registered by the collector.

3.3.3 Increasing Emitted Light

This is the simplest factor to consider increasing efficiency. This is due to the fact that the issue of adding more light is a simple design task to solve. All one must do to increase total light emitted is to acquire higher-powered sources or more plentiful sources. These are simple feats to achieve.

However, there are some limitations to consider.

The more light the emitter produces, the greater power is consumed. This is important for consideration since more power consumption usually raises operating expense. This raise in expense tends to come either in the form of battery replacements or in the form of electrical power consumed from an outlet, increasing the power consumption of the building.
It is also noted that greater amounts of light power also means that significantly more heat is dissipated. Keeping this factor minimal benefits the design. This is

because the result of too much heat dissipation could be potentially harmful to the equipment or the subject in question.

As such, increasing emitter power should be a latter compensation in design, instead of an immediate design solution.

It should also be noted that without proper wavelength filtering, increasing emitted light may also increase ambient noise, as some emitted light may reach the collector without fluorescing.

3.3.4 Increasing the Proportion of Absorbed Light that Fluoresces

This factor is potentially the most difficult factor to be influenced by the design parameters accessible within the scope of the project. ICG fluorescence is affected by a complex mixture of factors.

One particularly relevant process is that of “Quenching”. Quenching is the noted effect that increasing ICG concentration only increases measurable fluorescence up to a limit. Upon reaching this maximum fluorescence concentration limit, increasing ICG concentration decreases fluorescence, as shown in the figure below. This is explained by the tendency of ICG polymers to fluoresce much less than ICG monomers. The lower the given concentration of ICG in the particular sample, the more ICG is encouraged to bond with plasma instead of with other potential ICG molecules, leading to higher fluoresced light.

This means that system efficiency will increase approaching around the 80 micrograms per milliliter concentration amount. The assumption that the collector readings increase with directly in proportion to ICG concentration only holds true for below this amount, after which point ICG concentration has varying effects on fluorescence magnitudes. If the goal is to accurately measure concentration of ICG by measuring fluorescence, then the range of concentrations between 80 and 8 micrograms per milliliter is ideal. This is because the ICG concentration to fluorescence ratio relationship is linearly measurable between 80 and 8 micrograms per milliliter. This range could be targeted for reliable measurements.

The below figure displays the fluorescence of ICG as a function of ICG sampling concentration within blood plasma. The effects discussed above of quenching can clearly be seen, when around .1 mg/ml the magnitude of fluorescence falls off rapidly. It can also be clearly observed that there is a linear region which could allow for very accurate linear results.

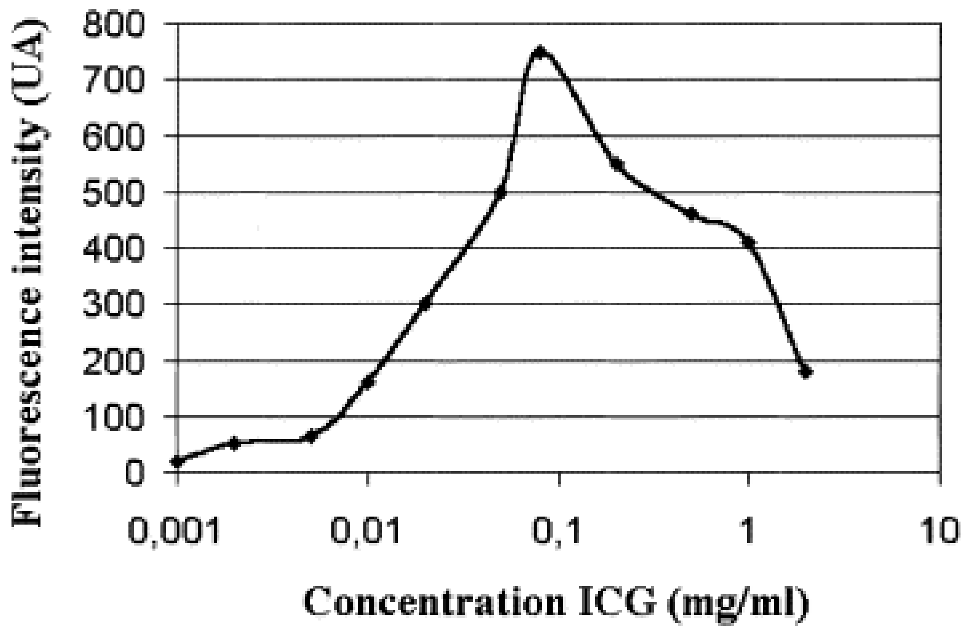


Table 4: Fluorescence intensity verses ICD concentration in blood plasma

3.3.5 Decreasing the Factor of Light Lost to Body Interference

Body interference is a factor reliant on the chemistry of the body and its various optical properties.

Because of the nature of this factor, body interference is the result of which part of the body elected to be used to mount the device, as different selections will require the emitted signal to transverse different areas of the body with different chemical make ups. Body parts with more accessible veins (in other words, veins that are closer to the surface, and not as obstructed by any other light-impeding materials) will impede signals significantly less.

Sites to consider include the ear and the nose. The finger or fingertip would be easier to mount, but may provide less clarity and more interference, since the body there is more resistive to the signal in question.

However, this factor is regardless expected to be highly minimal, since the body becomes very transparent at the near-infrared spectrum. ICG should fluoresce plenty enough to make this factor trivial. Plasma, skin, and other body factors become highly transparent at near infrared wavelengths, meaning that the transmitted signal will not be largely impaired by these factors.

Therefore, in general, the body interference factor should not be a significant modifier to our signal efficiency.

3.3.6 Decreasing the Amount of Ambient Noise Registered by the Collector

The task of decreasing ambient noise is primarily a task of filtering. In theory, if the collector is equipped with a narrow band pass filter only allowing the precise bandwidth at which ICG fluoresces to pass through to reach the collector in order to transmit the desired signal, the bulk of ambient light will be easily prevented from affecting the collector, since usual noise is a mixture of many complex chaotic signals from every possible measurable wavelength.

However, the efficacy of filtering out all but the fluoresced wavelengths is limited entirely if the ambient light within that selected filter's bandwidth is significant in comparison to the amount of received fluoresced light which is projected to be measured by the collector. In short, if the ambient light within that bandwidth is significant in comparison to the fluoresced light, the only other option available for the reduction of ambient noise at this wavelength is to attempt to seal off ambient light entirely, meaning the device would need to be skin-tight to limit ambient interference.

To solve this problem, we can merely shield the body from outside light by essentially covering the area with something opaque, like a black glove that goes over the targeted finger and our device. This means that the only light sensed by the sensor will be the light within the glove, which is limited to our emitter and the fluoresced light.

To tackle this sort of noise blocking within the desire near-infrared spectrum of 780 to 830 nanometers in wavelength, a material must be selected specifically to block out this wavelength range from reaching within the body around the targeted site. It is notable for this discussion that tin foil is a readily available material with the potent ability to shield off near infrared light.

Thus, solving the noise problem is primarily an issue of casing and physical manufacturing.

3.3.7 Emitter-Collector Subsystem Efficiency Summary

The below Figure 3.3.7.1 Summarizes the above analyzed criteria in one simple diagram. It seeks to illustrate the logical flow of various criteria. These criteria show has each part's need cascades from each previous need.

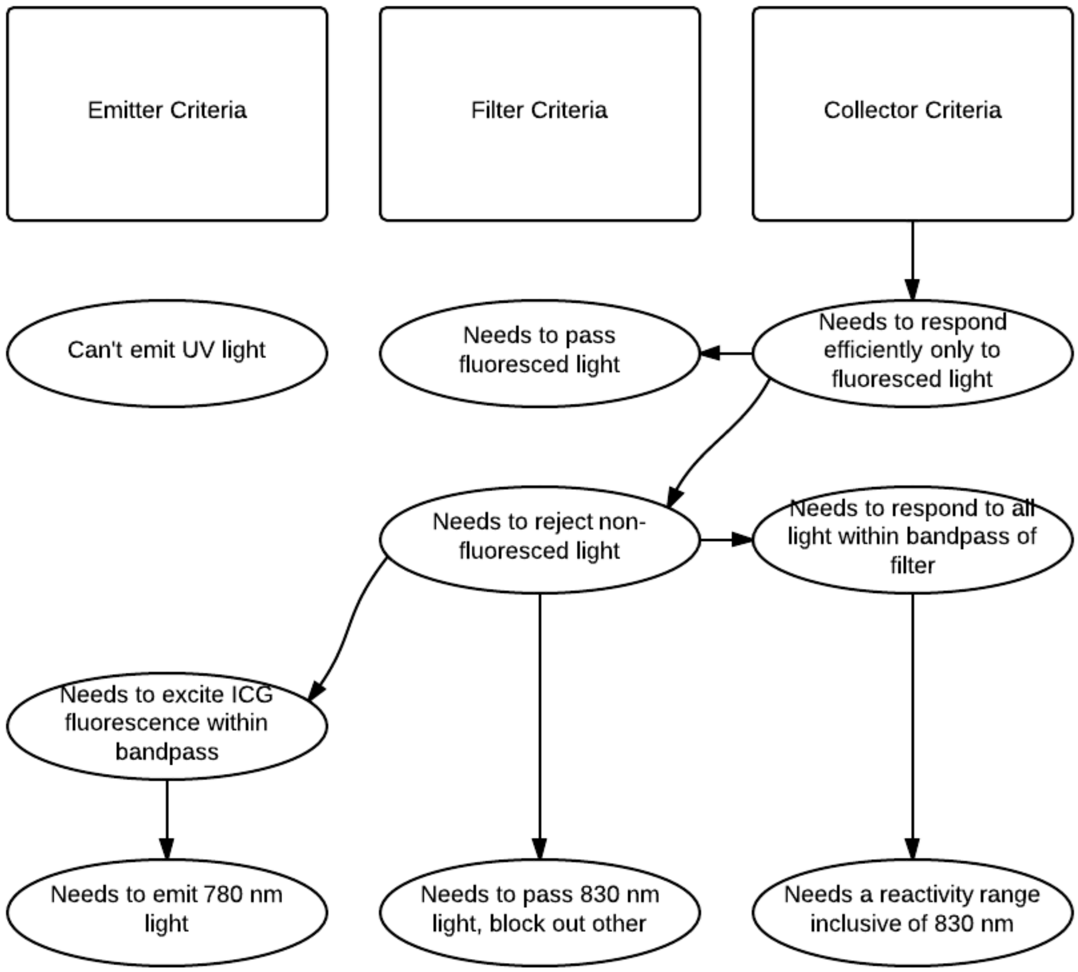


Figure 3: Criteria Flowchart of Emitter-Collector Subsystem.

3.4 Collector to Microprocessor Interaction

3.4.1 Analog-to-Digital Conversion

The MSP EXP430 G2 microprocessor which will be implemented provides multiple analog to digital convertor pins. These provide the necessary means with which to read the signal generated by the photodiode.

These pins operate with 10 bits of accuracy, providing the solid resolution of 1024 values between the maximum and minimum. Once this input is received, it must be compared to the reference voltage in order to determine the true voltage value output by the photodiode.

This allows the potential for calibrating the sensor to specific voltage ranges. By inputting a predetermined voltage into the msp430's reference voltage pin, the msp430 is then calibrated to read in any voltage between the predetermined reference and 0 volts, with a resolution of 1024 values between those two.

This means that if the voltage output by the photodiode is on the order of 100 mV, all that must be done to adjust the sensor to match this lower voltage is to use a voltage divider to decrease reference voltage to the order of a couple hundred millivolts. This decrease needs to be taken into account by the software on the msp430, in order to draw accurate output readings.

Providing adjustability to the reference voltage can allow for a much more dynamic device. If the readings are very low, the reference voltage can be turned down, and readings will then be keyed towards much lower values with higher resolution.

However, given the potential readings calculated in TABLE BLARG, and given the readily available 5 volt source already designed as both the LED780E power source, and utilized as the FDS1010 reverse bias voltage, and given that the range of data calculated in the table approaches 5 volts at non-ideal maximum, a set voltage reference of 5 volts could provide plenty of accuracy for the targeted ranges and plenty a high enough maximum magnitude on the higher end.

3.4.2 Automatic Recalibration Optional Feature

The adjustability of the voltage reference allows the potentiality for automatic calibration. If the reference voltage was potentially controlled by the MSP430 itself, it now gains a number of potential functionalities with respect to the desired signal.

The microprocessor itself at that point has the capability of reading a signal and understanding if the signal is too high or too low. It also then has the potentiality of altering the reference voltage with respect to the signal. If the input signal was on the lower end, the reference voltage could be cut in half. Cutting the reference voltage in half would provide double resolution to the lower half of the previous signal range, and the reading could be taken again. If the reading is still too low, the reference could be cut and read again, and repeatedly until the readings are in the center of the resolution. This approach would yield a much broader range of accuracy.

In order to properly apply this technique, a range of ADC reading values would be chosen as acceptable, whereas any values below or above the acceptable range would trigger an automatically calculated recalibration, through the msp430's altering of its own reference voltage.

It is notable for the selection of design parameters that if, for instance, 33% is selected as the lower recalibration threshold for a half cut of voltage reference and 66% is selected as the higher recalibration threshold for a double increase in voltage reference, then if the input was 33%, it would be doubled for the next calibration to 66%, at which point it would be halved again, and the sensor would never reach a range of satisfied calibration.

To handle this case, the MSP430 must simply be programmed with smaller recalibration tolerances. To reduce the probability of looping automated sensor calibration, the device will be limited to a lower recalibration range of within 20% of minimum and maximum values.

Given this recalibration range, the newly recalibrated readings will land within 40% of the maximum value for zoom-in recalibrations and above 60% of the maximum value for zoom-out recalibrations. The gap in this case is plenty large enough so that a calibration, once made, will not land the readings back within the opposite calibration zone, meaning that calibrations will rarely loop indefinitely.

However, even with all of this recalibration to find the most accurate viewing range, there is still the matter of an absolute minimum and maximum. The MSP430 must finally reach a result after which point it cannot calibrate further. These limitations will likely be constrained by the limitations of the externally provided voltage reference.

4 Project Hardware and Software Design Details

4.1 Hardware Design Details

The following section focuses on all aspects of the hardware for the biomedical sensor setup. Casing, collector, emitter, battery, charger, circuitry, microcontroller, and LCD screen will all be in-deftly discussed here. Due to the extensive nature of some of the information, not all circuits might be used. The main idea is that all possibilities are explored so the majority of potential future issues could be more easily fixed.

4.1.1 Sensor and Printed Circuit Board Casing

The casing for the sensor itself will be made of Isocyanate polymer, or as it is more commonly referred to as, plastic. Plastic is an easily morphed and cheap material to be used in the creation of uniquely shaped objects. One of the team member's parents offered their assistance in the creation of the sensor and printed circuit board casing. This parent is Thomas Wilkes, President of Guard-Lee, Inc. The company focuses on aerospace replicas and restorations. He has extensive experience in the area of design and creation of aerospace equipment. With the knowledge of manipulating a large variety of materials and understanding the design process, Mr. Wilkes will be a perfect asset in the creation of the sensor and circuit board casings.

Below are varying figures for the sensor casing. The first figure is the bottom view for the case. While circular in the picture, it is quite possible that the finalized version will look similar to an egg being cut in half along the major axis. Note how the bottom is split into two compartments. The collector and filter side on the right will be substantially larger than the emitter side. The main size limiting factor for the casing resides on the collector side. It is the filter that will decide upon the size of the case. The selected filter is 1 in. in diameter and so the dimensions up the casing itself can be estimated at 1 in. along the minor axis. Due to the emitter being along the major axis as well, its length will end up being 1.25 in. The emitter is a small LED so it is not strenuous on the size of the sensor.

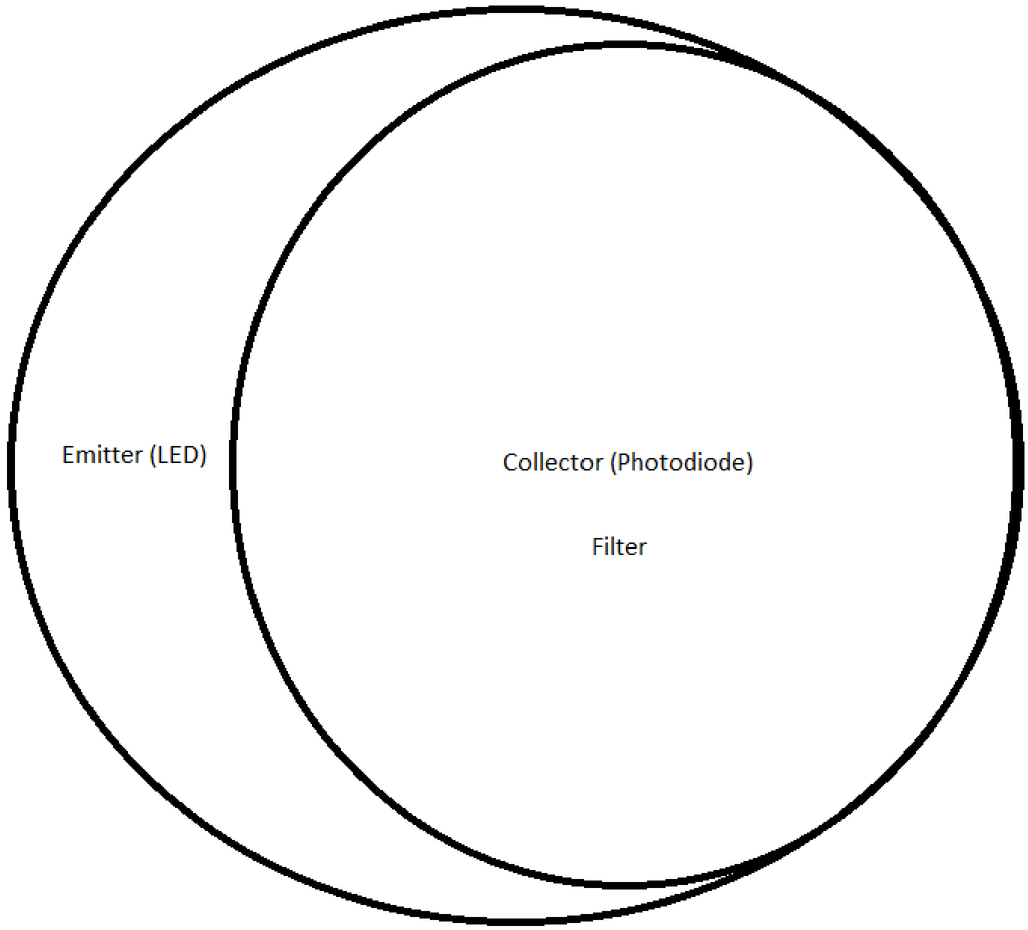


Figure 4: Bottom view of sensor case.

Figure 4.1.1.2 is the side view of the sensor casing. This image takes both the left and right sides of the case into account. The left and right sides could be compared to the top and bottom sides of Figure 4.1.1.1 respectively.

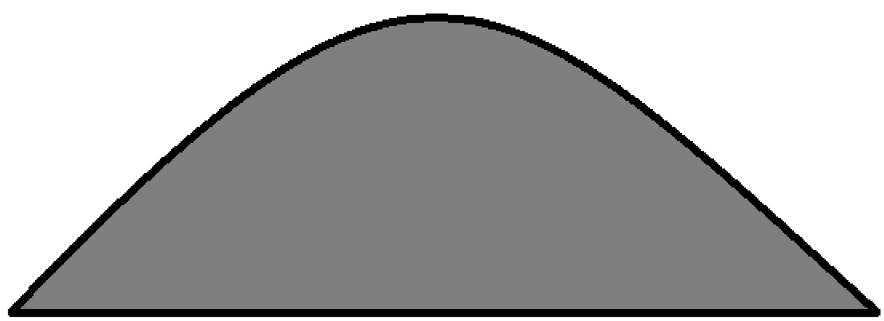


Figure 5: Side view of sensor case (note that both the left and right sides of the casing are the same)

The following figure is a representation of the emitter side of the casing. Note how in the picture there is a small white dot; this dot represents a small 5mm hole that will be cut out of the casing itself. Two small prongs come out from the back of the emitter (see figure 4.1.5.1), so hole is not required to be larger than 5mm in diameter. Also, the hole will be closer to the bottom of the casing than the top so that the signal from the LED will be as strong as possible.

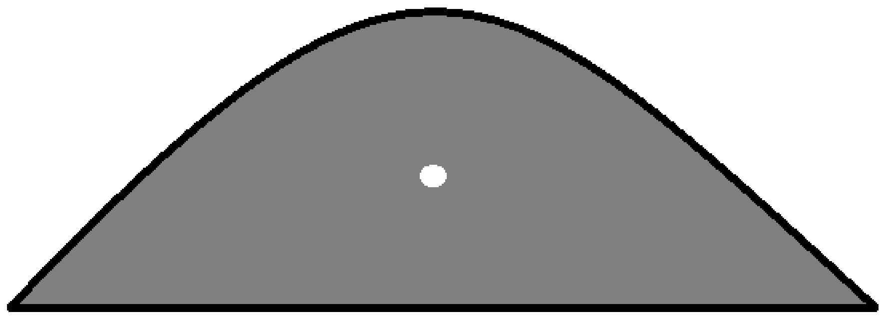


Figure 6: Emitter side of casing with 5mm hole

The next figure shows the collector side of the casing. This also has a hole being depicted by the white dot. The cut this time will be 1cm in diameter due to the increased size of the wires that must go through the opening. Like the emitter side, the hole will be closer to the bottom as well; however, this is slightly limited by the fact that there is a filter here. Because of the filter the collector will be forced to be a little higher than the emitter. Thanks to the intensity of the emitter and sensitivity of the collector, this change in height should not be a problem.

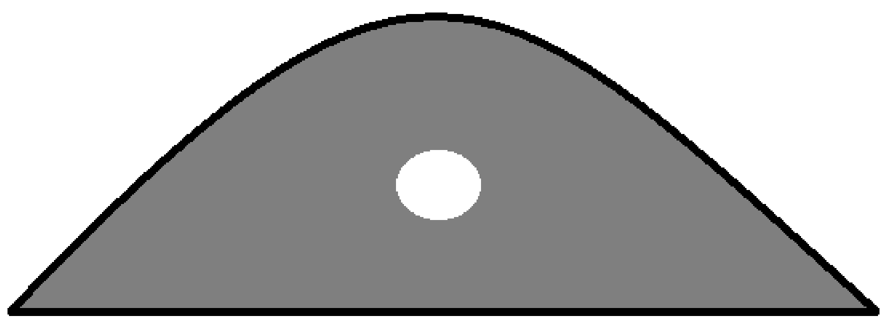


Figure 7: Collector side of casing with 1cm hole

The final figure for the sensor casing shows the top view of the sensor. As can be seen in previous figures the center will be higher than the sides in what appears to be a dome-like shape. The reason the casing will is curved upwards in the center rather than being flat is because a weight is going to be placed inside. Since the sensor is meant to rest on a patient's stomach and/or chest, it has to sit on them stably. Research was put into ensuring that the sensor itself would not be too heavy for people to have to withstand, but as it turns out the opposite issue appears to have occurred. In order to make sure the sensor doesn't move too much on the patient a weight will be added in the upper part of the dome to make sure it remains in place even if someone were to move slightly. It will simply be a small 2.5-lb weight. Figure 4.1.1.6 is an accurate example of what kinds of weights will be used.

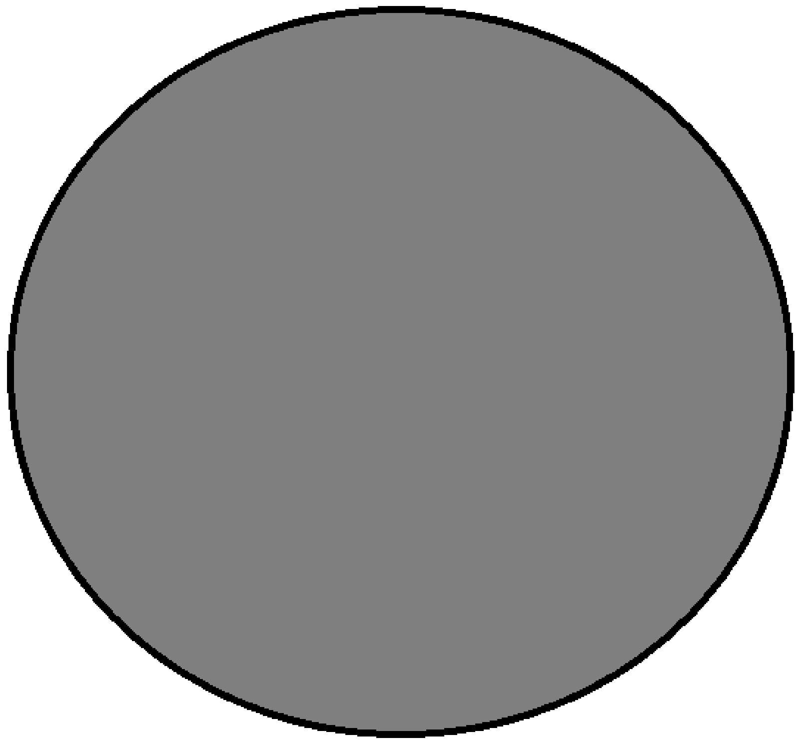


Figure 8: Top view of sensor case

Figure 9: Examples of small weight to be placed on upper part of the inside of the sensor casing (2.5-lb weight most likely to be used)

The following figure acts as an example of the Isocyanate polymer to be used. Although the color will be different, the material is the same and its purpose, like these barrels, will be to hold what is inside in place.

Figure 10: Isocyanate polymer (material to be used for the sensor and printed circuit board casing)

Up to this point the main point of the casing has been to hold the photodiode, LED, filter, and weight in place. It is meant to be light enough so that it does not hurt the patient it is being applied to while still being heavy enough to not move from small movements such as light breathing. Unfortunately the Isocyanate polymer is not meant to keep near-infrared light out.

To solve the problem of keeping near-infrared light out aluminum foil is used to cover the entire outside of the casing. To keep it cheap and simple non-heavy duty and non no-stick Reynolds Wrap is used; the same kind as can be seen in Figure 4.1.1.7:

Figure 11: Aluminum foil used as infrared protection

As can be seen by the following graph provided by Wikipedia, the reflectance of aluminum, gold, and silver are compared. The LED sends out waves around 750nm in length, but outside signals being sent in this range are not the real worry for the sensor. The more important wavelengths to keep out of the sensor are those of 810nm and higher. Since the collector collects at these wavelengths, erroneous results will be created if not kept out of the sensor area. Aluminum has a slight drop in reflectivity near the lower 800nm mark; however this drop will be negligible due to the weak signal that would be sent by dimmed lights and easily reflected and kept out of the sensor.

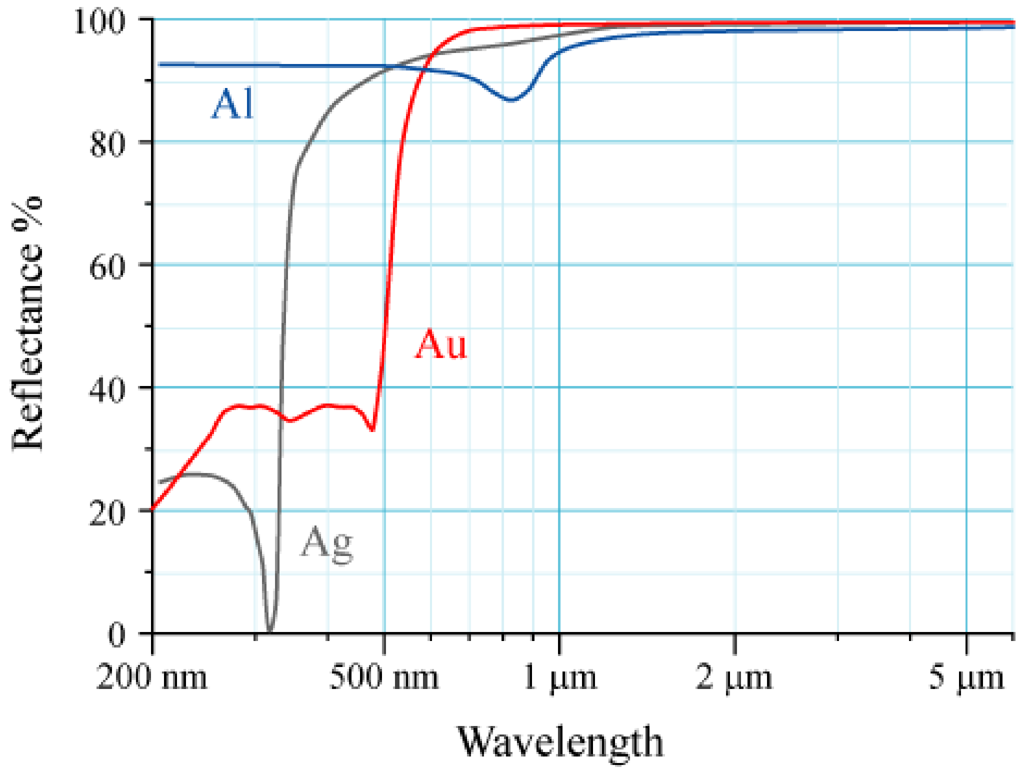


Figure 12: Reflectivity graph comparison between aluminum, gold, and silver

LCD and Controller Case

The Microcontroller and LCD will share the same case, with the Printed Circuit Board connecting them within the case. The case will be made of the same plastic material used to form the sensor-emitter array and will be made up of three pieces. The back will have slots for the components to rest in, an opening on the left side for the mini USB, a slot on the right side for the power switch, a 4/10 inch diameter hole in the top for the sensor-emitter array cable, and a wide slot at the base for the battery pack housing. The front face will have a large opening for the LCD display, two openings on the left, bottom area for the **[+]** and **[-]** buttons and two openings in the center and right bottom for the **[Info]** and **[Math]** buttons. The final piece is the cover over the battery pack that will rest flush over the back piece's battery opening.

The front of the case will be dominated by the LCD screen filling most of the face and aligned with the upper edge of the case. Two buttons will be located on the bottom left of the front face and stacked vertically; these will be the **[+]** and **[-]** buttons. The **[Info]** and **[Math]** buttons are oriented horizontally to each other in the bottom center and left. The LCD will be approximately 1.97 inches tall and 2.72 inches wide. The width will be the limiting factor for the case width, but the addition of buttons will extend the case height to approximately 3.1 inches.

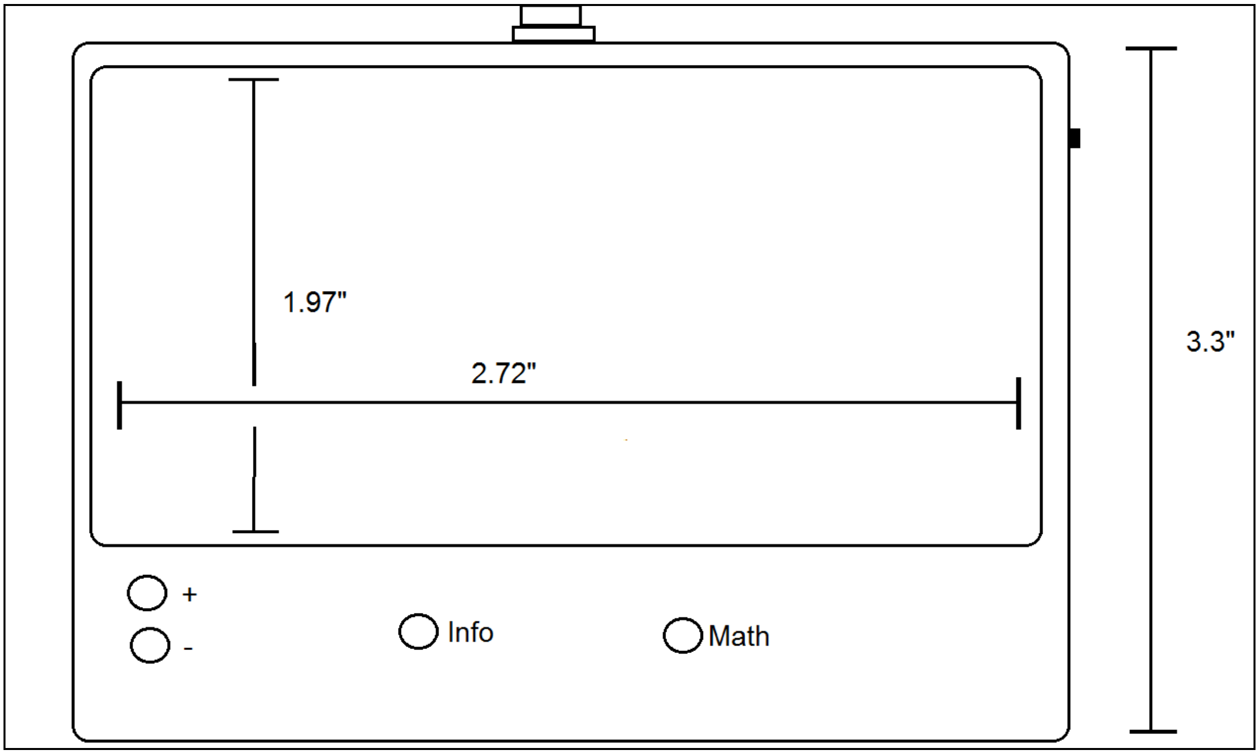


Figure 13: Case, Front View

The cable emerging from the top of the case contains the wires powering the Emitter and Sensor along with the wire transmitting the voltage signal from the sensor to the microcontroller. This cable will split when it reaches the Sensor-Emitter case. The case will be 2.9" wide and 1.5" deep. This will allow sufficient room for the LCD, Printed Circuit Board, and Microcontroller to rest stacked on top of each other and enough room for cable management and the battery pack.

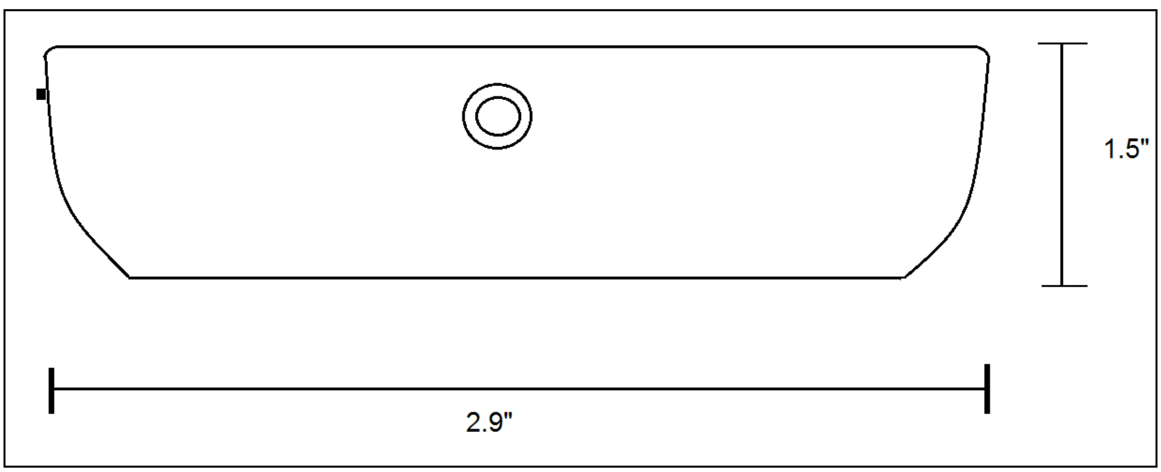


Figure 14: LCD Case, Top View

The power switch on the right-hand side will be a cutoff for the power to the microcontroller and the sensor-emitter array. It will be located approximately 1 inch from the top of the case to avoid accidental triggering.

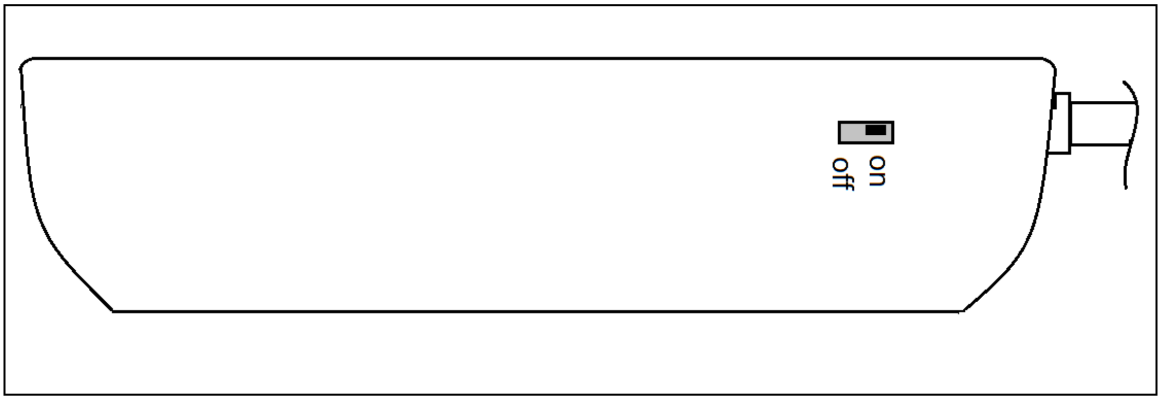


Figure 15: LCD Case, Right Side View

The left side of the case will have a mini USB to allow for programming or use off of battery power. This will allow for future alterations of the code, and may only be featured in the prototype. The end product may not need to feature code altering capability. It will rest toward the back of the case as the LCD will be on top of the microcontroller and the microcontroller mini USB port will be on the left, posterior of the case.

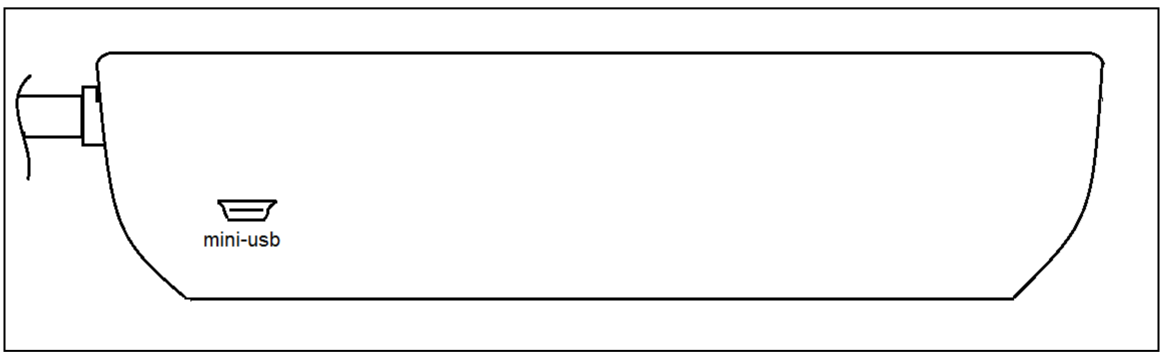


Figure 16: LCD Case, Left Side View

The Battery pack will be located within the lower of the back of the case, and it will have a plastic cover made of the same material as the case. The cover will have two tabs on the lower side that will slide and lock into two slits in the lower edge of the case. The upper edge of the cover will have a tab that will rest parallel to the case in a recession, and will have a hole for a screw to secure the cover to the case.

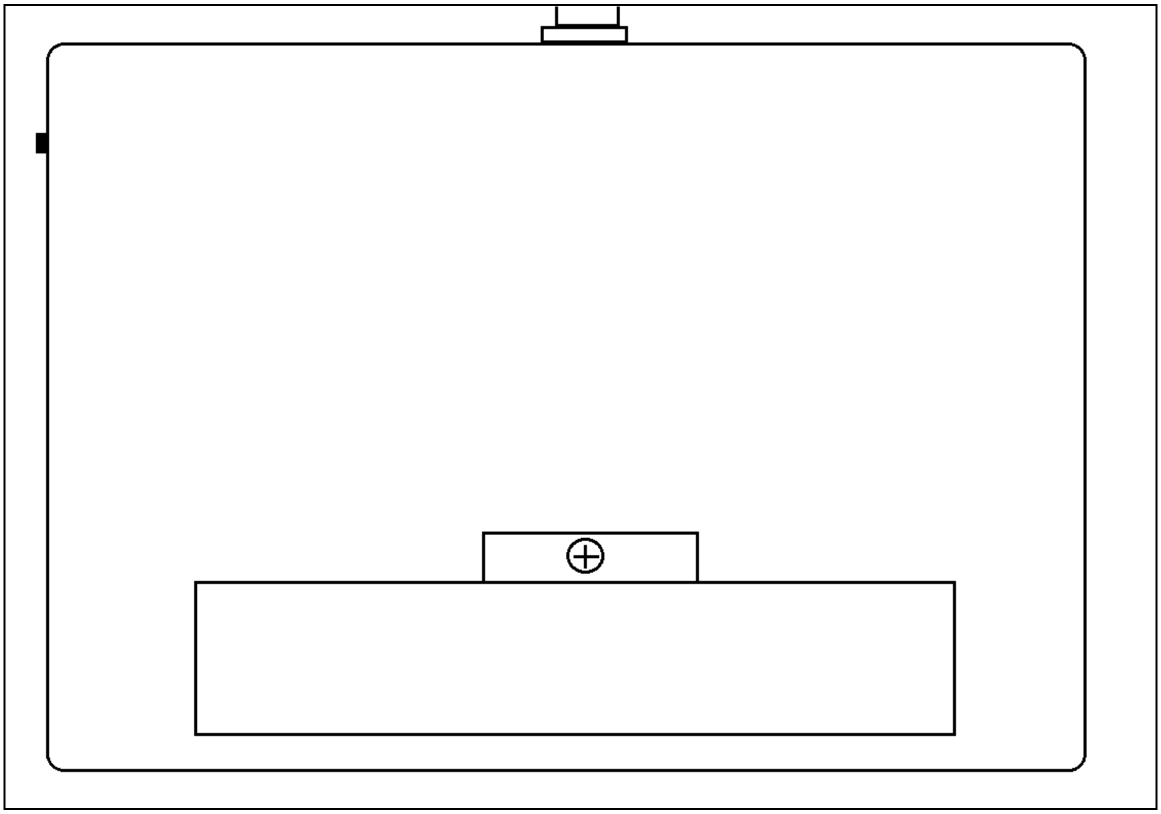


Figure 17: LCD Case, Back View

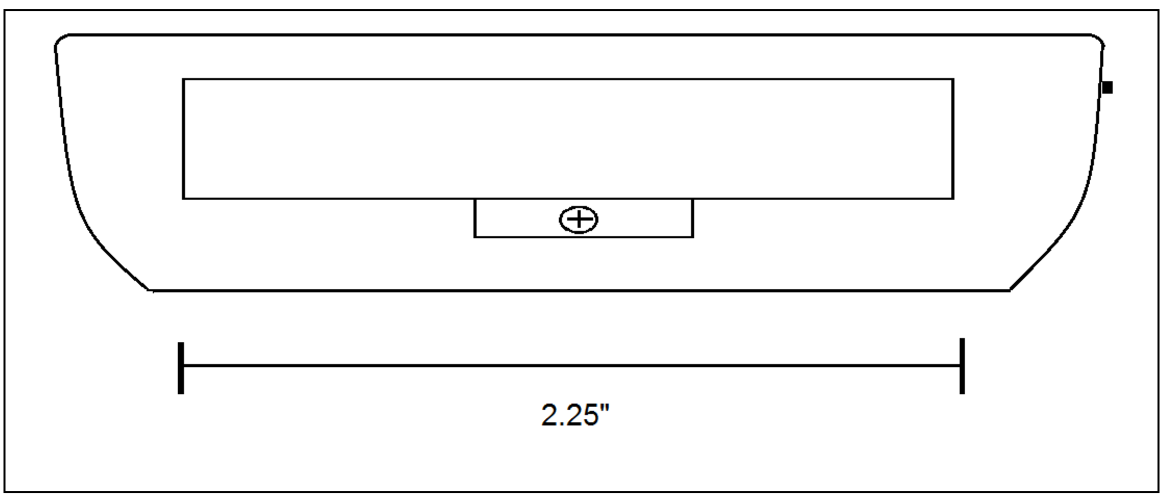


Figure 18: LCD Case, Bottom View

4.1.2 Charger and Rechargeable Battery Pack with Significant Circuitry

The power system is going to be one of the most important parts of this entire project. Without power, nothing will work and all research before this will be for not. All aspects of this power system have been thoroughly researched into and have been discussed over between the group members along with Dr. Weeks and Everett Yost, an insightful and very helpful technician working for Batteries America. A number of key issues with the power system were not thought of until Mr. Yost made the team aware of them.

To begin with, a flow chart is used to clarify the necessary parts to help make the power system possible:

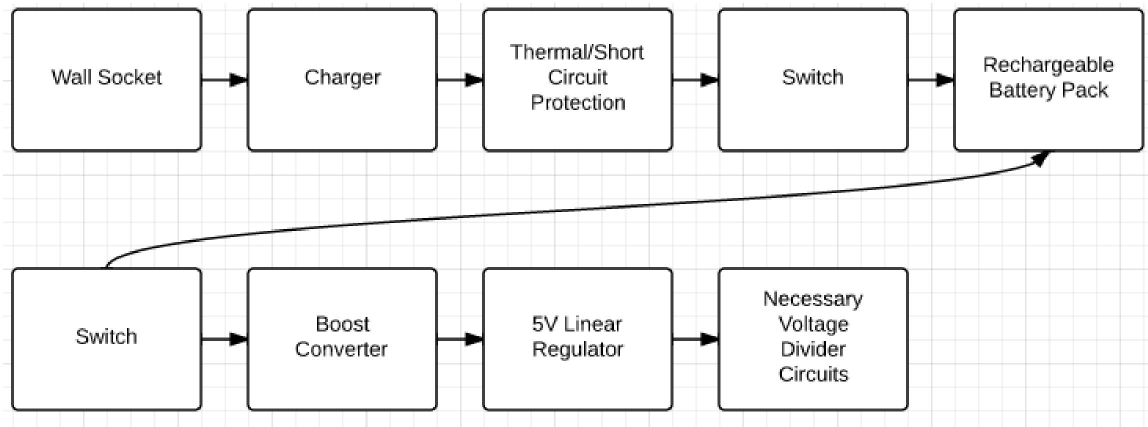


Figure 19: Flowchart diagram of power system

The key aspect of this system that the group's sponsor asked for was a sensor that was powered by a rechargeable battery. Surprisingly, a rechargeable battery circuit made everything much more complicated than originally anticipated. To explain how the entire power system works this documentation will follow the flowchart diagram of Figure 4.1.2.1. From the wall socket a charger will be connected identical to what an individual charges a cell phone or laptop computer with.

This charger will be provided by Everett Yost of Batteries America. According to Mr. Yost the charger will remain unavailable until mid-summer. Due to the fact that the charger will be custom made, there is no model or part number for it. There is no current picture online for the charger yet either because the battery must first be confirmed to work before a final charger is decided upon. Since it will be doctors and nurses who operate this device, the charger must be automatic, easy to use, and smart. A green light on the charger will signify that the battery is fully charged. It will be a simple 2-wire plug charging jack connection which connects the battery to the automatic charger. All other information for this charger will be made available in the coming months from Batteries America. Seeing as how the charger is one of the most expensive parts for this entire project, it is logical to make sure the cheaper components which it relies upon are tested first before spending the large amount of money on it.

The next topics to be covered are the short and thermal circuit protection circuits. It is important to note that these two circuits may or may not be necessary depending on which charger is decided upon. On the off-chance the charger does not take these issues into account these two circuits must be built.

Batteries can be very dangerous if not protected properly. If too much current or voltage is supplied to the battery it could cause overheating and melting of the battery itself. Too much overall heat could also cause a malfunction in the battery. Battery chemical spillage is a serious issue that must be avoided under any and all circumstances. To do this the steps in the next few diagrams might have to be taken.

There are two possible methods the group may implement to protect their battery. The first can be seen in Figure 4.1.2.1. This figure depicts a simple circuit for the prevention of any kind of short circuit occurring between a charger and the battery it is meant to charge.

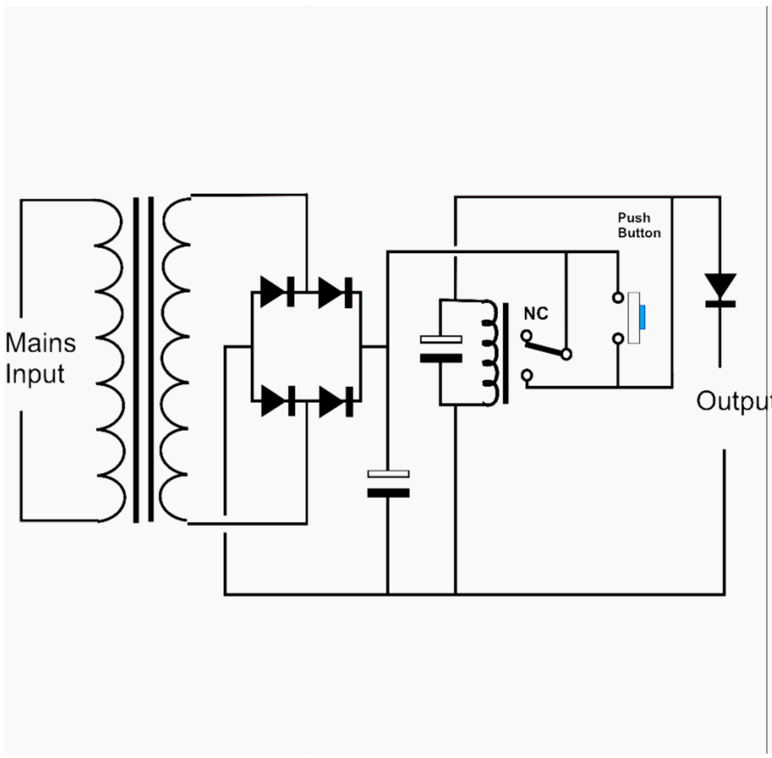


Figure 20: Short circuit protection circuit

The second possibility is simply using a fuse to protect the battery. Seeing as how fuses are commonly used devices for such issues and finding the parts for the different capacitors, diodes, switches, and the transformer of Figure 4.1.2.1 could become quite a hassle, it is more likely that this second possibility will be the part used.

Figure 21: 6V fuse for short circuit protection

In order to protect the battery from any kind of overheating a thermal protection circuit might be necessary. Unfortunately for the thermal circuit there do not appear to be any single parts which could possibly replace the entire circuit as the fuse does for the short circuit. The following figure shows one possible circuit that may be used for the protection of the battery from overheating possibly caused by the charger.

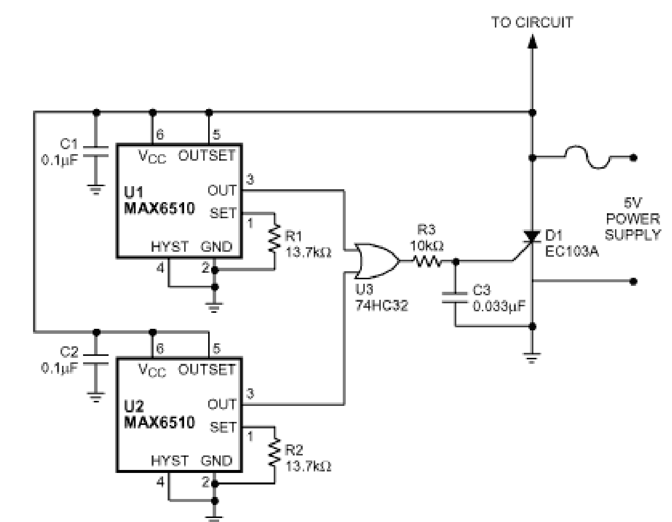


Figure 22: Thermal protection circuit

One final note to make about the charger is that it is important to have the device off while charging. If the sensor and related equipment are on while charging too much current made be getting pulled from the charger causing the device to overheat. Seeing as how the charger is expensive and difficult to attain it is important not overheat or break it.

The first switch between the two protection circuits as of right now will tentatively be a simple MOSFET. This switch's purpose is to keep the battery from discharging into the protection circuits while the charger is not attached. If these circuits are not necessary because the charger comes with those protections then the switch will not be necessary either. However this switch will be taken into account for now since worst case scenarios will be considered for the time being.

Fortunately one type of fuse was found to possibly solve both problems. A resettable bimetallic strip type fuse can protect a custom-built charger from overheating or shorting.

The next step will involve the battery itself. Choosing what kind of battery was one of the most strenuous parts of this entire section. Getting it to work properly was also strenuous, however that will be covered further down in the documentation.

The figure below gives a general comparison between typically battery types. The charge time, life cycle, internal resistance, load current, operating temperatures, typical costs, and a few other important aspects are all given for commonly used rechargeable batteries.

	NiCd	NiMH	Lead Acid	Li-ion	Li-ion polymer	Reusable Alkaline
Gravimetric Energy Density (Wh/kg)	45-80	60-120	30-50	110-160	100-130	80 (initial)
Internal Resistance (includes peripheral circuits) in mΩ	100 to 200[1] 6V pack	200 to 300[1] 6V pack	<100[1] 12V pack	150 to 250[1] 7.2V pack	200 to 300[1] 7.2V pack	200 to 2000[1] 6V pack
Cycle Life (to 80% of initial capacity)	1500[2]	300 to 500[2,3]	200 to 300[2]	500 to 1000[3]	300 to 500	50[3] (to 50%)
Fast Charge Time	1h typical	2-4h	8-16h	2-4h	2-4h	2-3h
Overcharge Tolerance	moderate	low	high	very low	low	moderate
Self-discharge / Month (room temperature)	20%[4]	30%[4]	5%	10%[5]	~10%[5]	0.3%
Cell Voltage (nominal)	1.25V[6]	1.25V[6]	2V	3.6V	3.6V	1.5V
Load Current - peak - best result	20C 1C	5C 0.5C or lower	5C[7] 0.2C	>2C 1C or lower	>2C 1C or lower	0.5C 0.2C or lower
Operating Temperature (discharge only)	-40 to 60°C	-20 to 60°C	-20 to 60°C	-20 to 60°C	0 to 60°C	0 to 65°C
Maintenance Requirement	30 to 60 days	60 to 90 days	3 to 6 months[9]	not req.	not req.	not req.
Typical Battery Cost (US$, reference only)	$50 (7.2V)	$60 (7.2V)	$25 (6V)	$100 (7.2V)	$100 (7.2V)	$5 (9V)
Cost per Cycle (US$)[11]	$0.04	$0.12	$0.10	$0.14	$0.29	$0.10-0.50
Commercial use since	1950	1990	1970	1991	1999	1992

Figure 23: Characteristics of commonly used rechargeable batteries courtesy of Battery University and author Isidor Buchmann

There were about three different types of batteries that could possibly have been chosen. The main three were Lead Acid, Li-ion, and NiMH. The first was quickly debunked for a few reasons. Lead Acid batteries are simply too dangerous to be used. There have been multiple known incidents of the batteries catching on fire thanks to some kind of malfunction in the battery. Yet again, since this will be installed in a medical environment with people who know little about the inner-workings of batteries and built by young but aspiring engineers just now researching and understanding such batteries, it was decided Lead Acid was not the way to go. Plus the recharge time on Lead Acid batteries is tremendous. It would be impractical for doctors and nurses to place a battery on charge for up to 16 hours when trying to use the entire sensor setup more than once a day. Operating and emergency rooms are random with how often they are used, so a once a day battery is of no use in such conditions even though it might last longer than other batteries.

Lithium-ion batteries have had a similar track record as of late. While having a fantastic life cycle and satisfactory charging times, these batteries have been literally exploding on airplanes recently. Another key issue is the cost. The typical battery cost for these according to the above figure is four times that of Lead Acid and almost double of NiMH. For the sake of keeping costs down and keeping the group's sponsor happy along with maintaining the safety of doctors and nurses and their patients, Li-ion batteries were not picked.

NiMH was found to be the optimal choice. These have been known to be safe and reliable and generally receive satisfactory reviews. The specific battery chosen can be seen in Figure 4.1.2.5. This is a SANYO Ni-MH eneloop battery. The desired voltage for the output of the circuit is 5 volts, however the way batteries work is they can only output a set voltage based on the number of packs they are installed with. These packs are put together by using heat sink around them and attaching wires on either end. The closest desired voltage for what the team needs is a 6 volt 5-pack Ni-MH battery. The battery itself is capable of 2000mAh and can sometimes be considered sufficient enough for up to 2200mAh. The specific model number used will be the 5/HR-3UTG. The two connections from the battery pack will be split into two separate connectors. One connector will be the 2-pin connector for charging the battery and the other will simply be wires. These wires will be soldered to a power bus that all other components will use to power themselves. The power of the MSP430 microcontroller will be provided through a voltage divider circuit. The soldering of the microcontroller must take a minimal amount of time due to the fact that the wires will be getting attached to a micro-USB connector which can likely take no more than 5 or 10 seconds of the intense heat emitted from the iron. The connections are also small so the group must be sure to keep any of the solder used from falling into the connectors themselves.

The safety and reliability of these batteries can be attributed to two factors: the first is that a simple bimetallic strip is all that is required between the battery and the charger to create a circuit protect from both thermal issues and short circuit problems and the second is that the only reason these batteries will blow is due to a buildup of hydrogen in them thanks to overcharging which is fixed/protected by the fact that in such a case there are vents that emit hydrogen.

Figure 24: 5/HR-3UTG eneloop 6V NiMH battery

The pull from the various devices on the sensor and related components are shown in the following table. Note that all current pulls are rated for their absolute maximum rating to take into account any and all extreme cases/situations:

Component	**Current pull**
Photodiode	10 mA
LED	20 mA
MSP430	1 mA
LCD Screen	100 mA
Total	131 mA

Table 5: Current of Components

It is of utmost importance that the sensor lasts long enough to be useful for the duration of the testing and even better if it can be used multiple times. Once again the actual use of this device is going to remain unknown for now, but that does not mean that a logically good guess cannot be made as to how long it should last. Using the above numbers, the following equations shows the amount of time at which device can be used:

$$\frac{2000 \text{ mAh}}{131 \text{ mA}} \approx 15.3 \text{ hours}$$

15.3 hours should be more than sufficient for what this device may be used for. Another advantage is the fact that a 7.2 volt NiMH takes a maximum of around four hours to charge. This means that the efficiency of the battery in terms of usage time to charging time is at nearly 400%. Being unable to use the device and charge it at the same time is not a big problem seeing as how it only takes two of these devices to be able to operate them 24/7, 365 days a year.

4.1.3 Switch, Boost Converter, and Linear Regulator

The wires between the output of the rechargeable battery and the power bus must go through three more components. Due to the physics behind rechargeable batteries a 6 volt battery does not in fact output a 6 volt charge all the time; in fact it is much more often different from that value. The particular battery in use has a range of actually being valued at as high as 7.25 volts and as low as 4.5 volts. There are some components that may overheat due to the higher voltage. Even if damage is not caused almost immediately to the different components, the lifespan of the various electrical components will undoubtedly be significantly shortened. The 4.5 volts also becomes a problem thanks to the solution for the high voltage and inconsistent voltage issue.

Since the battery will always be considered “on”, it is important to detach it from any circuitry. This will simply be done with the following switch:

Figure 25: Basic switch

In order to acquire a steady voltage from the battery, a linear regulator will have to be used. This regulator is based on one major parameter: it must output a minimum of the highest voltage required by any component. For convenience, the voltage decided on was equal to the highest required voltage, which is 5 volts. The component which requires this voltage is the reference node on the microcontroller. All readings and data acquired through testing will be completely reliant on the accuracy of this voltage; for this reason a fluctuating or gradually decreasing voltage is completely unacceptable.

The following figure depicts the boost converter to be ordered:

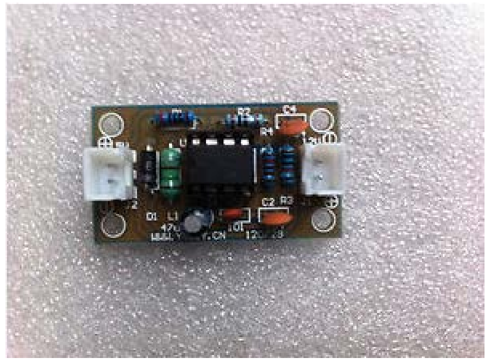


Figure 26: 5V to 12V boost converter

The problem with the linear regulator is that it will require a minimum of around 5.4 volts to work properly. An advantage to this device is that is function normally up to 24 volts which gives it a large range in which the boost converter can over-boost the highest voltages without causing any problems with the final output.

The following figure is the linear regulator that will be used:

Figure 27: +5V linear regulator

The reason 5V is sought after and not anything lower is because an op-amp will likely have to be used. Op-amps require a V_{cc} that the team will be unable to supply. There is no practical way to increase the voltage other than by using means unavailable for use. Since a direct and consistent power source is not available, the method for supplying the necessary voltage is more complicated than any member of the group had previously worked with. This made the power subsystem as a whole a research intensive portion of the project.

With the required 5V supplied to the main power bus, all components can now be properly powered. Using basic voltage divider circuits any voltage lower than the 5V will be capable of being attained. The most common required voltage outside of the 5V will be 3.3V. With all power properly supplied, the entire power subsystem is completely finished.

4.1.4 Collector Design

4.1.4.1 Collector Design Characteristics

The collector needs to efficiently absorb light in a range targeted on ICG's maximum fluorescence wavelength, specifically at 830 nanometers in wavelength. This means an 830 nanometer photodiode is required.

Photodiodes provide readily available sensing of light, as they generate current or voltage upon their active area's exposure to sufficient compatible light. To do this, they must simply be biased using an external voltage source. By biasing them in the reverse polarity, they are readied to generate current given a source of light.

The below table describes various photodiode wavelength absorption ranges for varying substrate materials. From this table, it is clear that Silicon, Germanium and Indium Gallium Arsenide photodiodes touch on the desired wavelengths of light. However, research into the performance of these various kinds of photodiodes provides insight that silicon diodes allow for much higher performance within the desired wavelengths of the sensor's target, for a much reduced cost. This is due to the fact that silicon photodiodes have much higher efficiency at the required wavelength with turning input source light into current to be read by the analog to digital pins.

Silicon photodiodes are much more specifically targeted, and supply a better reading for the design goals of this project.

Material	Electromagnetic spectrum wavelength range (nm)
Silicon	190–1100
Germanium	400–1700
Indium gallium arsenide	800–2600
Lead(II) sulfide	<1000–3500

Table 6: General ranges of photodiodes given varying substrate materials

However, the silicon photodiode collector range is still too broad, and must be limited by a filter external to the diode. If it is not, then the photodiode will completely absorb all light emitted from the emitter in addition to the targeted spectrum. Because of this, a filter outside of the emitter's wavelength range is required.

Since silicon photodiodes respond to a mixture of wavelengths from 190 nanometers to 1100 nanometers, and since this project requires a targeted collection of light from a narrow band surrounding the 830 nanometer wavelength range, a filter must be chosen to limit collected light to this small scale. A relatively small filtering band pass range should be selected to sufficiently mask out noise without masking out much of the desired signal.

Optical filters with small band pass ranges are readily available for multiple purposes. By selecting a filter surrounding the 830 nanometer wavelength band pass with a small degree of bandwidth relative to the emitter bandwidth, the signal received by the collector will be limited enough to not see any interference from the chosen emitter.

4.1.4.2 Collector Part Selection

ICG has been noted to show peak fluorescence around 830 nanometer wavelengths. The collector must be targeted to absorb efficiently this particular wavelength ranged.

This range is barely touched on with the use of Infrared photodiodes, but incorporated more comprehensively using visible range photodiodes. Visible range photodiodes show a desirable absorption peak around the sought 830 nanometers, which is desirable for strong readings.

The below graph, figure 4.1.4.2.1, is taken from www.thorlabs.com, and presents the visible light sensitivities of their various visible-light-range photodiodes in Amperes per Watt, as proportional to various light wavelengths. By observing these lines, it can be determined how many amperes of current are generated for any given amount of optical power input to generate that current.

As the graph clearly suggests, the sensitivity of their devices is very beneficial for the targeted spectrum of around 830 nanometer light wavelengths.
[http://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=285]

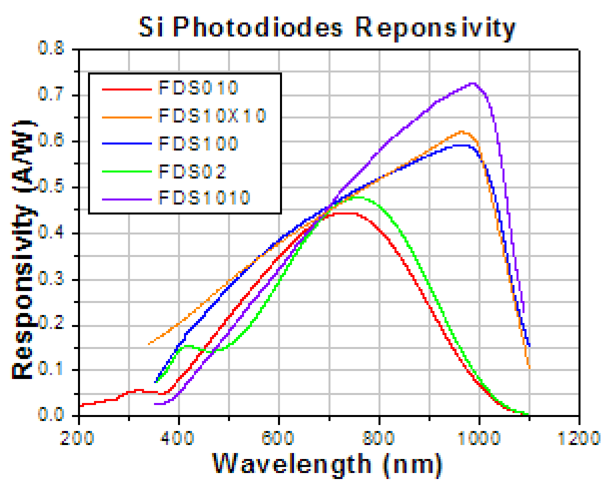


Figure 28: Spectral responsivity to varying wavelengths of light for Thorlab's various products for silicon photodiodes within the visible light range

Of the products listed in Thorlabs' roster for visible light photodiodes, the FDS10X10 and FDS1010 boast the largest exposure area, as squares with 10 and 9.7 millimeter widths, respectively.

Of these two, both have desirable responsivity graphs. They can be seen as the orange and purple lines in the figure above. The FDS1010 shows more responsiveness at the given wavelength of 830 nanometers. It would appear to be around .62 Amperes per Watt for this photodiode, whereas the FDS10X10 presents about .55 Amperes per Watt.

Moreover, the FDS1010, at a price of $48.80, weighs in at around half the cost of the $100 FDS10X10.

Thus, the FDS 1010 provides a cost-effective method to sense light waves in ICG's ideal fluorescence spectrum. It is available from Thorlabs for $48.80. The data sheet presents the max reverse bias voltage as 25 V. For simplicity's sake, the photodiode will be reversed biased to 12 V, since that is the voltage of the power source.

Below is a depiction of the FDS1010 silicon photodiode, chosen for this project, in figure 4.1.4.2.2.

Figure 29: The FDS1010 9.7mm photodiode:

4.1.4.3 Collector Circuit Diagram

The datasheet for the FDS1010 silicon photodiode reads a maximum reverse bias voltage rating of 25 V. Given the 5 V source provided by the design, the LED will be biased at 5 V.

The below figure 4.1.4.3.1, taken from the FDS1010 photodiode's Thorlabs spec sheet, displays the recommended circuit diagram for use with the FDS1010. The design implemented for the collector circuit will contain the same noise filter of 1 killiohms of resistance and .1 microfarads of capacitance. The V_o + terminal shown will be connected to one of the MSP430's analog to digital converter pins, and the Vo - terminal will lead to the common ground. The load resistor will consist of a 500 ohm resistor in order to convert current generated from exposed light into voltage readable by the analog to digital conversion pin.

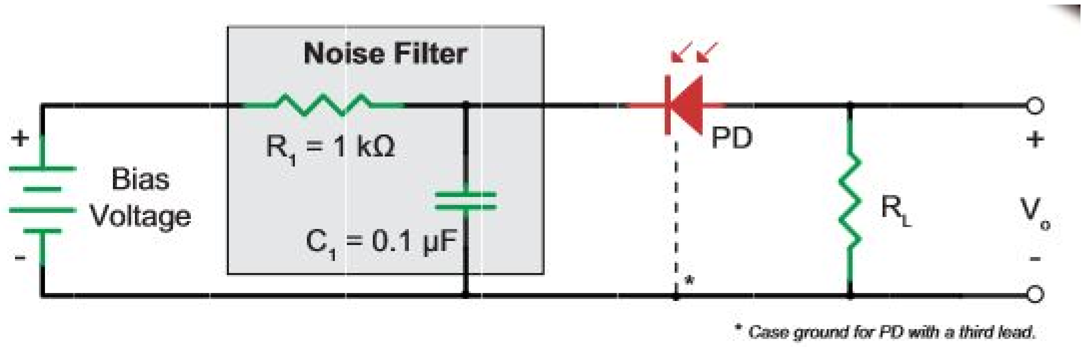


Figure 30: The suggest circuit diagram for the FDS1010 collector circuit

The spec sheet for the photodiode displays a rating of 1.05 nanoamps for dark current when biased at 5 V. This means that without any light input, 1.05 nanoamps will flow through the biased diode. The following table provides the steady state DC analysis of the circuit elements during this reverse bias current state.

	Voltage	Current	Power
Voltage Source	5 V	1.05 nA	5.25 nW
R1	1.05 uV	1.05 nA	-
FDS1010	5 V	1.05 nA	5.25 nW
RL	10.5 uV	1.05 nA	-

Table 7: The voltage analysis of the suggested FDS1010 collector circuit with no excitation light

This data shows that the effects of dark current are of negligible magnitudes.

The LED780E spec sheet establishes an optical power output of 18 milliwatts at 20 milliamps current. The performance of the collector circuit elements can be estimated by assuming different values for how much of this power gets successfully fluoresced by the dye and reabsorbed by the photodiode. The below table shows analysis of the circuit elements above for various photodiode optical power absorptions. These calculations are made assuming that the light absorbed is at 830 nanometers in wavelength.

The spec sheet for the FDS1010 shows graphically that at 830 nm wavelengths, the diode generates about .6 amps per optical watt of input.

Percent of 18 Watts Absorbed	Watts Absorbed	Current Generated	Vout	Power through R1 (1 k ohm)	Power through RL (500 ohm)
1	.18 mW	.108 mA	54 mV	11.7 uW	5.83 uW
2	.36 mW	.216 mA	108 mV	46.7 uW	23.3 uW
5	.9 mW	.54 mA	270 mV	292 uW	146 uW
10	1.8 mW	1.08 mA	540 mV	1.17 mW	583 uW
20	3.6 mW	2.16 mA	1.08 V	4.67 mW	2.33 mW
40	7.2 mW	4.32 mA	2.16 V	18.7 mW	9.33 mW
60	10.8 mW	6.48 mA	3.24 V	42.0 mW	21 mW
80	14.4 mW	8.64 mA	4.32 V	74.6 mW	37.3 mW
100	18 mW	10.8 mA	5.4 V	117 mW	58.3 mW

Table 8: The Voltage output and power analysis as functions of varying inputs optical power absorbed by the collector as percentages of light emitted by the emitter.

It is impossible for the collector to absorb one hundred percent of the 18 watts of optical power emitted by the emitter. As is apparent by the listed values, Vout approximately approaches 5 volts as the absorbed wattage approaches 18 milliwatts. Because of this, in non-ideal cases, Vout will not exceed 5 volts. This permits the design to utilize the same 5 volt source for the MSP430 ADC pin's voltage reference as the LED's power source and the voltage source used to bias the FDS1010 silicon photodiode.

This table provides a broad spectrum of the order of magnitude of the potential data ranges that may be received by the photodiode. It also provides data for maximum power ratings on the chosen resistor values.

This circuit was further simulated in the multisim environment to test various component values. The following was the circuit model implemented, using a current source as the photodiode.

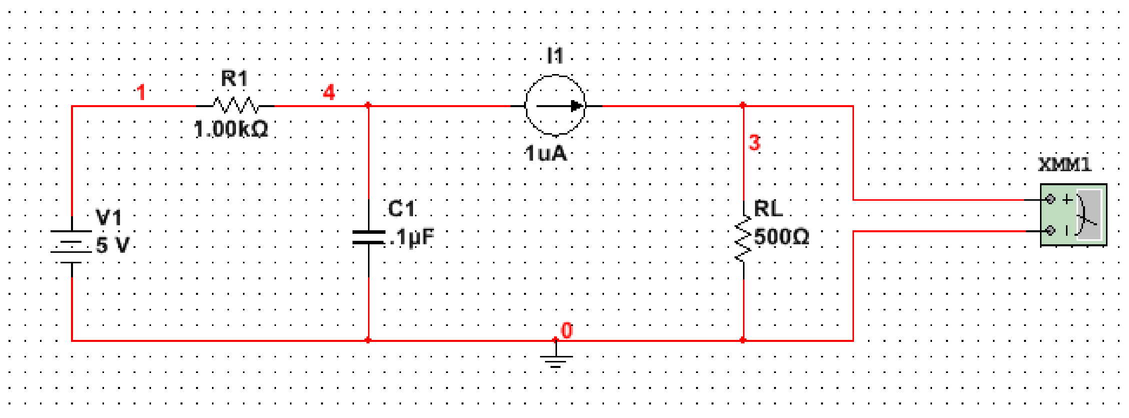


Figure 31: The simulated collector circuit, using a current source as the implemented photodiode

Upon simulating this circuit for its power characteristics, a DC sweep was performed. In this sweep, the current from the current source was selected as a variable term. This means that it could be altered many times by the computer in order to determine how the circuit would perform under a broad range of characteristics.

Using this DC sweep method, the power analysis for each resistor was discovered, as above. After the sweep, the following graph was obtained.

It displays with helpful clarity the performance of each resistor under the given amount of current. This provides useful information for the design. To make sure no resistors are burned, it must be made certain that no power ratings are exceeded. This graph allows the analysis of many circumstances at once, and displays the power ratings required for various ranges of analysis.

The starting point of 1 milliamp was selected as the lower test point. This marks the point where around 10 percent of the optical power output by the emitter was registered by the collector.

An ending point of 10 milliamps was selected as the maximum measurement value. This point represents around the value that would be generated by the photodiode if it experienced the ideal case of the photodiode receiving 100% of the optical power released by the LED.

This value, of course, is not expected, as it would require that all light output by the LED gets fully absorbed by the ICG without any scattering or divergence of signal. The light would then need to be entirely fluoresced by the substance, and then all reabsorbed by the collector, which would require all fluoresced light to be aimed back at the collector instead of its normal distribution.

However, the value may be approached under the circumstance of significant ambient noise, or the presence of signals that were not intended to be measured by the device.

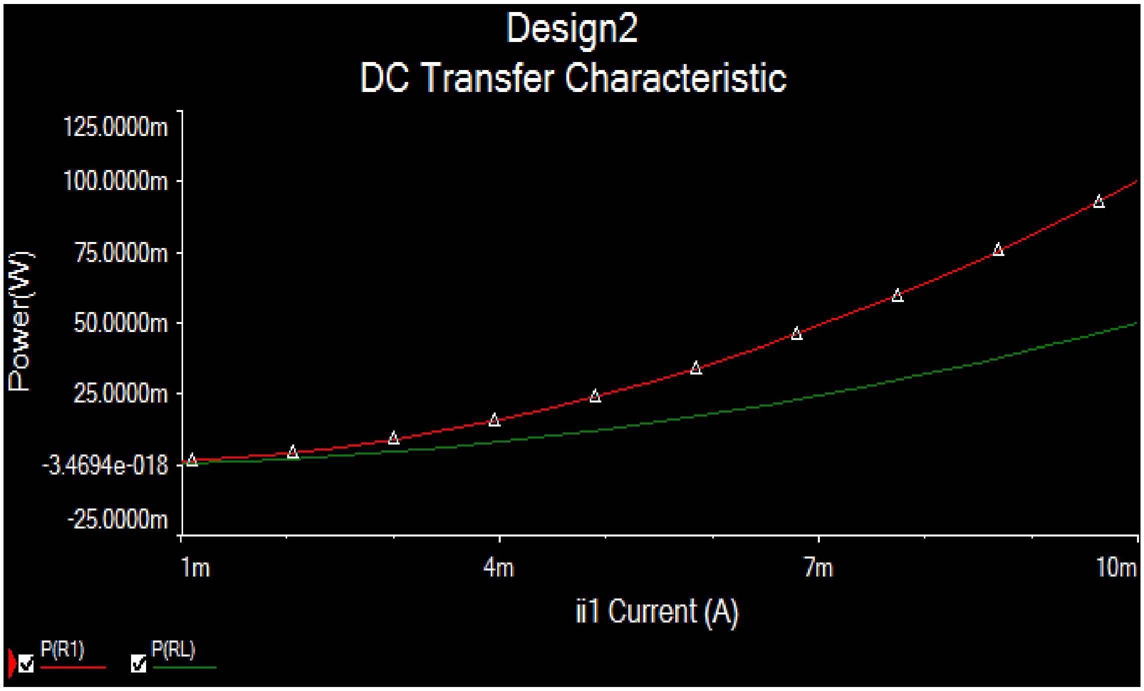


Figure 32: The DC current sweep power through Resistor 1 (red) and the load resistance (green).

As expected, the power through each resistor is on the order of milliwatts. The current through each resistor is kept equal due to the capacitor being considered an open circuit during DC steady-state analysis. This would cause the expected power through the two different resistors to remain a constant factor relative to each other. Since R1 is twice the resistance of RL, it can be easily observed that the power through resistor 1 is in fact twice that of the load resistor.

The values calculated by this analysis approximate the order of the values found in the hand-analysis of the table. Given this order of performance, the values displayed allow us to determine how to best measure the output voltage of the sensor.

The output voltage is generated by the current that the photodiode generates from the light it is exposed to. The generated current is then put through the circuit loop, dissipating power through the load resistor. This creates a voltage drop over the load, which can be measured in order to determine the sought signal. The voltage will be measured by an analog to digital converter located on the msp430's pins, and measured from an input reference value, which will be set at 5 volts, for convenience of measurement.

This operates like a Thevenin/Norton equivalent, as a current source (the FDS1010 photodiode) put directly through a resistor is the equivalent circuit to a voltage source across the same resistor in series.

Hence, the voltage across the resistor will give the reading sought by the design goals of this project.

To simulate this, the DC sweep option was once more employed, sweeping values from 1 milliamp to 10 milliamps of current generated by the photodiode. This relationship was determined to be linear, as a set factor increase in the photodiode's current generation creates an increase in load voltage of the same factor. The below figure displays the output of this current DC sweep simulation. As expected, the relationship is linear.

The load resistor of 500 ohms shows a relationship with current and voltage as in ohm's law.

This graph functions as a way to see how varying input in the form of fluoresced light will be viewable by the MSP430's analog to digital pins. By observing how this graph changes with respect to current output, it can be seen how increasing ICG fluorescence will be viewed from the point of the program. Increasing the fluorescence linearly will create a linear increase in the given voltage readings, with a predetermined slope. That slope will be identical to the one displayed in this simulation, and is determined by the value of the load resistor, since it generates the voltage from the current.

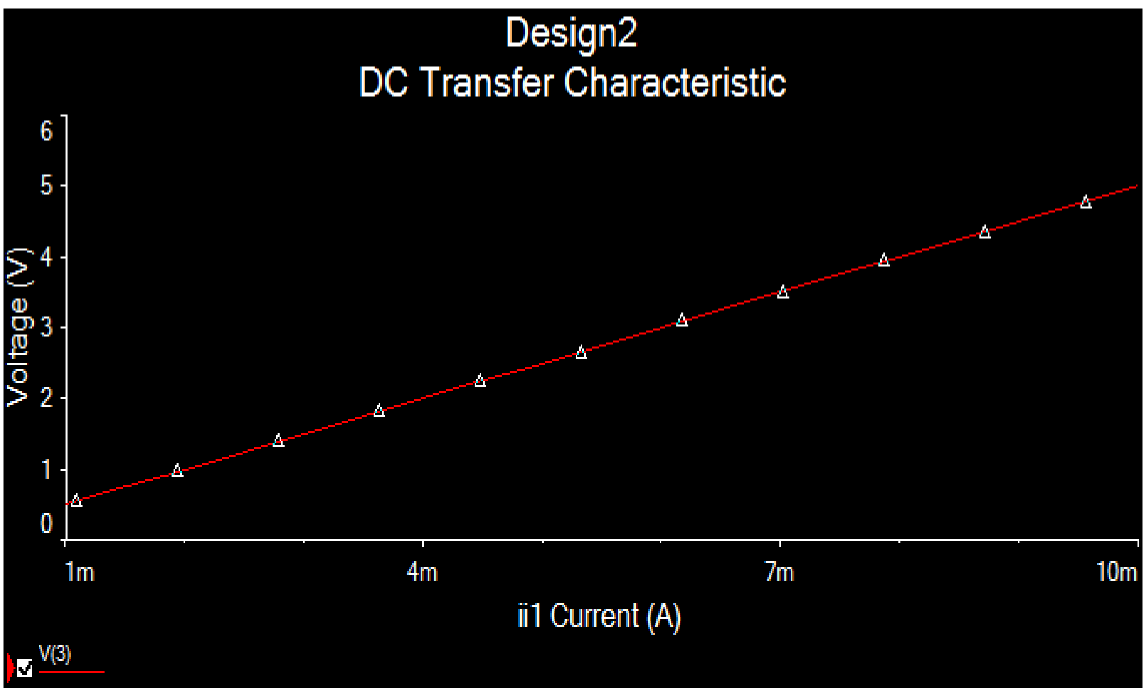


Figure 33: The DC current sweep displaying the voltage across the load resistor, to be measured by the Analog-to-Digital MSP430 pin

4.1.5.1 Emitter Design Characteristics

Due to the fluorescence properties of ICG, 830 nm wavelengths provide the maximum readings when sampled from blood plasma. The collector should be targeted for collecting optical fluorescence within a very short range of that value. To match this, the emitter should emit light on the order of 780 nm, so that fluoresced light is optimized for 830 nm.

From the below table, three potential emitter options are summarized. This table is mainly consulted for the sake of simplicity, as it displays the various capabilities of separate technologies researched to produce the excitation source light required of the emitter for exciting fluorescence in ICG. The requirements of the selected emitter for consideration involve cheap availability, and especially a helpfully limited but not monochromatic wavelength range.

Of the options presented in this table, Halogen lights have far too broad of a spectrum, making their use impractical for this project’s designs without an additional filter. This is because the wavelength range emitted by this light could easily overlap with the wavelength range which the collector will be targeted for. This would result potentially in large amounts of interference picked up within the collector directly from the emitter without yielding a proper signal. Moreover, the diode laser provides a wavelength range too limited for the design of this sensor, sense the emitter should provide a range of light so that ICG can more readily fluoresce to all light within the range. This is in addition to the higher cost of the diode laser, and thus disqualifies the laser from implementation.

Thus, of those options listed below, an LED presents the most attractive package for the sensor’s design intent. Its relatively narrow wavelength spectrum is perfect for providing a broad range of light to be fluoresced by the sampled ICG, while not running the risk of overlapping with the collector’s reading bandwidth, and hence providing a solid, reliable, non-interfering signal.

Property	Halogen	LED	Diode laser
Wavelengths	Visual-NIR	Rather narrow	Monochromatic
Price	Cheap	Cheap	Relatively expensive
Maintenance	Some	Not much	Some
Power	High	Rather high	High (pulses)
Pulses	Mechanically	Electronically	Electronically
Speed	Slow	Quite fast	Slow-very fast
Stability	Poor	Good	Good-very good
Special	Visual imaging	Small size	Extreme performance
Benefits	Cheap	Easy to control	No filtering needed
Drawbacks	High power loss	Filter needed	Speckle pattern
	Filter needed	New tech.	White light needed

Table 9: A comparison of different excitation sources for consideration

The major caveat with using LEDs as the emitter comes down to paying close attention to the emission wavelength band. LEDs have a relatively narrow emission bandwidth, and as such they are contained to a specific region for emissions. Thus, it must be made certain that this range does not intersect with the collector subsystem’s collection bandwidth, or the sensor will take in a heavy concentration of unwanted noise.

In addition, LEDs are readily available and very cheap. To find one within the expected 780 wavelength range for emission of the excitation light should pose no difficulty.

4.1.5.2 Emitter Part Selection

The emitter will be constructed of a simple circuit involving an LED targeted to emit near infrared (NIR) spectrum light wavelengths. It will, in addition, possess a specifically targeted Full Width, Half Magnitude (FWHM) limited to a range such that the collector does not read the light emitted directly. The Full Width Half Magnitude will limit the range of the emitted light to a certain distance from the centered light wavelengths, meaning that wavelengths past the Full Width Half Magnitude point from the center frequency will not be emitted.

This means that due to the currently selected filter’s range, the emitter’s Full Width Half Magnitude distance from the center point wavelength cannot enter the range of 820 nanometers or higher, since this emitted light would begin to directly interfere with the photodiode’s performance, causing it to register amounts of light not sought as the true signal.

The most readily available emitter for this type of performance has been selected from Thorlabs. They provide a 780 nanometer wavelength epoxy-encased LED. This maximum-magnitude wavelength is ideal for the absorption of light from ICG. The LED itself boasts a FWHM of 30 nanometers, meaning it emits light within the range of 750 nanometers to 810 nanometers in wavelength, providing a sufficient 10 nanometer gap of allowance before the lower end of the spectrum for the collector is reached.

This wide range of emission provides plenty area for the ICG to absorb and fluoresce light within the collector’s wavelength sensitivity range. A typical spectral distribution is displayed below in Figure 4.1.5.2.1, and showcases how spread out a typical LED of this caliber is when it comes to spectral distribution.

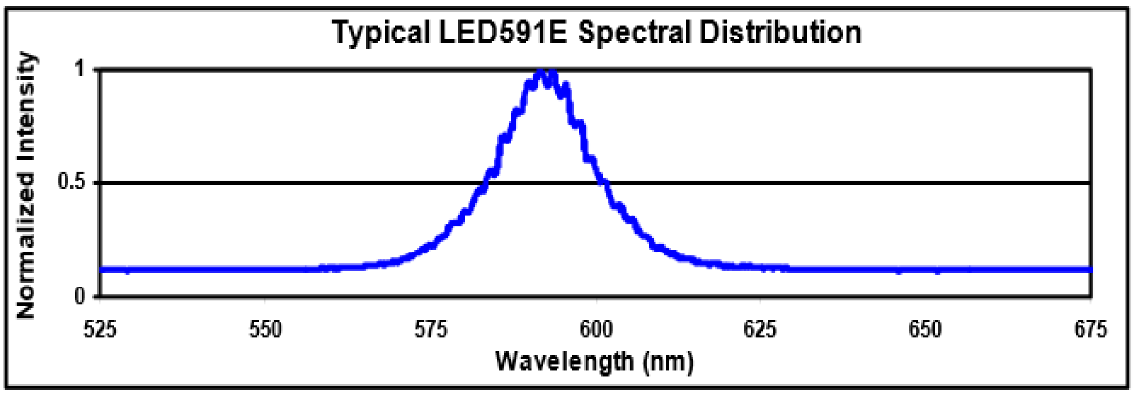


Figure 34: Typical Thorlabs LEDXXXE Spectral distribution, supplied by the Thorlabs Epoxy Encased 780 Nanometer LED spec sheet.

The below is a picture of the epoxy encased 780 nanometer LED. They are sold by Thorlabs in a package of five, for a total of $26. This package should provide plenty spares in case any part gets damaged.

Figure 35: The Epoxy Encased 780 nanometer LED

The spec sheet for this device gives the typical forward voltage as 1.75 V. This voltage shall be used in power analysis.

If one of these LED’s does not provide enough light to fluoresce from ICG adequately, the potentiality for multiple to be applied is always available, as all five will be ordered regardless.

4.1.5.3 Emitter Circuit Diagram

The emitter and collector have simple circuit designs. All that these circuits must do is to emit and to collect light, respectively.

The emitter circuit is particularly simple. The below figure displays a simple representation of the basic implementation of the chosen LED. The LED datasheet provides the following statistics for the LED: It possesses a typical forward voltage at 20 milliamps of 1.75 volts and a maximum of 1.95 volts, a maximum of 100 milliamps current, and a power dissipation of 190 milliwatts.

For a typical LED circuit, a resistor is hooked up in series with the forward biased LED. A 5 volt power source would indicate that after a voltage drop of 1.75 volts across the LED, 3.25 volts must be lost across the resistor. Since the LED is designed to output light at most efficiency with 20 milliamps of current, the resistance needed can be calculated from Ohm’s law, as follows:

$$V = I * R$$

$$3.25 = .02 * R$$

$$R = 162.5 \text{ Ohms}$$

For the sake of preventing any burnt components, the power consumed by the resistor is calculated as follows:

$$P = I^2 * R$$

$$P = 400 * 10^{(-6)} * 162.5$$

$$P = .065 \text{ Watts}$$

Thus, a 162.5 Ohm resistor rated for .065 Watts is required for the LED circuit.

This circuit was further analyzed using the analysis client Multisim. In order to more fully understand the performance of this circuit given its simple operation.

For this analysis, the closest LED to this project's selected parameters was used. The chosen LED for the simulation was an infrared LED, and had an active voltage of 1.825 volts, as opposed to this project's selected diode, which yields 1.75 volts. The current through the circuit was measured, and even though the diode parameters are slightly different, the current was discovered to be nearly the same. This is displayed in Figure 4.1.5.3.1 below.

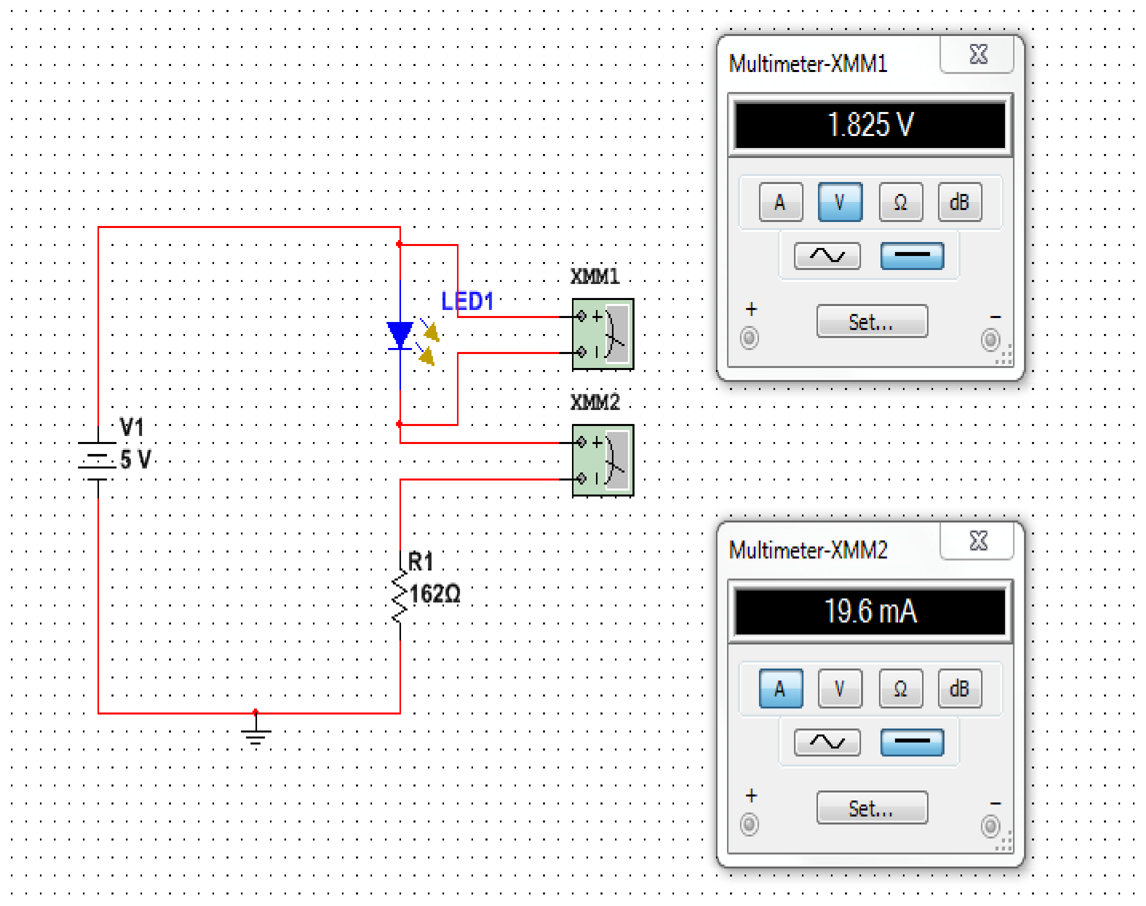


Figure 36: The Emitter Circuit Simulation

4.1.6.1 Filter Design Characteristics

As stated in section 4.1.4, the collector in its unfiltered state does not provide the proper capacity to measure the sought signal. This is due to its responsiveness to wavelengths of light. The silicon photodiode wavelength responsivity has a very broad range over many wavelengths of light. Its capacity begins in the visible wavelengths, and extends well into the beginnings of the near-infrared spectrum.

Because of this, obtaining a signal at a specific limited predetermined range is nearly impossible. This is due to the large amount of ambient noise involved. If the photodiode responds to every wavelength available within that broad range, the sought signal at the specific frequency will be overpowered by all the other magnitudes of surrounding wavelengths.

This calls for a specifically chosen optical filter. The filter should provide a relatively narrow Full-Width-Half-Magnitude bandwidth, to allow only a specific range of wavelengths through. This range should correspond to a tight and constrict area around the peak wavelength fluorescence of Indocyanine Green.

Since the peak fluorescence value of Indocyanine Green is 830 nanometers in wavelength, the filter should consist of a narrow wavelength bandwidth focused on the 830 nanometer wavelength.

4.1.6.2 Filter Part Selection

Since the FDS1010 and its family of photodiodes pick up all light from 400 to 1100 nanometers in wavelength indiscriminately, the light given off by the emitter combined with the ambient noise the sensor is exposed to should create a significant need for filtering. These ambient signals pose significant difficulty for accurately measuring the sought signal, as the interference would prevent the underlying information from standing out. By filtering out all light except a short range around the maximum fluorescence magnitude value, the ambient interference as well as the light directly from the emitter can be minimized, allowing the true signal to become readily available.

This filtering should allow for a much higher signal-to-noise ratio, providing a significantly robust signal from which to analyze data. The data for analysis must be specifically the light released only from ICG after it has absorbed and re-fluoresced the light.

The ideal collector wavelength for reading ICG fluorescence from ICG dissolved in blood plasma is 830 nanometers. Since this is the maximum fluorescence range for ICG, a narrow band pass filter centralized around this value should provide ideal noise reduction, allowing the system to hone in on the desired data.

The figure below, taken from www.thorlabs.com, presents the specifications of a line of filters produced by Thorlabs. These filters provide a well-contained, compact band pass light-filtering functionality.

The specific filter in consideration for purchase is the Thorlabs FB830-10-Ø1” Band pass filter.

The one inch diameter of this filter fits quite nicely over the selected photodiode of a square of width 9.7 mm. This means that the filter fits perfectly over the square photodiode, allowing full exposure of our sensor to the incoming light. With this filter fitting so nicely over the photodiode, the manufacturing of the casing should prove a much simpler task when considering how to fabricate the covering and how to generally design it.

A typical transmission spectrum graph is shown in the image below. For this particular filter, the full-width-half-magnitude (FWHM) wavelength is a narrow 10 nanometers, significantly filtering out ambient noise. Its maximum transmission wavelength around which the FWHM is centered is 830 nanometers, which has been stated already as the ideal measurement point. This means that this filter provides an ideal transmission focal point, allowing the most efficient measurements to be taken. Moreover, the full-width half-magnitude provides ample enough closure to block out the bulk of the ambient interference.

Thus, the FB830-10-Ø1" filter when fit over the selected FDS1010 silicon photodiode, will provide significant amperes per watt input of light whenever significant amounts of light of wavelengths 820 nanometers to 840 nanometers is projected through the filter and into the photodiode's active area. This range provides plenty of potential exposure to fluoresced light. However, it also amply masks away interference like that could cause significant reading errors. This includes light directly from the emitter.

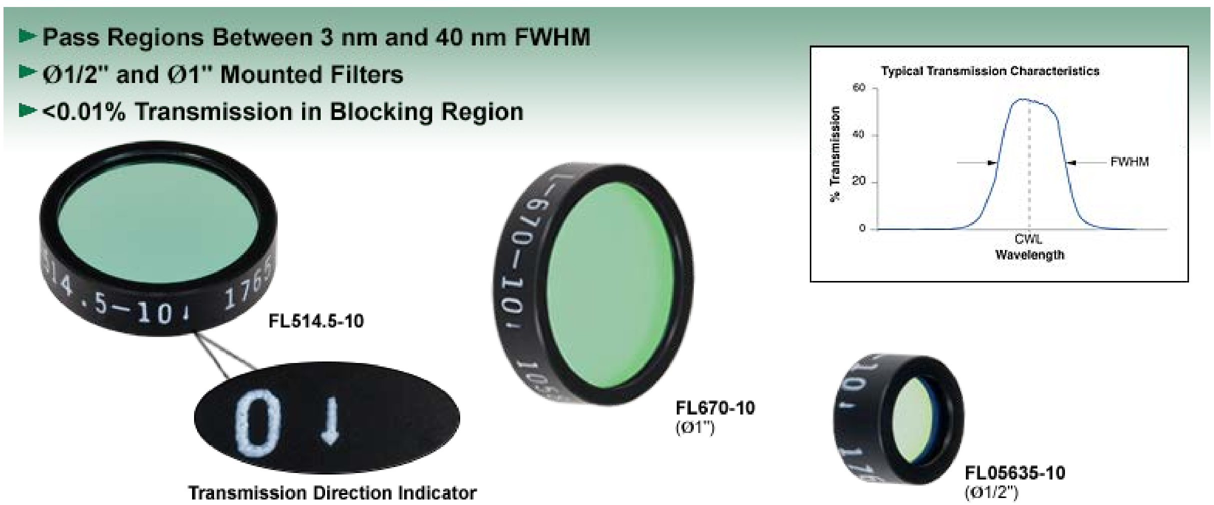


Figure 37: Filter

4.2 Controller-Display Subsystem

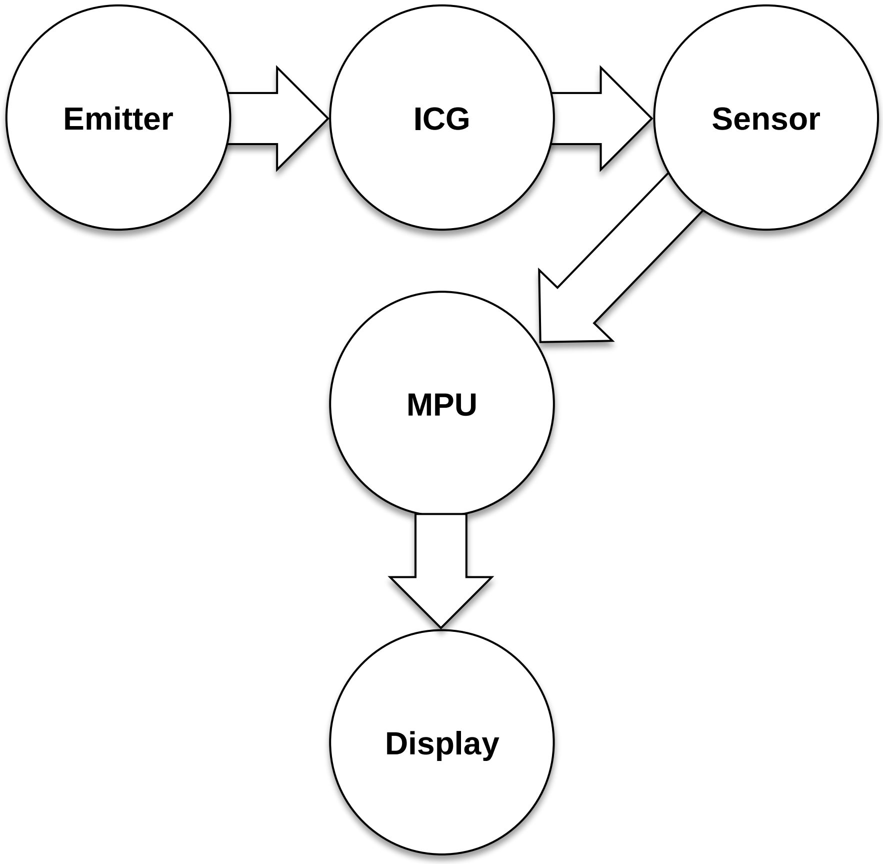


Figure 38: Hardware I/O Diagram

4.2.1 Microcontroller Subsystem

Option 1: Arduino Uno

The Uno is an Arduino board based on an ATmega328 microcontroller. It features fourteen digital I/O pins with four analog inputs. Fourteen pins may be enough for our needs, but it provides no room for expandability. If a fault is found in the design later on that would require an additional peripheral, there would be no available pins and a new board may be required. The Uno runs at 16 MHz with an input voltage range of 6V - 20V with a recommended range of 7V - 12V. The input voltages are a bit high; the power system is being built around the 3V – 5V range. Using an Uno would mean stepping up the voltage or procuring a different set of batteries.

The Uno has a large moment of memory. At 32 kB of flash with half a kilobyte reserved for the boot loader. Its memory would be more than enough for this project. Coupled with the 16 MHz processor; the Uno would quickly execute any software thrown at it. Purchasing the Uno would mean having access to Arduinos' microcontroller libraries. These libraries are very robust and easy to use. Having access to these APIs would greatly simplify software development.

Option 2: Arduino Mega

The next option is an Arduino Mega. Powered by an ATmega1280 the Mega is overloaded with fifty four digital pins with sixteen analog ports. Fourteen of these pins can be used to send a PWM signal. With this many pins the device is future proof if more components are added. The Mega is powered with a 16 MHz processor and has 128 kB of flash. Both numbers are outstanding and should be enough for the purposes of this project. The Mega comes with the same power requirements as the Uno with a recommended range of 7V - 12V but limits of 6V - 20V. This poses the same problems as the Uno as the power systems are just not designed around those lower limits. And like the Uno the Mega comes with full support of Arduino's microcontroller APIs.

Option 3: MSP430 LaunchPad

The third option is TI's MSP430 LaunchPad. The launch pad provides twenty digital pins, giving it more than enough expandability. The processor is clocked at 16 MHz and has 16 kB of flash memory and 512 B of RAM. The processor is well suited for power the software being developed, but the RAM may be insufficient. Power requirements, though, are within the specified range at 1.8V – 3.6 V. The MSP430 is designed for low powered environments, giving it an advantage in power consumption. The MSP430 is also a board the members of the group already have experience with. The entire group has experience programming the board with both C and assembly.

Decision

The MSP430 LaunchPad was chosen primarily since all members of the group have experience with the microcontroller and are familiar with the programming of the chip. The entire team has taken a course requiring the study of the MSP430. We have extensive knowledge of the controller and experience built upon several labs utilizing the device. The programming environment is familiar to the group and Texas Instrument's IDE (Code Composer) is free of cost and simple to use. Code Composer supports either C or assembly and the binaries can be written to the flash memory by a micro USB port.

MSP430 LaunchPad Features

- 16-bit CPU
- 20 digital GPIO
- Mini USB input
- 16kB flash

- 512B RAM
- Supports interrupts
- 16 bit timers including a watchdog timer
- 8ch 10-bit ADC
- Comparator
- Supports serial communication standards
    - I2C
    - SPI
    - UAR
- Supports MSP430G2xxx chips
- Input Voltage
    - 1.8V – 3.6V

Some advantages of the MSP430 are its low cost. The 430 is two to three times less expensive than some Arduinos with comparable features. Keeping the cost of the device low will greatly improve its marketability. The team also already possesses a number of LaunchPads from a previous class, so software development can start right away. The 430 also has an abundant number of general purpose input/output pins. With our current design only fourteen pins are needed. With two unused pins left over; we can add additional features in the future. Most GPIO on the 430 can be used for either analog or digital I/O, making it very versatile. It will allow for a wide range of combinations that will support most peripheral analog/digital line compositions.

Memory on the MCU is limited however. There is 16kB of flash memory and only 512B of RAM. Programming the all the required features on this controller may prove difficult because of the memory limitations. Finally the 430's input voltage range fits within our power scheme and the controller itself is made for low power environments. Directly below is pin out of all peripherals and their associated I/O on the LaunchPad.

MSP430 Pin	**I/O**	**MSP430 Pin**	**I/O**
P1.0 (digital out)	Display D0	P2.6 (digital out)	Display CD
P1.1 (digital out)	Display D1	P2.7	Unused
P1.2 (digital out)	Display D2		
P1.3 (digital out)	Display D3		
P1.4 (digital out)	Display D4	P1.7 (analog in)	Sensor In
P1.5 (digital out)	Display D5	P1.6 (digital out)	Display W/R
P2.0 (digital out)	Display D6	P2.5 (digital out)	Display RD

P2.1 (digital out)	Display D7	P2.4	Unused
P2.2 (digital out)	Display CS	P2.3	Unused

Table 10: MSP430 pin out

4.2.2 Display Subsystem

Controller-Display Interaction

The controller will be continuously sent luminosity levels from the photodiode sensor. The MSP430 will use a voltage comparator to find the ratio of the input voltage to a 5V reference provided by the power subsystem. The embedded software will read these values, record them and create and update a time graph of the incoming data. All controller output will be piped to the display using multiple digital or analog pins.

Display Technology

For the purposes of this project, an LCD display will suffice. LCD panels are most commonly built on TN (twisted nematics) technology. These liquid crystals are naturally twisted, but when an electric current applied; untwist. The manner in which these crystals react to a current is very well understood. Manipulating the current allows the passage of light for individual pixels to turn on or off. The crystals themselves produce no light of their own; a backlight is needed illuminate the display.

Output

There are two possibilities for output currently being discussed. The more simple approach would be to just display a magnitude. This would involve measuring the signal, then programing the necessary pixels to display a numeric output between 0 and 100. Software would be needed to convert the signal from a pin, then scaling it to programming the three digits of precision to the display. Going with this route would ease our display requirements. The project would no longer need a display with at least 30 PPI, instead a simple monochrome 16x2 LCD would suffice. It also has an added benefit of reducing the overall cost of the device. The disadvantage being that the history of the measurements would not be recorded or easily available to the physicians.

The second approach involves incorporating a more complex graphical LCD. A display would be needed with the capabilities to displaying a time graph. This will allow displaying the current magnitude and also the previous values of the level of indocyanine green in the patient. Such a feature would be useful for medical personnel to monitor the levels of indocyanine green currently in the patient, the rate of change, past intensities of dye, as well as other applications. Information such as the slope of the graph may prove useful in its applications as a blood-oxygen level sensor. The device is currently being designed with the assumption that we will be displaying a time graph according to this approach. Below is a possibility of what the final output will look like.

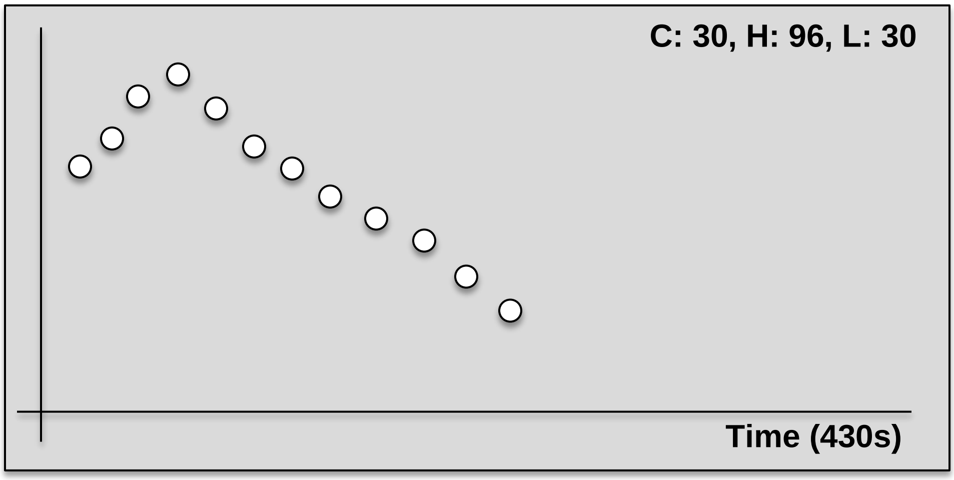


Figure 39: Possible time-graph output

Option 1: COG 128x64 Graphic LCD Module

Our first option is a 71x52mm, 128x64 pixel COG LCD panel. With this resolution either a time graph or only the magnitude of the indocyanine green can be displayed. At this size and pixel count, its PPI also exceed our minimum requirement. To power the LCD; a voltage of -0.3 to 7 volts will be used and a voltage of -0.5 to 11 volts will be needed to power the panel's logic. These power lines will be coming from the main controller, which will also be routing the signal from the sensor and possible amplifying and/or converting that signal to a wave the LCD can understand.

The LCD will need an input of between -0.3 to 0.3 volts. The individual pixels of the display are controlled through onboard memory by an array of 132x65 bits of RAM. Each bit can be configured to represent the desired state of a corresponding pixel. And it is guaranteed that writing to the RAM while a read operation occurs will not cause any flickering; as the input is writing to an I/O buffer beforehand. This monochrome display is a very viable option and will suit all of our design specifications.

Option 2: Serial Graphic LCD 160x128

The second option is a 4" diagonal 160x128 LCD with either a blue background on white text. The LCD can be configured to reverse the background and text colors. The Serial Graphic display exceeds our minimum pixel density at 32 PPI as well as being a good sized LCD. It can operate on 6-7V DC and at 100%

backlight; takes 220 mA to power. The Serial Graphic takes an input of 0-5V with six different baud rates up to 115,200 bps. It uses a serial input line with 8 bits of data with 1 stop bit. A potentiometer is included to adjust contrast levels. The Serial Graphic is the most expensive display being considered, but it's also the largest with the highest pixel count. And considering the voltage needed to power the display, the power system must be able to either step up to the required 6-7V or the power supply must be brought down to around 5V to power the microcontroller and other peripherals.

Option 3: 16x2 LCD

The next and most minimum option is a 16 character by 2 row LCD with built in LED backlight on a blue background with white text. It supports an English character set with support for foreign language characters. There is also a potentiometer to adjust the contrast. To control this character LCD we will need six pins; an RS pin for the type of command being sent, four data lines for the character data being sent and an EN pin to enable reading of the four data lines. Powering this LCD will be a simple matter as it just needs a 5V line to power the onboard logic and .3V to power the actual LCD.

This is by far the simplest display available and the most inexpensive. It would be perfect for showing just the current magnitude of the levels of ICG present in the patients' blood. This display, of course, does not meet our design specifications. It is merely a redundancy in case we decide to opt out of developing a time graphic output for this device.

Option 4: Nokia 5110/3310 Monochrome LCD

The fourth option is a 1.5" Nokia 84x64 LCD display. Its dimensions and resolution give it a PPI of a little over 40. The 5110 also has a built in backlight, perfect for our purposes and only requires a 3.3V to power the display and 3V lines for everything else. It also draws around 80mA maximum with the LEDs enabled. With the low power requirements, we would not need to step voltages up or down in order to utilize this display.

The 5110 needs five lines to control the display; a reset, chip select, data/command, an 8 bit data in and a clock line. Being able to control the 5110, with just five digital lines will simplify our microcontroller design, as well as free up pins for other functions. Adafruit also provides a graphical library for this LCD with support for bitmaps, shapes and text. Originally built for Arduinos, their libraries would need to be ported and compiled for the MSP430.

Option 5: 2.8" 18-bit color TFT LCD (ILI9328)

The last option is a 240x320 18 bit color TFT LCD with resistive touch capabilities. The display has a diagonal length of 2.8” and a PPI that very well exceeds our requirements. The ILI9328 comes with four backlight LEDs and can run on anywhere from 3V-5V. There is also enough onboard RAM that the microcontroller would not need to buffer the display’s state. The power requirements fit perfectly within our power scheme and no additional circuits would need to be designed around the display. The price paid for the bells and whistles though, is the complexity of driving the display. A total of twelve data lines; 10 digital and 2 analog will be needed to control the device (including touch screen capabilities). And as with the Nokia 5110/3310, Adafruit has provided an open source library capable of drawing text, shapes, and color bitmaps for Arduinos using C++. Of course we will not be using an Arduino for the purposes of this project.

Decision

Based on the design specifications and factors such as cost, ease of use and functionality the ILI9328 was chosen. The ILI9328’s size is perfect for our applications. Its resolution also eclipses that of any other potential display. And as an added bonus, it features a resistive touch screen, allowing us another type of input without the hassle of wiring up physical buttons. Another significant advantage is its ability to operate on 3.3V, meaning it can draw power from the same source as the MSP430 without complicating the power systems. It also has over 100 kB of RAM and can buffer the images itself. With just a monochrome display and bits representing the state of individual pixels would require 9.6kB alone, way more than the MSP430s half a byte of RAM. Lastly, having an open source graphical library will be useful as a reference. While Adafruits’ API is written for Arduinos in C++, the MSP430’s programming only allows instructions in C or assembly itself. The software team will be responsible for writing the customized software for the 430.

The ILI9328 Features

- TFT Liquid Crystal Display
- 240x320 RGB
- 262,144 Colors
- 172,800 bytes of RAM
- VSYNC
- 720 channel source driver and 320 channel gate driver
- Interfaces
    - i80
    - Serial Peripheral Interface (SPI)
    - RGB Interface
    - VSYNC Interface

- Power Saving Modes
    - 8-color mode
    - Standby mode
    - Sleep mode
- Input Voltages
    - 1.65V - 3.3V (input/output)
    - 2.5V - 3.3V (analog)
- Logic Voltage
    - 3.3V - 5V

The display itself will need twelve digital pins and the resistive touch input requires two digital pins and two analog pins. Pins will be reused so that only ten digital pins and two analog pins will be needed to control the entire display. This is due to the fact that the panel's resistance is high enough that it would not interfere with digital I/O and the reading of these pins would only occur in between LCD input. The display will need a 3V - 5V source and a ground, both will provided by the MSP430's V_{cc} and GND pin respectively. The eight digital control lines will run through the controller's 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 2.0, and 2.1 pins. Chip select (CS) will be wired to 2.2, the command/data (C/D) pin will be wired to 2.6, the write/read (W/R) to 1.6, read (RD) to 2.5, and reset (RST) tied to the MSP's own reset pin so a MCU reset will trigger an LCD reset. The touchscreens Y- pin and X- pins have to be connected to P.0 and P.1. And X+ and Y+ pins to the 1.2 and 1.3 pins.

The LCD will be responsible for displaying data from the sensor as a time-graph. A custom API will have to be made to support such a feature. Adafruit does have an open sourced library to control the display, unfortunately it is written for Arduino boards using Arduino libraries. A software team will have to write their own libraries to implement all of the planned features. Adafruit's library though will prove to be an excellent reference to how to go about writing the necessary software. Features for the device include the ability to manipulate individual pixels in the display, draw lines and simple shapes such as rectangles and circles.

4.3 Controller-Display Subsystem Software

4.3.1 General Code Outline

The code controlling this device will essentially consist of sampling the data input from the sensor and manipulating it into displayable data, then outputting it onto the LCD display. It will follow a fairly linear structure:

1. The code will start by defining the various pins on the MSP 430 Launchpad as variables for easier understanding of the code. This is also where the other components of the code will be defined, such as the

storage array for the sample values, the final average of the samples, a linked list for storing the heights of the data points, a timer for resetting the graph, etc.

2. The LCD_Layout method will display the static information on the LCD screen, such as: The graph outlines, height of the graph (Minimum light intensity and Maximum light intensity), and a grid for reference, if desired.

3. There will be two main functions used in interaction with the sensor. These functions will be triggered thirty times and averaged for thirty samples per displayed value.

    a. The first function will retrieve the voltage signal input from the appropriate pin input.

    b. The second function will be interpreting the voltage signal and converting the inputted value into a usable format number, a hexadecimal byte, 0-255 that will indicate the light intensity of the sample. This value will be stored in the samples array until they are all averaged together.

4. An arithmetic function will both store the thirty samples in an array as they are taken, and store the averaged value of all thirty samples in a separate variable, Avg_of_Samples.

5. The positioning function will take in the Timer and the Avg_of_Samples, and these values will be used to determine the next pixel location on the graph to display the next data point, and will set the appropriate height of the data point at the newly created end value in the linked list. If the end of the graph has been reached (the final column), the array will reset to the beginning (the first column) and overwrite each previous value as it is reached. Alternatively, when the end of the graph is reached, the entire graph will shift one pixel to the left, erasing the oldest value and inserting the new value in the rightmost column.

6. After every value is added to the linked list, the LCD is refreshed to show the full graph including the new position, the previous, non-overridden positions, and an indicator indication the newest position.

7. A more in depth discussion of the LCD interface code can be found in Section 4.2.5 Display Software

Arithmetic algorithms are discussed in the following section along with a more detailed discussion of the individual processing functions.

4.3.2 LCD Layout

The values that display on the edges of the graph as reference will be the chosen minimum, median value, and the chosen maximum of the corresponding measurements. Light intensity along the left edge, vertically, and time will be on the bottom edge.

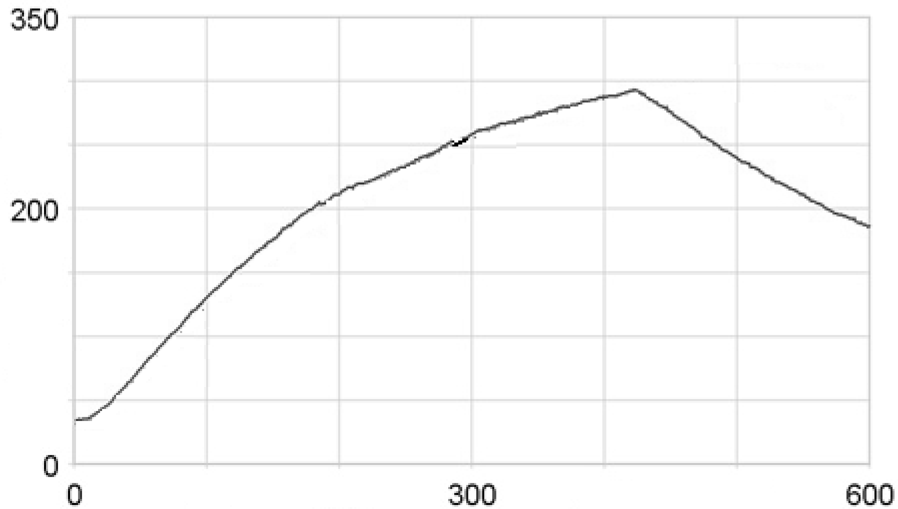


Figure 40: Example of LCD Graphical Layout

The graph will take up the majority of the screen and can be manipulated by some user preferences. The rest of the screen, as shown in Figure 4.2.2.3, will be used to display the data points or calculations performed on the data set, again chosen by certain user selections, with more discussion in the following sections.

4.3.3 Timing and Value Information Functions

The Information button will be used to interact with the device for generic information or viewing preferences, and not for mathematics or data manipulation. Due to limited space, the LCD will be able to display only a single value at one time, in a designated space relative to the main graph. Some of the values will be editable to allow the user to change how the data is collected or displayed.

Time Period

When the Information button **[Info]** is selected initially, the first item displayed will be the current length of time between each sample collection. This value can be adjusted using the plus **[+]** and minus **[-]** buttons and the changed value will be reflected in the speed at which the graph fills in.

Maximum Time

When the Information button **[Info]** is selected while Period is showing, the next item displayed will be the current Maximum time to reach the end of the graph. This value cannot be edited as it is the product of the time period between each sample and maximum number of data points (pixels) displayable in the graph space on the LCD

Maximum Light Intensity

When the Information button **[Info]** is selected while Maximum Time is showing, the next item displayed will be the current Maximum Light Intensity value displayable by the graph. This value can be adjusted using the plus **[+]** and minus **[-]** buttons and the changed value will be reflected in the values of the Maximum and Median along the left edge of the graph.

Minimum Light Intensity

When the Information button **[Info]** is selected while Maximum Light Intensity is showing, the next item displayed will be the current Minimum Light Intensity value displayable by the graph. This value can be adjusted using the plus **[+]** and minus **[-]** buttons and the changed value will be reflected in the values of the Minimum and Median along the left edge of the graph.

Note: the data points displayed on the graph will be shown on the pixel closest to the actual value, rounding up for a draw. For example, if the Maximum is 100 and the Minimum is 0 and the graph space is 25 pixels high, the value of 49 would be shown on the 12^{th} pixel from the bottom, while the value of 50 would display as the 13^{th} pixel.

Grid State

When the Information button **[Info]** is selected while Minimum Light Intensity is showing, the next item displayed will be the current Grid state. If this value is true, the grid displayed in the background of the graph for reference, and if false, the grid is switched off. This value can be adjusted using the plus **[+]** and minus **[-]** buttons to allow the user to toggle the grid off and on. The grid may require the use of the backlight to be more visible.

Graph Display Type

When the Information button **[Info]** is selected while Grid State is showing, the next item displayed will be the current Graph Display Type. This allows the user to cycle between:

- Normal curve, the default graph, displays the data as a continuous curve with respect to time.
- Bar graph displays the data as a series of columns. This display is more useful for showing outliers in the data. Very high measurements will be represented as much taller than the adjacent samples and can indicate high concentrations of the fluorescing liquid. Very low measurements will be represented as much lower than adjacent samples and may represent a drop in blood flow.

This value can be adjusted using the plus **[+]** and minus **[-]** buttons and the changed value will be reflected in the different graphs that are displayed.

After the Graph Display Type information is reached, pressing the info button will return the user to the Time Period value and begin the cycle again.

4.3.4 Mathematical and Data Manipulation Functions

The Math button **[Math]** will be used to interact with the device for more complex mathematical functions and information. Due to limited space, the LCD may need to switch its display and switch back to the graph on a cycle. Some of the values will be displayed along with figures to indicate what the figure represents. This will allow the user to view relevant data that is calculated from the collected and displayed information.

Average Intensity Measured

This will call a function that will take the sum of all gathered measurements and divides the sum by the total number of measurements taken in the current time period. This average will be displayed in the information window on the display.

Maximum Intensity Measured

As the measurements are taken, the maximum measurement is saved, and every time a greater measurement is taken, the maximum is replaced with the new value. This will call a function will display the current maximum in the information window on the display.

Minimum Intensity Measured

As the measurements are taken, the minimum measurement is saved, and every time a lesser measurement is taken, the minimum is replaced with the new value. This will call a function will display the current minimum in the information window on the display.

Current Data Curve Slope

One of the measurements that can be gathered is the slope of the curve formed by the most recent data points, giving the indicated direction of the fluorescence intensity. This value can be obtained by taking the derivative of the curve, or more easily, the slope between the last two data points. The latter option will be easier to perform with the limited processing power of the microprocessor and limited RAM. This will call a function will display the current slope in the information window on the display.

Average Data Curve Slope

A similar measurement calculated is the slope of the curve formed by all of the data points in the current set, giving the indicated direction of the fluorescence intensity for a longer time period. This value can be used in relation to the current slope to determine if the intensity is increasing or decreasing at an accelerated rate.

Data Curve Integral

Another of the measurements that can be gathered is the area under the curve formed by the data points, giving the integral of the fluorescence intensity. This value can be obtained by computing the integral of the curve, or more easily, measuring the area beneath each two data point and adjusted as necessary. The latter option will be easier to perform with the limited processing power of the microprocessor and limited RAM. This will call a function will display the current calculated integral in the information window on the display. The graph will fill in the area beneath the curve on the graph display. This view will only display when the integral data function is selected.

4.3.5 Software

Software Design

This section will detail the software library to be developed to control the display and output the necessary time graph and text required. The API will be written in C on TI’s Code Composer Studio. Using a higher level language instead of assembly will put a layer of abstraction between the developers and the physical hardware of the controller.

At startup the display will be initialized and all axes and labels will be written. All values will be set to their default values. The watchdog timer will be disabled and a timer will be started to show the time elapsed since the device was started. All pins and their direction will need to be set.

An empty linked list will be allocated memory and chained together. The purpose of the list will be to store incoming values passed to it by the microcontroller. Every data point on the graph will correspond to a location within the list. As that list gets full, the graph will be shifted left to make room for incoming data. Utilizing an array would mean shifting all the information within the array left and clearing *n* nodes at the end of the array. The runtime of such an algorithm would be O(n). With our low powered microcontroller; this option did not seem prudent. Having a linked list would decrease a shift to constant time or O(1) with two pointers. One pointer will save the location of the head of the list and the other the tail. Every time a shift is needed, the head pointer will be moved *n* nodes down the list, the *n* nodes would be appended to the end of the link, then the graph cursor would be set to overwrite the newly moved nodes at the end of the list. This would greatly reduce the CPU cycles necessary for storing the data points, but would require approximately twice the memory of implementing an array.

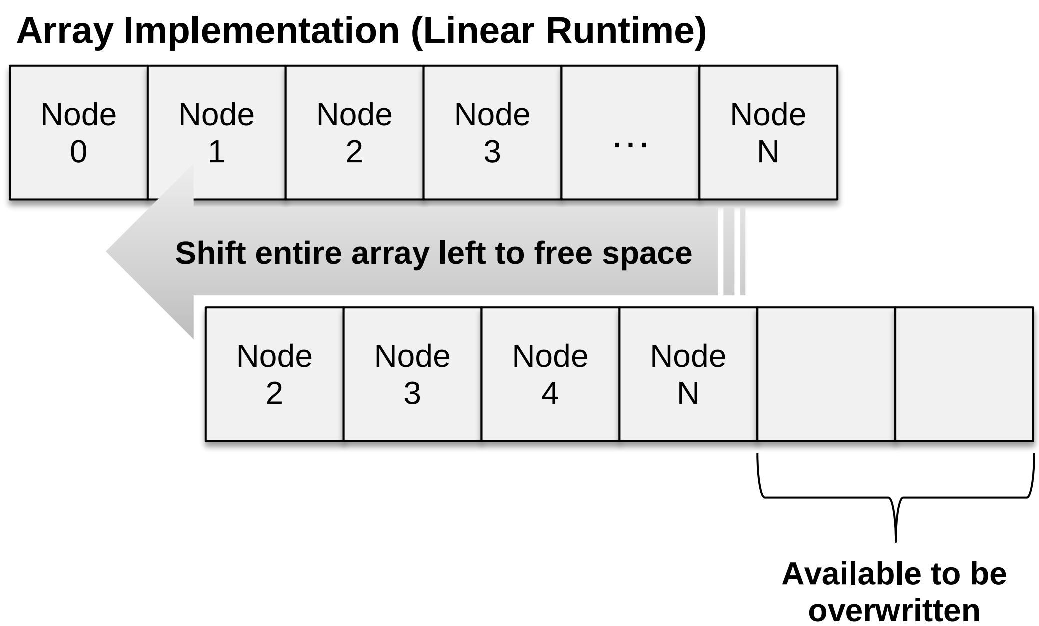


Figure 41: Array Diagram

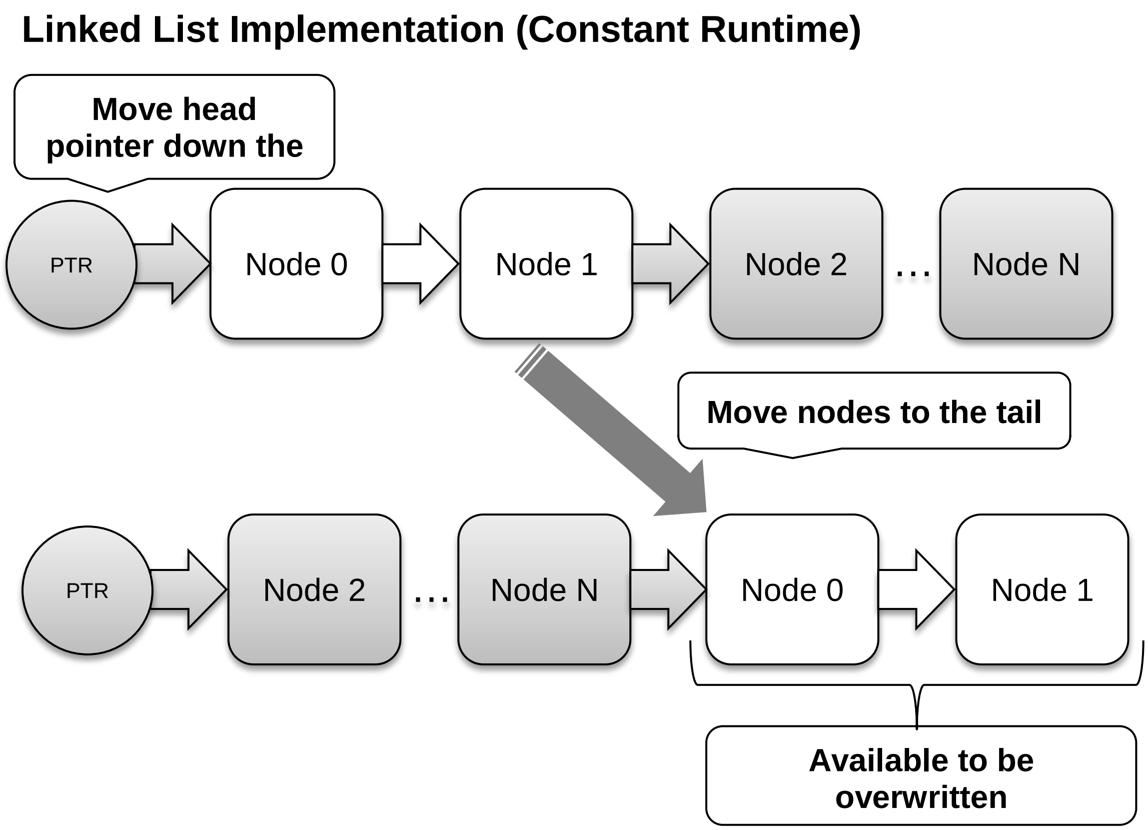


Figure 42: Linked List Diagram

The microcontroller will sample *s* number of times every second and take their mean. The MSP430's 1.7 analog pin will be used to compare the output from the sensor to a 5V reference. After reading the ratio from the designated pin, the graph will then be updated with the average luminosity detected by the sensor. The mean is taken after *s* samples to avoid overloading the display every time new data comes in. The top right of the output will also have the current luminosity level, the time elapsed and the high and low levels of luminosity. The library will be housed entirely in one class and be written in C. Adafruit's open sourced library will be used as a reference to help develop the custom API for this project.

The drawable area of the display will be limited as *a* pixels will be reserved on the left and *b* pixels on the bottom of the display will be reserved for the axis labels. All functions will account for these offsets and the area any function will be able to write to will be restricted to the right of and above these offsets. Unsigned integers (uint8_t) will be used as the primary data types as the MSP430 is memory limited. Uint8_ts are composed of 8 bits of data and can represent values between 0 and 255. This means out of the 240x320 available pixels the display provides, the drawable area will be at most 240x256 when accounting for the data type being used to control the pixels. The maximum drawable width will be (240 - *a*) while the maximum drawable height will be (320 -

b) with a maximum of 256. The area outside the control bytes range will set during initialization so that area will not go unused.

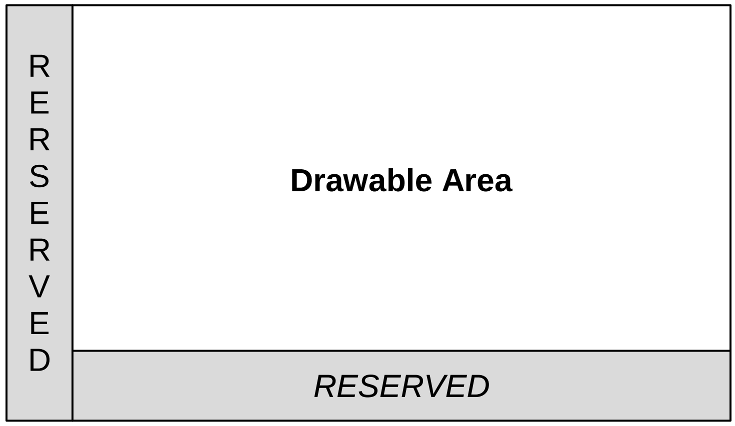


Figure 43: Diagram of drawable area

Lower level functions such as turning on individual pixels will be written first. After this is accomplished more complex features such as drawing lines, text and basic shapes such as rectangles and circles will be added on. Text must be written to an accompanying object. The object will reserve an area of the screen and all text displayed must be within an object. For lines, the text will be centered above the line. For rectangles and circles, the text will be centered with shape. Objects will be implemented by way of a struct containing the amount of characters of the string, a pointer to the string itself, and the area the object will occupy, and the type of shape it will be representing. Options such as displaying text without an outline will also be possible due to the fill feature for the setRectangle() and setCircle() methods. The fill can be defined as no fill, full fill, or no fill and no outline.

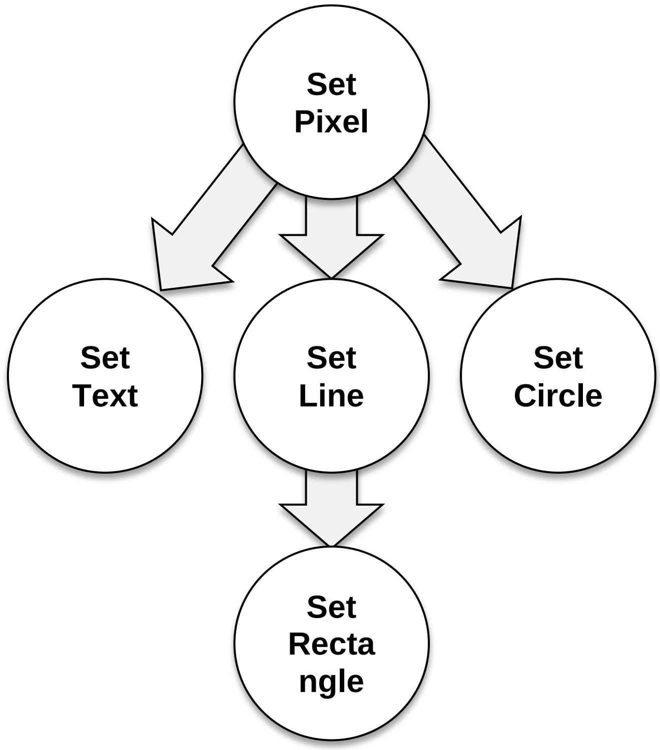


Figure 44: Function dependency

Rotation of objects will also be a feature. Simple rotational algorithms will need to be written. Something to consider would be use of matrices may not be supported in the MSP430's libraries. Another method of rotating pixels will need to be implemented. Only angles in increments of 45 degrees will be supported. As well as Horizontal and vertical flips. Such a method would need to compute the coordinates after the transformation to ensure it does not extend beyond the screen.

At the moment color output is desired but not necessary. If time and memory allow, the library will be expanded to take advantage of the LCDs RGB capabilities. Existing functions would need to be rewritten with to allow RGB values as parameters. Adding colors may be useful for the graph and make the display's output appear to be more professional. For now, a simple monochrome display will have to suffice.

Some math functionality will also be included. The ability to calculate slopes between data points will be needed. This function will simply be a rise over run computation using data points within the linked list. An integral function will also be provided; this function will calculate the area beneath the graph given two data points. A simple loop through the linked list will go through every node in between the two points and do a summation of their values.

Lastly, the display touch capabilities will need to be utilized. Touch input would be useful for controlling the display, editing settings and user interaction. All of this can be done only in software and would not require special hardware or any additional pins from the microcontroller. For example, a list of settings can be manipulated using the touch interface. Options including sample rate, the number of data points, contrast, or backlight level. Event listeners would need to be implemented to handle any touch related inputs.

Again the MSP430 is limited to only 16 kB of flash, requiring the use of very optimized and efficient code. The actual length of the code cannot extend beyond several hundred lines. 8 bit unsigned integers will used extensively to reduce the size of RAM needed to operate. The data points will be the largest single use of memory of the software, *n* data points would mean having *n* bytes of RAM needed if we were to implement an array or 2*n* bytes if the linked list is used. Currently an optimal size of *n* is not feasible to calculate. Only once the software is running and memory usage identified can *n* be determined. Some features may be dropped in the final source due to memory constraints.

Class States

Definition	Display_Height
Description	The number of vertical pixels of the display

Definition	Display_Width
Description	The number of horizontal pixels of the display

Definition	Left_Offset
Description	Left set of pixels reserved for the label of the Y axis. Drawable area is defined as right of this line.

Definition	Bottom_Offset
Description	Bottom set of pixels reserved for the label of the Y axis. Drawable area is defined as above this line.

Variable name	graphCursor
Type	uint8_t
Description	Used to keep track of the current position of the graph

Variable name	maxLumRecorded
Type	uint8_t
Description	The maximum level of luminosity recorded. This value is scaled to be between 0 and 100.

Variable name	minLumRecorded
Type	uint8_t
Description	The minimum level of luminosity recorded. This value is scaled to be between 0 and 100.

Pointer name	DataList* ll_head_ptr
Description	A pointer to the head of the linked list.

Pointer name	DataList* ll_tail_ptr
Description	A pointer to the end of the linked list.

Struct name	Object {uint8_t numChars, char* string, uint8_t x, uint8_t y, uint8_t height, uint8_t width, boolean visible}
uint8_t numChars	Length of the string being displayed.
char* string	Pointer of string being displayed.
uint8_t x	Starting x position of the top left corner of the object. If the object is of type circle, this will represent the center x coordinate.
uint8_t y	Starting y position of the top left corner of the object. If the object is of type circle, this will represent the center y coordinate.
uint8_t height	Height of the object. If the object is of type circle, this will represent the radius.
uint8_t width	Width of the object. If the object is of type circle, this will be zero.

bool visible	Set to determine if the object will be visible
char[] type	Can either be a line, rectangle, square, or circle.
Description	An object struct used for containing all information of a shapes. All text must be contained within an object.

Struct name	DataList {uint8_t value, uint8_t* ptr}
uint8_t value	Length of the string being displayed.
uint8_t* ptr	Pointer to next node.
Description	Used for the data point linked list.

Class Behavior

Function	boolean setPixel(uint8_t x, uint8_t y, boolean set)
uint8_t x	The x coordinate of the pixel from the top left corner of the display
uint8_t y	The y coordinate of the pixel from the top left corner of the display
boolean set	Determines if the pixel will be switched on or off. True indicates on and false off.
Returns	Will return true if successful, false if the setPixel was not within the bounds defined by the height, width and offsets.
Description	Basic command for control individual pixels. Accounts for the offsets defined in the class' state.

Function	int8_t getPixel(uint8_t x, uint8_t y)
uint8_t x	The x coordinate of the pixel from the top left corner of the display.
uint8_t y	The y coordinate of the pixel from the top left corner of the display.
Returns	Will return 1 if the pixel was on, 0 if the pixel was off, and -1 if the pixel was beyond the displays maximum height or width.

Description	Returns the current state of the pixel at (x, y).

Function	void clearScreen(boolean option)
boolean option	Determines the extent of the pixels to clear. True: Clear everything. False: Clear everything within the drawable box (does not erase the axis labels).
Description	Sets all pixels within the display to off. Will repeatedly call the setLine() function to clear horizontal pixels.

Function	boolean writeText(Object *obj, char* string)
Object *object	The Object containing location information
char* string	The pointer containing the string to write.
Returns	Will return true if successful, false if the text will extend beyond the bounds of the Object.
Description	Will write a string within the Object.

Function	boolean setLine(uint8_t x1, uint8_t y1, uint8_t x2, uint8_t y2, boolean set)
uint8_t x1	The starting x coordinate of the line from the top left corner of the display.
uint8_t y1	The starting y coordinate of the line from the top left corner of the display.
uint8_t x2	The ending x coordinate of the line from the top left corner of the display.
uint8_t y2	The ending y coordinate of the line from the top left corner of the display.
boolean set	True will indicate to activate those pixels, while 0 will erase those pixels within the line.
Returns	Will return true if successful, false if the pixels were not within the bounds defined by the height, width and offsets or if the line was not straight.
Description	Used to draw horizontal or vertical lines within the display. Calls the setPixel() function.

Function	boolean setRectangle(uint8_t x, uint8_t y, uint8_t length, uint8_t width, uint8_t fill)
uint8_t x	The starting x coordinate of the line from the top left corner of the display.
uint8_t y	The starting y coordinate of the line from the top left corner of the display.
uint8_t length	The length of the rectangle start at x and y.
uint8_t width	The width of the rectangle starting at x and y.
uint8_t fill	The fill option with 0 no outline with no fill, 1 being no fill with outline only, 2 being full fill black, and -1 being erase the area of the rectangle. More may be added on later.
Returns	Will return true if successful, false if the pixels were not within the bounds defined by the height, width and offsets.
Description	Used to draw a rectangle within the display. Calls the setLine() function multiple times.

Function	boolean setCircle(uint8_t x1, uint8_t y1, uint8_t radius, uint8_t fill)
uint8_t x	The starting x coordinate of the line from the top left corner of the display.
uint8_t y	The starting y coordinate of the line from the top left corner of the display.
uint8_t radius	The radius of the circle.
uint8_t fill	The fill option with 0 no outline with no fill, 1 being no fill with outline only, 2 being full fill black, and -1 being erase the area of the rectangle. More may be added on later.
Returns	Will return true if successful, false if the pixels were not within the bounds defined by the height, width and offsets.
Description	Used to draw circles starting from a specified center.

function	void initialize()

Description	Will draw the axes, label them and initialize the current level, high and low to zero, allocate the linked list, disable the watchdog timer and start the time eclipsed timer.

function	void shiftGraph(uint8_t n)
uint8_t n	The number of units to move left.
Description	Will set the ll_head_ptr to *n*th node. The *n* nodes will then be moved to the end of the linked list and the cursor set to the total nodes - *n*.

Function	boolean rotateObject(Object *obj, char[] rotation)
Object* obj	The object with the dimensions and area to rotate.
char[] rotation	When passed “horizontal” or “vertical” will flip the object on its horizontal or vertical axes. Can also rotate in 45 degrees increments if passed +/- “45”, “90”, “135” or “180”.
Returns	True if successful, false if the object was unable to be moved due to size or location.
Description	Rotates an object or TextBox in increments of 45 degree angle or along its horizontal or vertical axes.

Function	boolean touchEvent(uint8_t x, uint8_t y, uint8_t radius)
uint8_t x	Approximate center x coordinate of the touch event.
uint8_t y	Approximate center y coordinate of the touch event.
uint8_t radius	Approximate radius of the event. The area the touch event occurred will be treated as a square, the radius refers to the half the length of the sides of the square.
Returns	Returns true if the touch event was handled, false otherwise.
Description	Function for dealing with a touch event. Given the area of the input will determine the appropriate response.

Function	float calculateSlope(uint8_t p1, uint8_t p2)

uint8_t p1	The first point
uint8_t p2	The second point
Returns	The rise over run between the two points.
Description	Calculates the slope between two points using the data points within the linked list.

Function	float calculateIntegral(uint8_t p1, uint8_t p2)
uint8_t p1	The starting point
uint8_t p2	The ending point
Returns	The area beneath the graph including every value in between p1 and p2.
Description	Calculates the integral between two points using the data points within the linked list.

function	void main()
Description	Continuingly reads input from the microcontroller. After taking these samples for one second, averages all values together and updates the display with a new column. Will also update the current, high, low and time values.

4.4 Printed Circuit Board

4.4.1 Design Process

Need for a PCB

The MSP430 Microcontroller will need to have many connected wires for power, input, and output. It will have several subsystems making independent and overlapping connections to the limited number of ports. In order to reduce the amount of overlapping wires and components, we will be designing and purchasing a custom printed circuit board.

Virtual Design

This project will use the Freeware edition of EAGLE-CAD to design the layout of the printed circuit board. The software will allow us to design a two signal layer printed circuit board limited to 100 mm by 80 mm which will provide enough area for the device's needs.

Fabrication

The EAGLE-CAD format can also be used in the next step, production and purchase. OSH Park is a community printed circuit board order that takes designs from a group of people and combines them into one panel. The panel is ordered from a fabricator and when the OSH Park receives it, they split up the appropriate orders and deliver them. This allows purchase and fabrication of "individual" PCBs in 2-3 weeks and for approximately five dollars per square inch. OSH will accept designs in the EAGLE-CAD file format, which will allow the group to design the PCB with EAGLE and fabricate it through OSH in under a month for $5 per square inch.

Duplication

For the sake of safety, and the possibility of breaking the only working device, this project will involve the creation of two duplicate devices for a total of three ICG Fluorescence Intensity Detectors. This means that we will order three PCBs using the same design and connect them in the same way. With one design fabricated for three builds, we can get more productivity from the time spent in EAGLE-CAD developing the PCB designs.

4.4.2 Component Interactions with PCB

I/O

The Microcontroller has 16 input/output pins. The LCD and Sensor will both have connections to these pins, involving many wires in a confined space. One way the PCB will help is by directly connecting the LCD to the correct I/O and power pins. Another way will be for the PCB to extend the pins to the edge of the board.

The PCB will have soldered connections to all of the pins on the face of the microcontroller and, through wires within the board, will route them to connection points that match the LCD interface pins on the opposite side of the board. This will allow the microcontroller to be soldered to the PCB and the LCD soldered to the opposite side, completing the connection with no interfering wires and maximized usage of space.

Along with pairing the microcontroller and LCD, the PCB will route the remaining pins (Vcc, GND, and sensor input pins) to one or two sides of the PCB. This will allow for the connection of wires for the sensor and emitter input and power. The design should make wire management fairly simple by having all wires parallel to each other and potentially bundled.

Power System

The battery subsystem for the device will supply a constant five volts of input voltage. Due to the fact that the microcontroller and LCD will be using a voltage different from the Sensor-Emitter subsystem's reference voltage, the PCB will include the lead for the battery subsystem that will split into two parallel paths.

One path will connect the five volt source to a point that will be used as the voltage reference for the sensor. This point will need to be readily accessible by the sensor I/O wire and the microcontroller input.

The other path will consist of a voltage divider, or two resistors in parallel configured in such a way that one of the paths will have a voltage of 3.3 volts. The path with 3.3 volts will connect to the input power lead for the microcontroller and through it, the other components.

5 Design Summary of Hardware and Software

The following diagram gives a general idea of how the entire biomedical sensor will be designed and arranged:

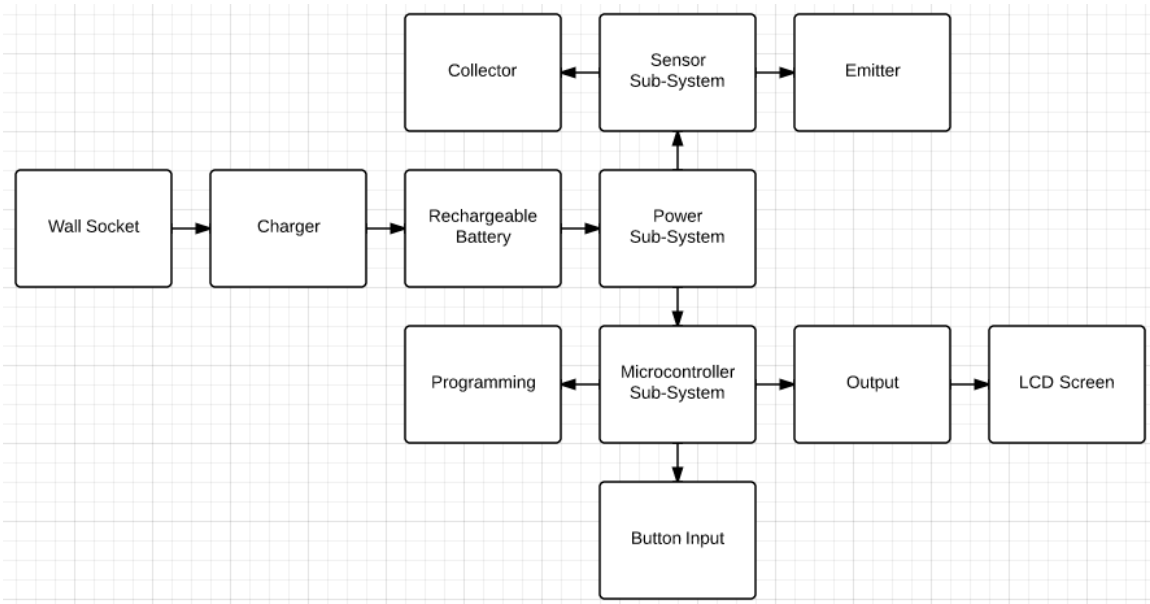


Figure 45: General Design Summary

5.1 Design Summary of Hardware

5.1.1 Design Summary of Casings

The casing for both the sensor and the printed circuit board will be made out of the Isocyanate polymer. This polymer more typically known as plastic will be cheap and easy to mold into the desired shapes. Thomas Wilkes, president of Guard-Lee has already volunteered to help in the production of these casings. The sensor casing will simply be shaped like a half egg cut along its major axis. The casing for the battery, microcontroller, and printed circuit board will be rectangular in shape.

The sensor casing has two main objectives. The first is to ensure the collector, emitter, and filter are all stable, and the second is to keep any undesired near infrared light out of the photodiode's readings. As a side objective the sensor will also be fitted with a 2.5-lb weight in the upper-portion of the dome to keep it from moving much on a patient's chest and/or stomach. Basic kitchen aluminum foil will be wrapped around the entirety of the casing to keep any erroneous data from entering into the collector's readings.

The following figure shows the reflectivity of aluminum foil based on wavelength. Note how around the 800 nm range which is where the collector begins seeing data, there is a high level of reflectivity due to aluminum.

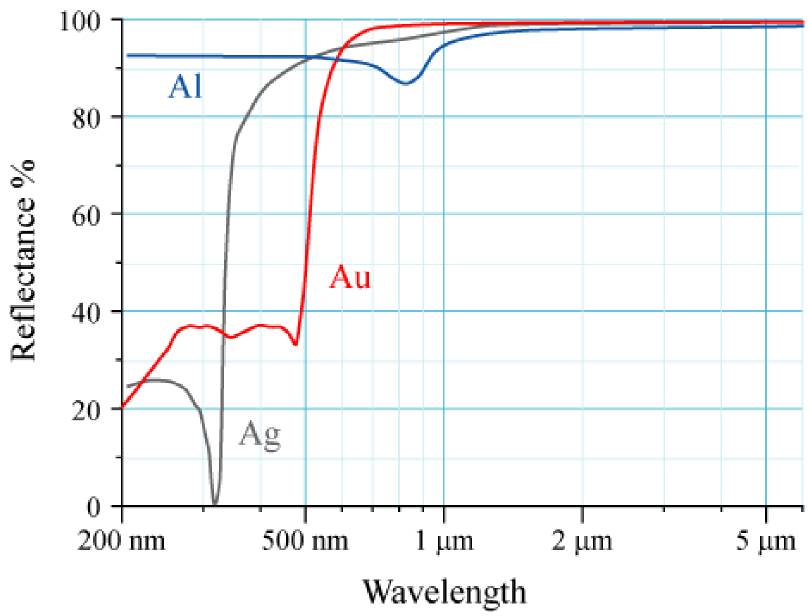


Figure 46: Reflectivity vs. Wavelength for aluminum

5.1.2 Design Summary of Battery and Charger

The battery to be used is the SANYO NiMH eneloop rechargeable battery. The model number is 5/HR-3UTG and can be seen in the next figure. This is a 6V 5-pack 2000mAh NiMH battery which will last for over 15 hours and require no more than 4 hours of recharge time. A rechargeable battery is required in order to be consistent with other medical equipment of this nature and a minimum of 5V had to be achieved in order to be able to power all components properly. There is going to be a 2-pin connector which is what will be used for the charging of the battery and two separate leads leading off of the wires to be soldered onto a power bus which will then power all components of the biomedical sensor.

Figure 47: 3/HR-3UTG eneloop rechargeable battery

The charger for this battery is still unknown since it is a custom charger which is out of stock. There is no part or model number for it and the charger itself will not be available for around another 2 months. What is known is that it will have the same 2-pin connection as the battery so they will be compatible, the charger will have a green light come on when it is finished charging, and it will be an automatic charger which requires no prior setup and needs only be plugged in from the wall to the battery. The only protection necessary between the battery and the charger is a resettable bimetallic strip type fuse which will take both temperature and short circuit issues into account. The specific fuse will be chosen once the charger is decided upon.

5.1.3 Design Summary of Boost Converter and Linear Regulator

The following figure depicts a 5V to 12V step-up boost power converter. This will be used to increase the inconsistent voltage of the battery to a value between 5.5V and 24V. The reason the voltage must be boosted is because the 5V linear regulator that will be used required a minimum of around ~5.4V in order to work properly. This value is capable of going as high as 24V without causing a change in the output voltage. Thanks to the boost converter satisfactory values for the input voltage can be accomplished.

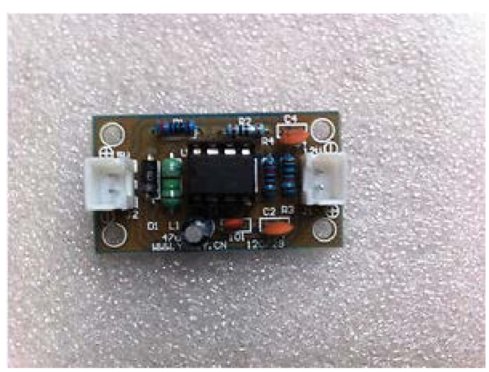


Figure 48: 5V to 12V step-up boost power converter

The circuitry itself requires that a set voltage is output from the battery. To accomplish this goal a linear regulator is placed into the circuit. The regulator is set to output the highest necessary voltage so that no op-amp is required due to the lack in this power subsystem's ability to provide a Vcc for such an amplifier. The reference voltage for the MSP430 is the highest required voltage and must under all circumstances be consistent. Any alterations to this voltage will cause the data displayed on the LCD screen to be inaccurate.

5V can easily be changed to any other required voltage using simple voltage divider circuits. Each component will have its own voltage divider, lowering the voltage to the required values to make the entire biomedical sensor work properly. The following figure is the +5V fixed-voltage regulator that will be used in this design.

Figure 49: +5V Fixed-Voltage Regulator 7805

With these two components, the entire power subsystem is complete. From the wall socket, to the charger, to a fuse for protection, to the rechargeable battery, to a boost converter, and finally to the voltage regulator, these are the steps required to power all components of the indocyanine green biomedical sensor and accompanying equipment.

5.1.4 Collector Design Summary

The collector will consist of a few separate components. The pivotal component is the FDS1010 Silicon Photodiode. This photodiode is constructed to produce current in response to an exposure of light within the broad wavelength range of around 400 to 1100 nanometers.

A filter will be placed over the FDS1010 Photodiode. The photodiode will be set in a simple circuit that applies a 5 Volt reverse bias to the diode to place it in photoconductive mode. This circuit consists of a simple resistor-capacitor noise filter, and a load resistance. The terminals of the load resistor will be connected to the Analog-to-Digital Convertor and to the ground.

Figure 50: The Thorlabs FDS1010 Photodiode. The grey surface is the 9.7 mm width square active area

The voltage across the load resistor will be on the order of 54 millivolts up to but likely not exceeding 5.4 volts, unless there is highly significant interference. The expected values will be somewhere between these values.

The analog-to-digital converter pin of the MSP EXP430 G2 reads up to 10 bits of accuracy, which allows 1024 degrees of accuracy. Given a V_{ref} of 5 volts, this means the collector can register signals with an accuracy of within 4.8 millivolts.

5.1.5 Emitter Design Summary

The emitter system will be a simple device implemented to create light. This light will be targeted at a range chosen to induce high amounts of fluorescence from the given Indocyanine Green sample.

In order to accomplish this, a simple light source is needed. The light source chosen comes in the form of a simple LED. LED's were chosen because they have a somewhat narrow light emission bandwidth. This means that it will not emit any light near the Ultraviolet wavelengths. This is important because Indocyanine Green has been noted to break down into potentially harmful substances when exposed to conditions involving ultraviolet radiation.

Moreover, the limited spectrum of LEDs provides a bandwidth inclusive of a range broad enough to fully fluoresce in a complete manner with Indocyanine Green. Finally, the narrow bandwidth is useful because it means the LED will not emit light within the collector's band pass range, meaning the LED light does not need to be shielded from the collector. Hence, LEDs provide a convenient, tight package for all required criteria.

The specific LED chosen was an Epoxy-Encased 780 Nanometer LED from Thorlabs. The LED is shown below in figure 5.1.5.1. It is available for $26 and comes in a pack of 5 LEDs. One of these LEDs will be implemented in a simple circuit. It will use the 5 volt source and will be in series with a single resistor, of 162 ohms. This will provide 20 milliamps of current to the photodiode.

Figure 51: The Epoxy-Encased 780 Nanometer LED from Thorlabs

The photodiode will deliver 18 milliwatts of optical power. If 100% of this optical power released came back to the collector as 830 nanometer light, the output voltage expected would be on the order of 5.4 Volts. Since this is an overshoot case, since most of the optical power will be lost in refraction, failure to fluoresce, interference, scattering, and loss through the filter, and some to the efficiency limitations of the photodiode, this value will most likely not exceed the reference voltage of 5 volts.

5.1.6 Collector Filter Design Summary

The collector silicon photodiode reacts to a very broad range of collection wavelengths. However, since only a particular range is of interest to the design goals of this project, this range must be honed to a value closer to the fluorescence range of Indocyanine Green, to a range that blocks out the emitter light significantly.

In order to constrain this broad range to an applicable value, the FB830-10-Ø1" Band pass Optical Filter will be implemented. This filter passes light wavelengths in a short range around the light wavelength of 830 nanometers. It possesses a Full-Width-Half-Magnitude (FWHM) range of 10 nanometers. This means that the filter passes at least half of the light exposure between 820 nanometers to 840 nanometers in wavelength.

This filter is 1 inch in diameter, meaning that it can be placed easily directly over the photodiode.

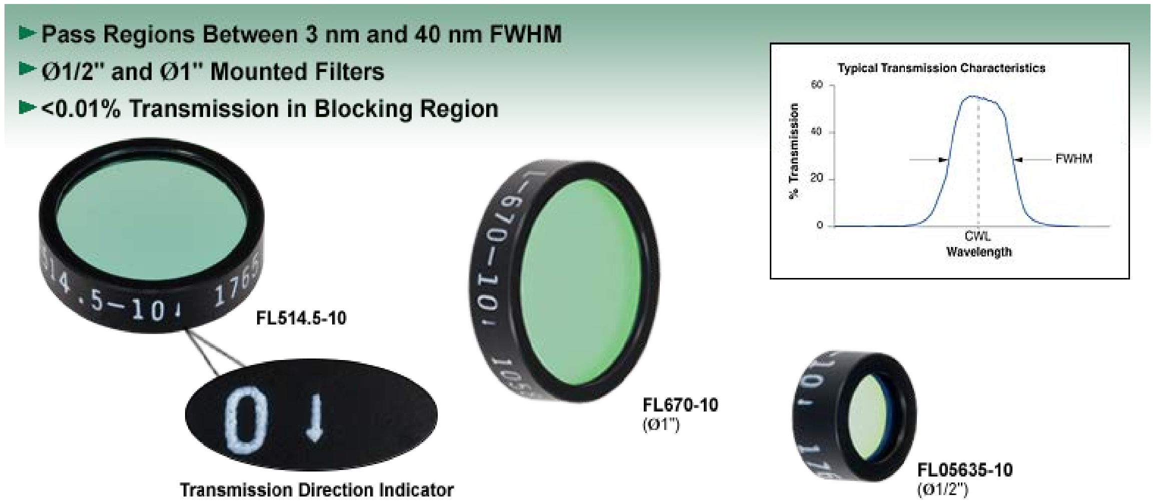


Figure 52: The Thorlabs FB830-10-Ø1" Band pass Optical Filter

5.2 Software Design Summary

5.2.1 User Interface Software Summary

This is a summary of the functions directly involve in user interface. The operational and implementation functions will be summarized in section 5.2.2 Operational Software.

This device is designed for the Emitter to constantly illuminate the patient's skin and the collector to constantly send a voltage signal to the microcontroller. The microcontroller will compare the voltage to a reference voltage to interpret the voltage value and translate that value into a Light Intensity magnitude. The microcontroller will sample this signal thirty times per second, as a default, and take the average of the samples to collect a usable data point.

The LCD will have a designated area for the graph, with all other space available to display values and characters related to the data and selected by the user.

The interface will allow for a variety of functions to affect the display, calculation and interpretation of the data collected. The user can change how the data is displayed by changing the medium, toggling features of the graph, and displaying values associated and derived from the data.

5.2.2 User Interface Button, Information

Using the Information button **[Info]** the user can cycle through various information or preference settings associated with viewing the main screen and graph. These settings include the time period between each sample and total time displayed, the maximum and minimum light intensity displayable on the graph, the grid state allows the user to toggle the grid overlay, and the graph display type toggles between different views of the data points. Several of these settings can be adjusted with the **[+]** and **[-]** buttons to customize the display further.

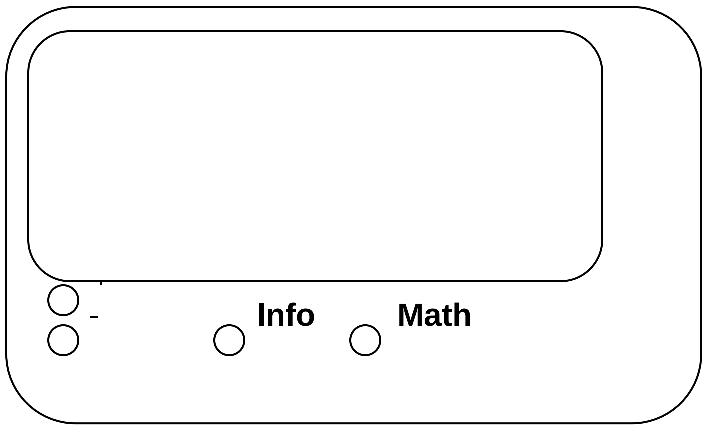


Figure 53: Rough drawing of the LCD case

5.2.3 User Interface Button, Mathematics

The remainder of the programmed user interactive functions involve mathematical computations on the data points. As with the Information functions, the Mathematical functions use a button, **[Math]**, to cycle through the various computed values:

The user can view:

- **Mean:** The Average of all the data points in the current data set.
- **Max/Min:** The maximum and minimum measured data values measured during the entire session.
- **Slope:** The slope of the last two points and the average slope of the entire data set.
- **Area:** The integral of the curve formed by the data points.

These computed values should suffice provide all of the desired information intended from the devices use and may be adapted to other devices in later versions.

5.2.4 Operational Software Design Summary

Summary

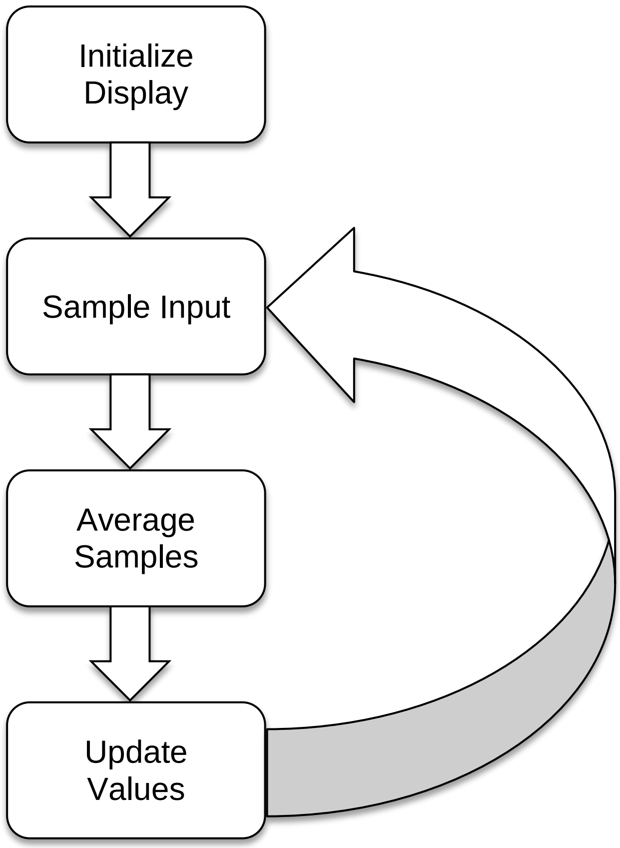


Figure 54: Process Flowchart

To summarize the software, all compiled binaries will have to be less than 16 kilobytes and all runtime operations limited to 512 bytes. An analog pin will be used to receive input from the photodiode and compared to a 5V reference. This ratio will be scaled to between 0 and 100 for convenience. Thirty samples a second will be recorded and averaged together. The mean will represent one data point on our graph, and be stored within a linked list.

A linked list will allow for faster manipulating of the nodes. The disadvantage being a linked list implication in this instance will result in roughly twice the amount of memory used. But all inserts will be at constant running time since nodes will only be modified at the head and tail of the linked list. This is due to the fact that only *n* data points will be displayed at once and our linked list will only be able to store those *n* values. As time goes on the linked list will surely fill up and due to our memory limitations we cannot simply allocate more memory for more nodes.

With an array implementation this would mean shifting the nodes left to accommodate the incoming data. This operation would have a linear runtime of O(n). With a linked list however, only the head pointer needs to be moved and the new free floating nodes moved to the end of the list. The linked list pointer will then be move to overwrite the new nodes at the tail. This is a constant time algorithm which will eat fewer CPU cycles. In both implementations the shift will destroy the oldest data as we cannot afford to continue storing that data. To alleviate this, the software will keep track of the minimum and maximum luminosity levels. After the new data point is stored within the linked list, it will be written to the display’s onboard RAM as a new data point.

As the graph begins to fill its horizontal plane, it will continually be shifted left. The graph's shift will coincide with the linked list shift. This is to ensure the linked list will always have adequate space for the incoming data. Due to memory limitations; the graphics drawable area will be bound to 256x256 pixels. 8 bit unsigned integers will be used to address individual pixels of the display. It was decided upon, being the optimal choice to conserve memory and adequately control individual pixels. Since the display’s resolution is 240x320, with a one byte control, 16 pixels will be unreachable on the vertical plane and 64 pixels unreachable on the horizontal plane. These 80 pixels will be unable to be accessed during runtime, but will simply be set up during initialization.

On power up, the software will first call an initialize function to draw the axes and label the graph. The MSP430's watchdog timer will be disabled. Values such as the cursor, maximum, minimum, current will be assigned to zero at this time. The cursor will point to the current column in the time-graph, maximum and minimum stores the highest and lowest values recorded since sampling began and current will just store the latest incoming data. The linked list will then be allocated memory and all microcontroller pins will be assigned. A time eclipsed timer would then be stored and input start to be recorded and stored within the linked list.

The input from the analog pin will start being read thirty times a second. The value will be averaged and then sent to the display as a height in pixels with location data. The display is not updated for every sample taken to prevent too much information from being sent to the display. This would only overload the screen and cause too quick of a graph movement. With a slower graph movement also means less shifts of the linked list; resulting in few clock cycles needed per minute. After updating the display the software will loop back into sampling mode and continue reiterating the software loop.

6 Testing

6.1 Sensor-Emitter and Case Verification Testing

6.1.1 Supplies

The Indocyanine Green Fluorescence Intensity Detector is designed to measure the intensity of the fluorescence of the Indocyanine Green dye in a patient's blood stream. The ideal way to test the device would be to inject a prescribed amount of Indocyanine Green dye into a patient, use the Fluorescence Intensity Detector, and record the results to see if the measured intensity falls within the expected range and if the intensity drops off at a perceivable rate over time.

Unfortunately, human testing involves a great deal of legal issues, especially when the tests involve injection or interaction with substances that are poisonous under certain circumstances. The use of animals raises more legal issues than human testing. This has led to the decision to use synthetic skin, muscle, and blood for the testing of the sensor-emitter subsystem of the Detector.

The simulated materials must exhibit certain properties to be accurate testing materials.

- Artificial Skin and Muscle
  - Both the Artificial Skin and Artificial Muscle need to exhibit similar transparency to real human skin and muscle. The simulated organs should affect how the emitted light or the reflected light will behave as human skin and muscle would when conducting the detection and precision tests. Any differences would give the tests a different result than when used on a real patient. All other properties are not important, as only the light-affecting properties will affect the desired measurements.
  - Both the Artificial Skin and Artificial Muscle can be purchased in 20cm by 20 cm patches from SynDaver, a lab based in Tampa, Florida that creates synthetic human tissues. These artificial skin and muscle patches are vacuum sealed and have a 5 year shelf life. They do not need to be refrigerated, but if removed from packaging, they will need to be stored in an air tight container, in a saline dilute to protect the hydrated material from desiccation.

- Artificial Blood
  - Needs to display similar translucence and viscosity of natural human blood. The ICG needs to disperse through the liquid as if it were human blood. Similar translucency is needed due to the fact

that the device is measuring fluorescence, so when it is excited, the ICG needs to fluoresce as it would in blood.

- A suitable Blood substitute can be purchased from BloodyMarvellous, a Welsh line of professional blood substitutes favored for ultra-realism and used in television productions as well as medical training.

Figure 55: Five liter container of blood substitute

Indocyanine Green dye is a critical element, the substance used in the testing and the factor that cannot be substituted. ICG is a very specific chemical that is designed precisely for bonding to proteins and fluorescing under excitation at certain wavelengths of light, and is used in medicine as an indicator substance in cardiac and circulatory conditions.

Indocyanine Green dye can be purchased at a high cost per milligram from various medical distributors, or requisitioned from hospitals. For our project, our sponsor may provide us with samples to use for testing, and we are to assume that is the case. If it is changed so that we must procure some ICG for the testing, we can purchase small amounts from manufacturers such as MP Biomedicals.

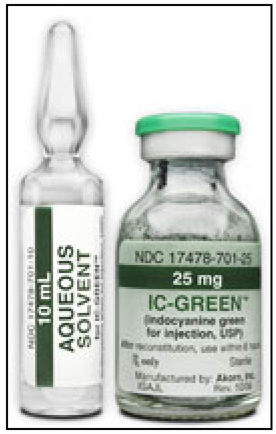


Figure 56: Indocyanine Green dye

The ICG will be in powder form, to be stored at 15-30 degrees Celsius, and combined with water at 10 mg ICG to 1 mL water. It will be used sparingly and only for tests due to its small quantities and high cost.

6.1.2 Test Standards

In order to retrieve usable data, the tests will need to maintain certain standards. There are many factors that can affect results and corrupt gathered information that we will need to guard against. Creating standards for the testing will eliminate some of these factors and keep the results more as long as the standards are adhered to.

External Light Sources

There are two problems with external light affecting the test results: False Excitation and False Readings.

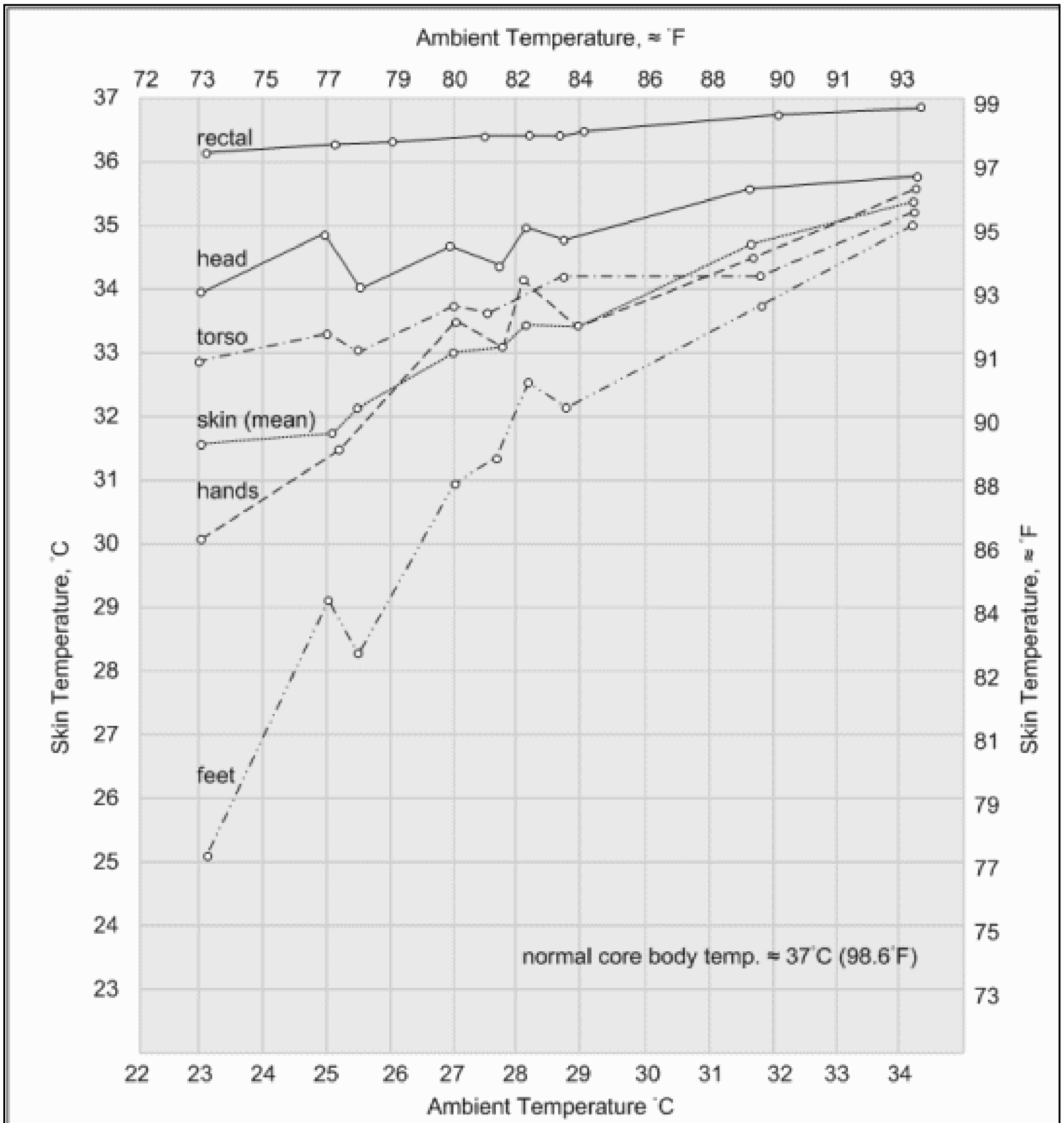
Indocyanine Green fluoresces with an intensity based on the light that shines on it, or excites it. False Excitation occurs when light other than from the Emitter excites the ICG and causes stronger than normal Fluorescing intensity. This could alter our readings by having a higher resultant data point.

False Readings can occur from external light sources that may have the wavelength read by the sensor. The sensor would read this as fluorescence regardless of the ICG and could result in erroneously strong results or even false positives, results when the ICG is not fluorescing.

These potential external factors can be mitigated by our choice to seal the device with aluminum foil. As discussed in section 4.1.1, Emitter-Sensor Subsystem, aluminum will effectively “photo-seal” the Sensor-Emitter array as long as the device is held against the area of skin to test.

Temperature

We will be warming the artificial blood and skin tissue to further simulate the human body.



Skin temperatures on different parts of a nude person measured at different ambient temperatures
Adapted from: Olesen, B.W., 1982, Thermal Comfort, Technical Review, Bruel & Kjaer

Figure 57: Skin temperature Graph, printed from HealthyEating.com, a free online educational resource

The Indocyanine Green may have different properties at room temperature than at body temperature. We will be maintaining a constant temperature of 32 to 34 degrees Celsius (90 to 93 degrees Fahrenheit) as this is the average temperature of the human extremities at room temperature.

Sensor test guidelines

All tests of the sensor will use a clear, plastic tube or bag to hold or move the artificial blood under a number of layers of artificial skin and tissue. The non-skin covered parts of the bag will be wrapped in aluminum foil to shield from external light sources. The sensor will be on top of the exposed "skin" and pressed firmly against the surface. The bag with the blood and ICG will have an upraised end for infusion of ICG or added blood and a lowered end to drain into a container. This will promote a simulated flow of blood.

Physical Test Guidelines

All Physical tests of the device will involve testing the amount of physical stress the device can handle. This means dropping it. These tests will try to simulate a drop while in use in its primary environment, a hospital. The drops will occur at the set height over a tile or tile-like surface and dropped straight down, LCD facing up, with no force aside from gravity affecting it. This means no throwing, tossing, or sliding off of tables and certainly no kicking or stepping on device. The screen is quite delicate.

Tissue Thickness

The amount of material between the blood and sensor will affect the brightness of the detected fluorescing light. We will attempt to test under the circumstances of several ideal body locations. The desired testing locations will include the index finger, the palm of the hand, the back of the hand, the facial cheek, the anterior side of the wrist, and interior thigh. We will replicate these sites by adding or subtracting layers of simulated human tissue as well as changing the ratio of Indocyanine Green to blood to match the relative volume of blood passing under that location.

Skin thickness is assuming no hair at the targeted site; this will require shaving the site in the case of an actual patient. The thickness of the artificial skin will be 1.2 mm.

Exterior areas of the body such as the Dorsal forearm, shoulder, and exterior thigh are approximated to have a skin thickness of 2 to 2.3 mm. We will use two layers of artificial skin and tissue to simulate these areas.

Interior areas of the body such as the interior forearm, interior thigh, and facial cheek are approximated to have a skin thickness of 1.5 mm. We will use only one layer of artificial skin and tissue to simulate these areas.

Gripping or more used areas of the body such as the palm, the soles of the feet, and the lower back are approximated to have a skin thickness of 3 mm. We will use three layers of artificial skin and tissue to simulate these areas.

6.1.3 Test Types

We will use several types of tests to calibrate the Indocyanine Green Fluorescence Intensity Sensor and show the accuracy of measurements. Several tests will also stress the design of the casing and simulate wear and tear or misuse. Even though proper testing of the device is desired, if the test is deemed too harsh for the device to survive, it will not be conducted in favor of further use and testing of the project.

- Infusion Test; a variable amount of ICG is added to an artificial tissue and blood sample to measure the Emitter-Sensor system's response. This test will time the delay from the addition of ICG till the first reaction from the project's display and add another dose of ICG after set time intervals of no response. The device will fail if no response is recorded. This will test the sensor's measurement speed and measurement/display time lapse.

- A Decay Test; a sample of IGC infused artificial blood will be flushed and replaced with clean artificial blood at a variable rate to see that the recorded intensity drops at a relative rate. This will test the sensor's accuracy with regard to changing fluorescence intensity over a prescribed time period.

- The Sensor Drop Test; we will drop the Emitter-Sensor casing from a variable height without striking the floor to test for damage to the cable and cable anchor points. This will test the cables elasticity and durability.

- The Device Drop Test; we will drop the device twice from pre-decided heights to test if the device sustains and physical or functional damage. This test will require the case to pass a visual test and device to perform a task after the fall. If both tests are passed, the device will be deemed safe from drops of that test's height. This test is designed to test the device's durability from every day wear and tear.

Infusion Test

Amount of Variable per Type Table

Type	Layers of skin/tissue	Artificial Blood (mL)
Interior	1	10
Exterior	2	15
Palm	3	20

This test is a Sensor test and will follow the Sensor test guidelines. The test will begin with the sensor on and taking measurements. The artificial blood will be clear of ICG at the start and will not drain for the duration of the test. A small amount of ICG will be added to the blood (.5 percent of the volume of blood) and the sensor will be timed until it reacts to the added ICG. If no reaction is seen within ten seconds, another dose of ICG will be added to the solution. This will repeat at ten second intervals until an ICG content of 2.5 percent is reached.

The Infusion Test will be considered passed if the sensor detects a significant increase in ICG fluorescence intensity, with a significant increase determined as equivalent to a 1 percent ICG concentration. If the sensor does not detect the ICG after ten seconds with 2.5 percent concentration, the test will be considered failed.

Decay Test

Amount of Variable per Type Table

Type	Layers of skin/tissue	Artificial Blood (mL)	Rate of New Blood (mL/s)
Interior	1	20	.5
Exterior	2	30	.75
Palm	3	40	1

This test is a Sensor test and will follow the Sensor test guidelines. The test will begin with the sensor on and taking measurements. The artificial blood will begin with a concentration of 5 percent ICG at the start of the test. New artificial blood, without ICG, will be introduced to the solution at the rate of 2.5 percent of the initial blood volume per second, injected into the upraised “infusion” end of the container. The injection will continue until the artificial blood volume has been increased by 50 percent, approximately 20 seconds, and the solution will not be drained for the duration to the test. The sensor will be allowed to take measurements for 10 seconds after the injection period has ended to allow for the solution to mix and settle.

The test will be considered passed if the sensor measures a decline in concentration down to 50 to 80 percent of the original ICG concentration. This is based on the calculation that the same volume of ICG present in 150 percent of the original artificial blood volume should show as two thirds of the original concentration.

$$5\% * 20mL = 1mL;\ \frac{1mL}{30mL} = 3.33\%;\ \frac{3.33\%}{5\%} = 66.7\%\ of\ original\ concentration$$

If the Decay Test shows a decline in ICG concentration, but not between 50 and 80 percent, the test will be considered partially correct, as the direction, but not magnitude, was correct.

If the test shows no change or an increase in ICG concentration, the test will be considered failed.

Sensor Drop Test

This test is a Physical test and will follow the Physical test guidelines. The test will begin with the sensor and monitor units held separately. The sensor cable will be measured out a determined length from the sensor and anchored to a stable surface using tape or a similar temporary adhesive, assuming the adhesive has enough strength to prevent the device from falling further than the determined distance. The anchor point must be higher than the drop distance to avoid collision with the ground. Kinetic physical trauma is not a test variable. The sensor unit will be held next to the anchor point, such that when dropped it will fall straight down with no horizontal sway, and on a mark it will be dropped and not interacted with until vertical movement has ceased. The sensor device will be scrutinized for physical damage around the cable connection and the device will be powered on to ensure both the sensor and emitter receive power, and the microcontroller receives data from the sensor.

The determined heights will begin with a one foot drop and increase in height by a quarter foot until a drop of two and a half feet is reached, or until the device does not pass a test.

The Sensor Drop test is considered passed if the device does not fail a test up to and including the two and a half foot drop. The device will have failed a test if, after any test, physical damage is observed around the cable anchor point (eg. the cable is loose) or there is some error internally. An internal error consists of the sensor or emitter not receiving power or the microcontroller not receiving input from the sensor.

If there are duplicate devices created, for the possibility that one is broken, then if one of the devices fails or passes the test it will be assumed that all of the devices will duplicate the results. This test will not be performed on more than one device, due to increased chance of multiple device failure.

Device Drop Test

This test is a Physical test and will follow the Physical test guidelines. The test will begin with the sensor and monitor units held separately. Both devices will be held a determined height above a tile or tile floor. This needs to be performed over a tile or rubberized floor to simulate a hospital setting. Both the sensor and monitor devices will be dropped from the same height, at the same time with a distance of two feet between them. After the devices have come to rest, the sensor device will be scrutinized for physical damage, the monitor will be scrutinized for physical damage, and the device will be powered on to ensure both the sensor and emitter receive power, the microcontroller receives data from the sensor, and the monitor displays with no differences from before the test.

The determined heights will begin with a half foot drop and increase in height by a quarter foot until a drop of one and a half feet is reached, or until the device does not pass a test.

The Device Drop test is considered passed if the device does not fail a test up to and including the one and a half foot drop. The device will have failed a test if, after any test:

- Physical damage is observed on the sensor device (eg. the case is cracked or the components are loose)

- Physical damage is observed on the monitor device (eg. the case is cracked or the display is damaged)

- There is some internal error. An internal error consists of the sensor or emitter not receiving power, the microcontroller not receiving input from the sensor, or the display having damaged pixels or missing data.

If there are duplicate devices created, for the possibility that one is broken, then if one of the devices fails or passes the test it will be assumed that all of the devices will duplicate the results. This test will not be performed on more than one device, due to increased chance of multiple device failure.

6.2 Controller Testing

MSP430 Voltage Test

Purpose: To verify the MSP430 is providing the correct range of voltages to its pins. This is to ensure no electronic components will be damaged once they are connected.

Procedure:

1. Connect power subsystem to MSP430
2. Connect multimeter to each individual pin and record the voltage

Outcome: The MSP430 will pass if the range of voltages falls within safe operating levels for each component I/O's. MSP430 may fail due to the power subsystem. If the MSP430 fails; the MSP430 will be sent back and a replacement will be requested.

MSP430 Amperage Test

Purpose: To verify the MSP430 is providing the correct range of amperage to its pins. This is to ensure the electronic components will be provided enough amps to power their circuits.

Procedure:

1. Connect power subsystem to MSP430
2. Connect all components to their pins
3. Connect multimeter to each individual pin and record the amperage

Outcome: The MSP430 will pass if the range of amperages falls within levels specified for each component within their datasheets. MSP430 may fail due to the power subsystem. If the MSP430 fails; the MSP430 will be sent back and a replacement will be requested.

Power Draw Test

Purpose: To determine the total system draw once all components are connected and running. The total amount of amperage being drawn by the system must be accounted for and used to determine the approximate running time of the batteries on one charge.

Procedure:

1. Connect power subsystem to MSP430
2. Connect all components to their pins
3. Connect multimeter to the battery leads and measure amperage draw of entire system

Outcome: The device will pass if the amperage draw is small enough that the battery can last for fourteen hours before reaching its minimum voltage range. If the device fails, components may need to be scaled down or new batteries may be needed.

MSP430 Comparator Test

Purpose: To test the comparator on the MSP430 to see if it is providing the correct ratios. The comparator should accurately report the ratio between the sensor's output and a 5V reference source.

Procedure:

1. Connect photodiode to microcontroller using an analog pin

2. Connect power to both the controller and photodiode
3. Connect multimeter to photodiode output
4. Load sample program into microcontroller to output comparator values to the screen
5. Provide a light source between 800nm and 900nm
6. Gradually increase and decrease the level of light

Outcome: The comparator will pass if the ratios reported to the software coincide with the voltage on the multimeter over the 5V reference voltage. If the comparator fails; the MSP430 will be sent back and a replacement will be requested.

MSP430 Speed Test

Purpose: To ensure a stable and smooth user interface. The MSP430 must have enough processing power to effectively display the time graph and respond to user input in a quick manner.

Procedure:
1. Connect power subsystem to MSP430
2. Connect all components to their pins
3. Power on all components
4. Initialize software
5. Observe display output

Outcome: If the display output appears too sluggish or is exhibiting unstable behavior then the MSP430 will fail. In either case the program may be that the microcontroller is unable to keep pace with the software or the software is simply too bloated to function on the controller. The test will pass if interface is responsive and new data points are updated every second.

6.3 Sensor Testing

Filter Test

Purpose: To test the photodiode's filter to make certain only the 820nm to 840nm wavelengths are getting through. The ICG will emit luminosity only at these wavelengths, therefore light from outside this range will be of no purpose and must be filtered from the sensor.

Procedure:
1. Connect photodiode to microcontroller using an analog pin
2. Connect power to both the controller and photodiode

3. Load sample program into microcontroller to output any input from photodiode pin to the screen
4. Test sensor with multiple light sources emitting different wavelengths

Outcome: The filter will pass if it only responds to sources emitting light between the 820nm and 840nm wavelengths. The filter will fail if it shows acute sensitivity to light sources outside this range.

Sensor Input Test

Purpose: To test the photodiode's luminosity output. The sensor should only pick up light from 820nm through 840nm, the range at which the indocyanine green will emit its response to the emitter.

Procedure:

1. Connect photodiode to microcontroller using an analog pin with the filter attached
2. Connect power to both the controller and photodiode
3. Load sample program into microcontroller to output any input from photodiode pin to the screen
4. Provide a light source between 820nm and 840nm
5. Gradually increase and decrease the level of light

Outcome: The sensor will pass if there is a direct correlation between level of light and voltage as the luminosity is gradually adjusted. Sensor may fail if the filter is not up to specifications. If the sensor fails; it will be sent back and a replacement will be requested.

6.4 Emitter Testing

Wavelength Test

Purpose: To test if the emitter is producing light in the necessary range to excite the ICG. The wavelength needs to be between 750nm and 810nm to properly excite the ICG.

Procedure:

1. Connect photodiode to microcontroller using an analog pin with the filter attached
2. Connect power to both the controller and photodiode
3. Load sample program into microcontroller to output any input from photodiode pin to the screen
4. Inject ICG into a container of water

5. Connect emitter to power source
6. Direct emitter at container

Outcome: The test will pass if the ICG is excited by the emitter. The photodiode will detect any luminosity produced by the ICG. The test will fail if the ICG is never excited.

6.5 Display Testing

Pixel Test

Purpose: To test for any dead or stuck pixels that might hinder the display of graphical information. Defective pixels are a common occurrence in LCDs. With such a low resolution, every pixel is crucial.

Procedure:

1. Connect display to microcontroller using the necessary 12 pins
2. Connect power to both the controller and display
3. Load sample program into microcontroller to flash red, green, and blue images continuously on the screen.
4. Check for any anomalies in the display

Outcome: If there are no pixels stuck to a certain color and no dead pixels, the display will pass the pixel test. If the display fails; it will be sent back and a replacement will be requested.

6.6 Software Testing

Touchscreen Input Test

Purpose: To test if the software can accurately pinpoint a touch inputs. The touch screen interface will be an important facet of the user interface. This test is to ensure the resistive touch is calibrated correctly.

Procedure:

1. Connect power to MSP430
2. Connect display using the 12 required pins
3. Connect power to display
4. Use stylus to touch screen at random coordinates
5. Run sample program to output coordinates of touch inputs

Outcome: The test will pass if the touchscreen seems to accurate record the coordinates of a touch input. The display will fail if the reported locations are too far off of the actual input.

Pixel Manipulation Test

Purpose: To test if the software can turn on or off individual pixels. Once this is working, all other more complex functionality can be implemented. The ability to draw shapes and write text all descend from this function.

Procedure:

1. Connect power to MSP430
2. Connect display using the 12 required pins
3. Connect power to display
4. Run sample program to turn on/off specific pixels

Outcome: The test will pass if the specified pixel is able to be turned on and off within the software. The test will fail if LCD is unresponsive to commands.

Slope Calculation Test

Purpose: To test if the correct slope between two points and the overall slope of the graph is being computed.

Procedure:

1. Connect power to MSP430
2. Connect display using the 12 required pins
3. Connect power to display
4. Run sample program feeding it test data from the collector
5. Freeze graph after *n* samples have been sent
6. Calculate slope between each two points
7. Compare to actual values

Outcome: The test will pass if the slopes are properly being computed. The test may fail due to rounding errors from using a data type that does not have enough precision. The test will fail if the computed values deviate too much from the actual values.

Integral Calculation Test

Purpose: To test if the correct integral is being calculated between two points on the graph.

Procedure:

1. Connect power to MSP430
2. Connect display using the 12 required pins
3. Connect power to display
4. Run sample program feeding it test data from the collector
5. Freeze graph after *n* samples have been sent
6. Calculate integral of the graph
7. Compare to actual values

Outcome: The test will pass if the area underneath the graph is being calculated correctly. The test may fail due to rounding errors from using a data type that does not have enough precision. The test will fail if the computed values deviate too much from the actual values.

Memory Utilization Test

Purpose: To calculate the amount of memory the entire software suit is utilization. This is important to leave an unused portion of memory in case unexpected behavior occurs. Any bugs that end up pushing the memory usage to over 512 B will cause the program to crash.

Procedure:

1. Connect power subsystem to MSP430
2. Connect all components to their pins
3. Power on all components
4. Initialize software
5. Log memory utilization over time *t*

Outcome: The software will pass if the software's memory usage stays under 512 B for time *t*. The test will fail if at any time the software's memory usage exceeds that of the memory available.

6.7 Other Testing

Optical Seal Test

Purpose: To test if an aluminum enclosure will block out all light. Any ultraviolet light will cause the ICG to produce an unknown toxic substance. To avoid poisoning patients and avoid potential lawsuits; the subject must be properly shielded.

Procedure:

1. Connect photodiode to microcontroller using an analog pin

2. Connect power to both the controller and photodiode
3. Load sample program into microcontroller to output any input from photodiode pin to the screen
4. Place device inside the aluminum foil enclosure
5. Step outside

Outcome: If no light is ever detected by the photodiode the aluminum enclosure will pass. The test will fail if any UV light or any light is detected by the photodiode. UV light in contact with the ICG will produce a potentially toxic substance; the aluminum enclosure is designed to prevent such an event.

7 Administrative Content

7.0.1 Milestone Summary

January

This month's accomplishments include the meeting of the group's sponsor, Doctor Thomas Looke and the final decision for the project. Our group was lucky to have a member with familiarity to Dr. Looke, a sponsor of several other senior design group projects, and he met with us to discuss some ideas for a project. Given a few options, our group decided to choose an idea that required both hardware and software understanding, and seemed to be the more original and interesting project. This fit with our split majors of Electrical and Computer Engineering, and challenged the lack of originality amongst most Senior Design projects. From there, we began to brainstorm on how to accomplish the intended function of the device, and what constituent components would be necessary in the design. We came up with a list of required components, and began to discuss various arrangements. The group also created the table of contents for the Senior Design 1 final paper, setting up the tentative outline for the final product.

February

In February, we began to research options for components and put together a list of physical requirements and input/output requirements, such as correct wavelength spectrum for emitter. This led us to weight the options for various components; for the Emitter, Near-Infrared-LED versus Filtered Full-Spectrum LED, for the Sensor, Photomultiplier Tube versus Photodiode, etc. We also began looking at prices for the various components and mediums through which the components could be purchased.

March

In March**,** the group began work in earnest on the Senior Design 1 paper. We divided the paper into sections: Hardware-oriented, Software-oriented, and Miscellaneous, and started to select sections into which we would write. This paralleled our finding of an open source International Biomedical journal titled: "A Review of Indocyanine Green Fluorescent Imaging in Surgery". The journal provides a great deal of insight into Indocyanine Green Fluorescent Imaging along with several useful figures and tables pertinent to the project.

April

In April, the group finished gathering relevant specifications for the power supply system, the Microcontroller, and the display System. With these figures, we studied electronics suppliers like DigiKey and TI to catalog and compare required parts. The Printed Circuit Board design process was studied and a tentative budget put together. The final touches were added to the Design document and we used FedEx to print and bind the final report.

7.1 Milestone Discussion

So as to complete this project in a time efficient manner within the two semesters permitted for Senior Design I and Senior Design II, the group talked over various milestones which could be used to help accomplish the completion of the project within the time allotted. These milestones have to do with everything, from the first designs and goals for the sensor, to acquiring all the knowledge from research necessary to begin the project, to the completion of required documentation and paperwork for presentation, to the gathering of any equipment needed to make the biomedical sensor work, to the development of a prototype, to the testing of the sensor, and finally to the finalization of the entire sensor system.

February 21, 2013 – The first milestone the team hoped to accomplish towards the end of February was to have an idea of what goals and objectives the sensor was going to be designed to. After taking some time to agree upon which project to actually pick this milestone was difficult was accomplish on time. Requirements from class asking for a table of contents caused the group to accelerate the decision making process. Fundamental knowledge of what parts would be required to accomplish the task of receiving an output based on input from a fluorescing dye were found. Specifics were not yet known, although a general idea was finally there. The completion of this milestone in the mid to late February date made it possible to complete all further tasks as the semester progressed.

Milestone met? – Yes

April 1, 2013 – With the goals and objectives complete, further progress could be made towards the completion of the group’s project. The next step in logical progression for the project would be to conduct research. It was the hope of the group to be completely done with research by the beginning of the month of April. Due to the unknown nature of this assignment research had to be extensive and thorough. By this date much research on the sensor had been conducted. It is unfortunate that there was still a little more to research to be done on how the different parts of the project were supposed to interact. A bare minimum of all research on the indocyanine green and what wavelengths to used had to be completed by this time. Also, knowledge on how to use the MSP-EXP430G2 had to be gathered so as to understand enough to be able to program basic commands into the microprocessor. When all of this research was completed, the group had a much better understanding of what the project was all about and a greater idea of how the sensor was actually supposed to be put together.

Milestone met? – Yes

April 12, 2013 – Knowing that the research for the project was extensive and difficult because it branched into the biomedical field which was effectively unknown territory for two electrical engineers and two computer engineers; the group decided that there would be two milestones for research on the sensor. This second research milestone would require most all of the little details on each aspect of the entire project to be known. For the emitter and collector the circuits had to be known. Power levels and currents and voltages throughout the first basic circuits along with the voltage of the power source were all required to be known at this point. Specific parts should have all been selected by now for each individual section.

Milestone met? – No

April 14, 2013 – Since the prior milestone was not met, this milestone was added to make sure all research was complete. There were issues with understanding how the LCD screen was meant to communicate with the MSP-EXP430G2. Some resistor values were also unknown since it was uncertain precisely which power source to use for the project. After all the kinks were taken care of, the group could get on the moving forward with the documentation for the sensor. It was unfortunate that a milestone such as this had to be added, but it was a necessary correction. One thing this did accomplish was it forced the group to work harder in order to finish on time and made the team desire to plan to avoid another occurrence of failed milestones from happening again. This desire was to carry into Senior Design II.

Milestone met? – Yes

April 21, 2013 – With research finally done, the group had a week to finalize all documentation and write the 120+ page report outlining the research, goals, and objectives created up to that point. There was no expectation for the pages to be in order yet, it was simply desired that all members had a minimum of their 30 pages per individual complete. This document was also to include instructions on how the device was to be tested and developed in Senior Design II. Due to the necessity of this milestone being completed on time, this was one of the most serious parts of the project thus far. Nothing else mattered as much as the completion of these 120+ pages.

Milestone met? -- Yes

April 23, 2013 – The paper itself was essentially due by this date. Although there were still two days remaining, it was the goal to have everything complete ahead of schedule. By this time all pages had to be completed, all preliminary research done, and everything had to be in order. The only real difference between this milestone and the one two days before it was that the pages had to be placed in order and the table of contents finalized. Also, the paper had to be printed and placed in a binder. The entire report had to be completed and prepared to be submitted in each form that was expected of the group. All work had to have been double checked by another member to make sure there were no typos. No parts had to be ordered yet seeing as how the group had the entire summer to do some testing if necessary.

Milestone met? – Yes

August 26, 2013 – This is the first week after the first week in which Senior Design II occurs. Summer will have gone by and little to no work will likely have been done due to the busy schedules of each member over the break for Senior Design. Classes were scheduled to commence on the nineteenth of August, so the twenty-sixth gives the group a week to accomplish the goals for this milestone. At this point the group hoped to have ordered each individual part for the entire project. Not all parts have to have come in by now, but all order need to be sent out.

Milestone met? – TBD

September 26, 2013 – An entire month will have gone by for the group to need to accomplish another goal. The reason for this long period is so that each part has had plenty of time to have been shipped by their respective companies and received by the team. It is hoped that by this point the group has had time to play with the various parts. The power source was to be tested to make sure the proper voltages and power were being supplied to each part. The circuit for the emitter was to be tested to make sure not too much voltage or current was being introduced to it; this was important so as not to cause any damage to the light emitting diode. The circuit for the collector was also to be tested to make sure some kind of current was being sent out based on the near infrared signal being sent to it. Also the connection between the MSP-EXP430G2 and the LCD screen was to be checked to make sure they are communicating.

Milestone met? – TBD

October 9, 2013 – With two weeks having gone by, the connection between the collector and the MSP-EXP430G2 was to have been tested and understood. The group hopes to have been able to see different readings on the LCD screen coming from the microcontroller due to the near infrared input being sent to the collector. At this point the casing will likely be requested to be created for the group.

Milestone met? – TBD

October 22, 2013 – With all parts hopefully now acquired, the team decided it was time to start the construction of an official prototype. The emitter and collector will be checked to make sure they fit inside of the newly received casing and all connecting wires/cables for each individual part fits around the plastic and tin foil. Aesthetics at this point are actually of importance. Everything must not only fit, but they must be compact and look nice and clean. Since all parts are expected to have been tested by this point, the group should not be too worried about compatibility of parts. This milestone is done well over a month before the project is due so that the team has plenty of time to order any new parts if something breaks in the construction of the prototype or have a new case made if it is not properly sized or the holes are not placed correctly. It is the hope that some kind of reading can be measured by the sensor via the microcontroller by this point and it is all displayed on the LCD screen and while looking compact and aesthetically pleasing.

Milestone met? – TBD

October 29, 2013 – Two possibilities were to be explored at this point. The first was making sure the milestone before this was completed. If it was not, then by this date a new casing should have been ordered and any damaged or inappropriate parts are to be ordered and replaced. Hopefully no part will have to have been replaced for this section. The second possibility was that at this point testing was to commence on the dye itself if all parts were found to work appropriately. This means the artificial skin, muscle, and blood must all already have been received as well. Indocyanine green will have to have been provided by the group's sponsor at this point as well so that it could be directly injected into the synthetic human parts. Direct testing of the sensor in its casing onto the artificial parts injected with indocyanine green was to begin. Hopefully some kind of reading will be accomplished by now so that the group can tell the entire setup is functioning properly.

Milestone met? -- TBD

November 13, 2013 – At this point the dye will hopefully have been tested enough so the group could figure out the kinds of readings they were receiving from the injected dye. The dive into the unknown is in full bloom at this point. Hopefully some kind of consistent reading was received by the sensor and the microcontroller gave logical and reasonable output. The LCD must also be functioning properly and displaying what needs to be displayed. If all of the above criteria are met, then the analysis of the data could truly commence. With consistent readings the team can then figure out what the best course of action to take is. Finding the slope of the line may in fact be the best plan of action. Another possibility would be to find the integral of the curve for the past few seconds. Whichever one is decided upon, it is important to note what the decision means.

Milestone met? – TBD

November 30, 2013 – The plan was to have had everything done by now. All parts are in and ready to be used. The programming of the microcontroller is complete and completely compatible with the LCD screen. The sensor must emit and receive information properly and consistently. Everything will have been tested in a similar environment to what will be presented in the final presentation. All tests will have been successful and the presentation completely ready to be critically evaluated.

Milestone met? -- TBD

Date TBD – This is the last straw and the final milestone the group must accomplish for their work with the biomedical sensor to be complete. The sensor and accompanying equipment will be presented to a review board of a few select professors who will examine the sensor to check if all the goals and objectives already stated earlier in the documentation were accomplished satisfactorily or not. This milestone is equivocally important to that of the end of Senior Design I milestone. The group had to have everything finished and professionally furbished and ready to be presented by this point. All of the work previously done on the project will be relying entirely on the success of this date. It would mean the difference between passing or failing for all four of the students on the team.

Milestone met? – TBD

Now that all milestones were established and the goals and objected agreed upon unanimously by the group, all member must now fulfill their ends of the bargain. It would be each individual's job to ensure that every goal that had not yet been accomplished would be in a timely and efficient manner. Any late work from any single member should be made aware of to the rest of the group so all members could act together to rapidly catch up to the scheduled completion of the project. Although entirely administrative, these milestones could in a way act as one of the most important aspects for the project. Without the accomplishment of each goal and stepping block on the road to completion, each member would be destined to fail. Therefore, to avoid falling behind all members would be held accountable to completing their work. Each member would critically review and ensure that all necessary and scheduled assignments are completed in a timely manner.

The table on the following page provides a quick summary of what was discussed in the above administrative section for milestones. The dates and whether or not the milestones themselves were completed on time along with a short description of the individual milestone are all presented in *Table 7.1.1*:

Date	Milestone Description	Was the milestone date met?
2/21/2013	Goals and objectives defined	Yes
4/1/2013	All basic research complete	Yes
4/12/2013	Advances research complete	No
4/14/2013	Make-up research for previously failed milestone complete	Yes
4/21/2013	All individual 30+ pages complete	Yes
4/23/2013	The documentation is formatted and brought together properly	Yes
8/26/2013	All parts ordered	TBD
9/26/2013	All parts received and basic testing begun	TBD
10/9/2013	Connection between LCD screen and microcontroller established successfully	TBD
10/22/2013	Initial prototype constructed	TBD
10/29/2013	1. Fixing of any broken or malfunctioning parts, or 2. Testing of dye using the prototype sensor	TBD
11/13/2013	Establish what the microcontroller and sensor are actually supposed to interpret	TBD
11/30/2013	All testing and the creation of the entire product are complete	TBD
TBD	Present project in front of the review board	TBD

Table 11: Milestone Descriptions

7.2 Budget and Finance Discussion

7.2.1 Bill of Materials

This section reveals the name of the part purchased, the part number if there is any, the supplier for the part, how many were order, and the total price for each part. Shipping and handling will also be included in the pricing and the total amount spent can be seen in the bottom right corner of Table 8.2.1.1

7.2.2 Financing Issues

Due to having a sponsor for this project, the financial burden on the group is greatly lightened. The Florida Hospital, or more specifically, Dr. Looke is sponsoring this project. An offer of up to $3,000 had been made to the group to see if they could create this sensor. Preliminary knowledge of the various parts leads the team members to believe the set amount of possible funding will be more than enough to finance the project. Fortunately, due to the generosity of one of the member's fathers, the casing for the sensor device itself will be completely free and thus help lighten the financial burden for the project in its entirety.

Issues the team to could run into would be the inability to receive a receipt for an item, forgetting to print or keep a copy of a receipt, or losing the receipt to any one item. Without proof of cost and purchase, the group members would be unable to receive reimbursement for any bought devices. Aside from these three unfortunately possibilities, the group appears to be financially sound and not worried about spending too much money.

7.3 Budget and Financing

Financials

Item	Source	Qty.	Price	Shipping
MSP430 Launchpad	Texas Instruments	3	$29.97	$0
LED Emitter (5)	Thorlabs	1	$26	$0
Photodiode	Thorlabs	1	$48.80	$0
Filter	Thorlabs	1	$84.67	$0
2.8" 18-bit color TFT LCD	Adafruit	1	$40.00	$3.99
Plastic Sensor Casing	Guard-Lee	1	$0	$0
Synthetic Blood (5000 ml)	bloodymarvellous	1	$266.56	$53.31
Synthetic Skin (20cm x 20cm)	SynDaver	3	$75	$8.93
Synthetic Muscle (20cm x 20cm)	SynDaver	3	$120	$8.93
Indocyanine Green (100 mg)	MP Biomedicals	1	$165.05	$0
Reynolds Wrap Aluminum Foil	Amazon	1	$5.91	$0
Small Weight	Amazon	1	$2.50	$0
Paper Binding	FedEx Office	1		
6V Fuse	Parts-Express	1	$1.25	$0
Rechargeable Battery	Batteries America	1	$27.00	$0
Automatic Charger	Batteries America	1	$89.99	$0
5V to 12V Step-up Power Converter Module	EBay	1	$1.25	0
+5V Fixed-Voltage Regulator	RadioShack	1	$1.99	$0
Medium-duty SPST Toggle Switch	DelCity	1	$3.02	$0
Sum			$988.96	$75.16
Total (shipping included)			$1064.12	

Table 12: Finance table

Appendix C: Permissions

Short Circuit Protection:

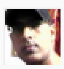
Chris McCord April 18, 2013 at 8:47 PM

Hi Swagatam,
I am a senior design student looking to create a biomedical sensor. This circuit could be useful in the protection of our power source. With your permission may I make a copy of this diagram for our documentation?

Regards,
Chris McCord

Reply Delete

Replies



Swagatam Majumdar April 18, 2013 at 9:19 PM

Hi Chris,

Yes you may do it.

Regards.

Battery Comparisons:

Hello Chris,

Absolutely, we just ask that you cite a reference to Battery University and the author, Isidor Buchmann.

Have a great day!

Brandon Crick| Marketing Communications Manager

Cadex Electronics Inc.
22000 Fraserwood Way, Richmond BC V6W1J6
604.231.7777 x319 phone | 604.231.7755 fax | www.cadex.com

Please consider the environment before printing this email.
>>> On 20/04/2013 at 3:22 PM, "Battery University" <web@batteryuniversity.com> wrote:

> Someone has submitted a Battery University contact form.
>
> Here are the details:
>
> Entry Date: 2013-04-20 03:22 PM
>
> Attachments: 0
> Collection Name: Contact Form
> First Name: Chris
> Last Name: McCord
> Email: 1337draco@gmail.com
> Company: UCF
> Comments: Hello,
> I am a student at the University of Central Florida and am currently working on a senior design project. Your site contains a very useful table for the comparison between battery types. With your permission may I copy the table into our documentation and reference your site?
> City: Orlando
> Country: USA

Artificial Blood:

Dear Daniel

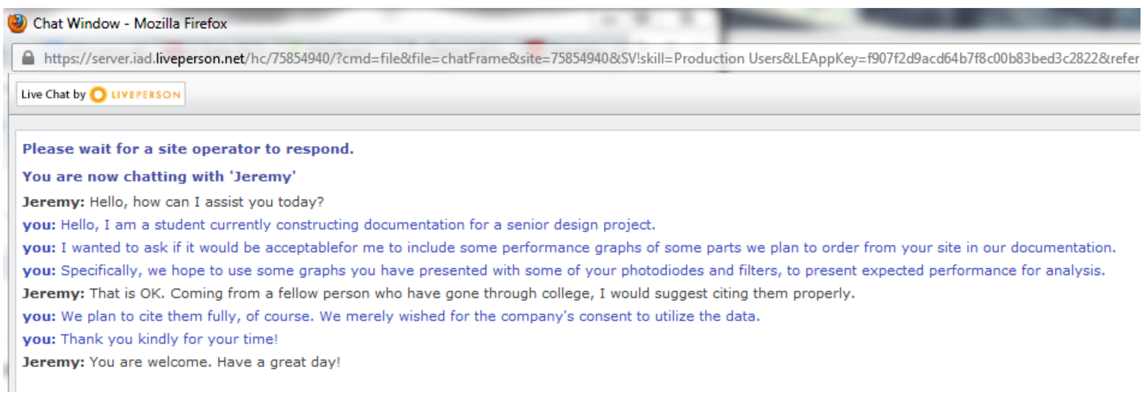
Your project sounds interesting- can I ask what you're investigating and if we may be able to view the results if our blood products are used. In principle I don't see any reason why you cannot include images of the blood product you choose to buy from us.

Kind regards
Angharad
Bloodymarvellous

On 20 Apr 2013, at 20:03, "Daniel Arfstrom" <danielarfstrom@gmail.com> wrote:

> Name: Daniel Arfstrom
> Email: danielarfstrom@gmail.com
> Message:
>
> I am in an engineering design group in the University of Central Florida. We are designing a device that needs to be tested with artificial blood and skin samples. We are considering purchasing and using some your website's Medical Liquid Blood: Dark. I would like to include the photograph of 5 litre container in the design document, and I am requesting the permission of this company to use this image. Thank you.

Thorlabs



Chat Window - Mozilla Firefox

https://server.iad.liveperson.net/hc/75854940/?cmd=file&file=chatFrame&site=75854940&SV!skill=Production Users&LEAppKey=f907f2d9acd64b7f8c00b83bed3c2822&refer

Live Chat by LIVEPERSON

Please wait for a site operator to respond.

You are now chatting with 'Jeremy'

Jeremy: Hello, how can I assist you today?
you: Hello, I am a student currently constructing documentation for a senior design project.
you: I wanted to ask if it would be acceptablefor me to include some performance graphs of some parts we plan to order from your site in our documentation.
you: Specifically, we hope to use some graphs you have presented with some of your photodiodes and filters, to present expected performance for analysis.
Jeremy: That is OK. Coming from a fellow person who have gone through college, I would suggest citing them properly.
you: We plan to cite them fully, of course. We merely wished for the company's consent to utilize the data.
you: Thank you kindly for your time!
Jeremy: You are welcome. Have a great day!

References

http://www.hindawi.com/journals/ijbi/2012/940585/tab6/