

Noninvasive PoC Anemia Detection Device

Team 11 - Project Proposal
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Introduction

Objective

The purpose of this project is to design and prototype a non-invasive point of care device for the detection of anemia. The minimum viable product will deliver two complete detection systems for data capture, a processing system for data analysis and detection, a power system for delivering the required capacity and charging needs, and a diagnosis indicator to relay the results to the testing administrator.

Background

Anemia is a condition that affects nearly 2 billion people, according to the WHO. Anemia is an entirely preventable disease, and once detected, the patient can take corrective action to restore their iron levels to a healthy state. According to Miller et al, the probability that you are affected by anemia increases five-fold in underdeveloped geographies [1]. Current non-invasive POC detection methods can be relatively expensive, and are difficult to move from place to place which makes them all the more inaccessible to the geographies that need it most. We propose to build a more portable and cost effective non-invasive anemia detection method by combining image and spectroscopy based detection methods in a wearable device that can be taken to regions without adequate medical facilities and used to help diagnose this preventable disease.

High-level Requirements

1. [The](#) device we build will be required to provide accurate binary diagnosis of anemia at least 9 times out of 10.
2. The device should be able to provide diagnosis based on data from both the oxygen level from a fingertip pulse oximeter[2], and the hemoglobin level based on RGB heuristics given by the pallor of the conjunctiva [3].
3. The device will deliver all 10 diagnoses on a single charge, and be able to deliver diagnoses even while charging.

Design

Block Diagram

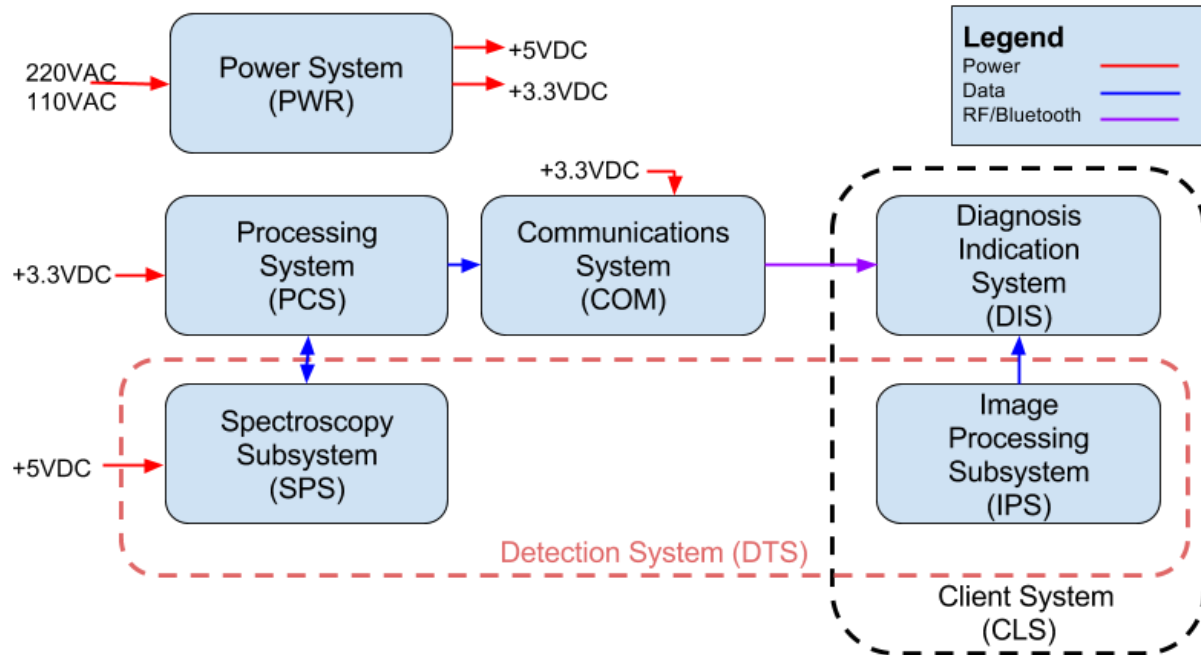


Figure 1: High level block diagram

The high level design shown consists of the core modules required to power our detection, processing, and communications systems, as well as the core detection and processing systems required to implement our detection algorithm. The Client System is described later in this document as being a system implemented entirely in software, and run on an Android smartphone. The Processing System will consist of an undecided embedded processor and some simple DSP required to implement the SpO2 detection algorithm required for the Pulse Oximetry data.

Power System (PWR)

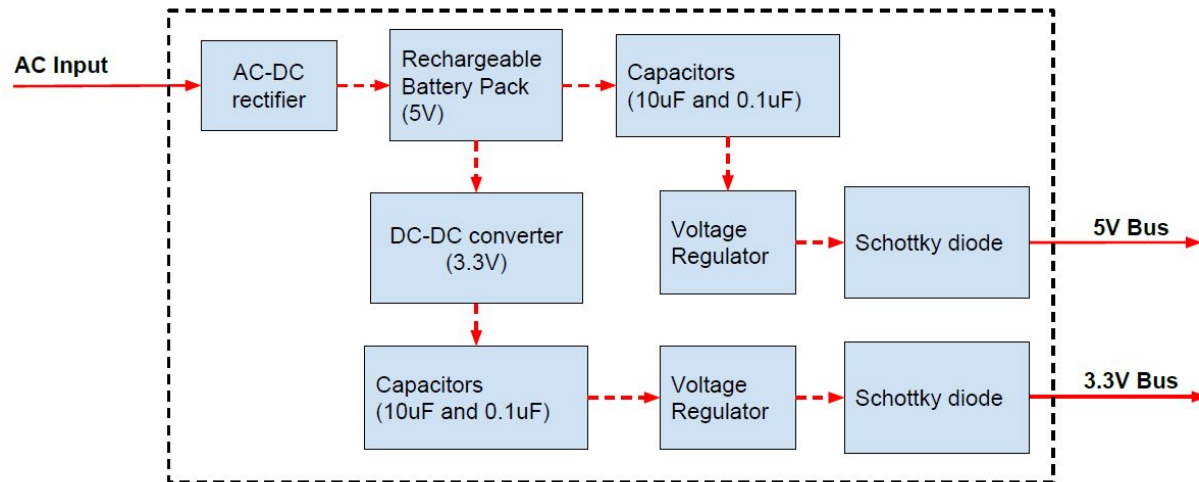


Figure 2: Block diagram of the power system

The power system will be used to first convert and then deliver power to all other subsystems, with the exception of the CLS. It will first convert 120V AC power to 5V DC. This low voltage line will then be used to deliver charge to the local battery. From 5V given by the rechargeable battery, two individual low voltage DC lines will feed the rest of the circuit. The first line will remain at 5V and the second will be stepped down to 3.3V using a DC-DC converter. Both lines will go through a bypass capacitor, decoupling capacitor, and voltage regulator to smooth out signal and manage the power needs of downstream instruments. Lastly, for protection and isolation, the 5V and 3.3V lines will go through a schottky diode before providing power to other subsystems. It is our intention to use an off the shelf system that contains a rechargeable battery and AC-DC conversion. From there, the rest of the power system can be custom designed.

Current Consumption

We assume the following current consumption from each component:

Subcircuit	qty	Part Name	Supply Feed	Current consumption (total)
Timing Circuit	2	555 Timer	5V	30mA
Photodiodes	1	Monolithic Photodiode	3.3V	15mA (Isc)
	1	Red LED (660nm)	3.3V	20mA
	1	IR LED (940nm)	3.3V	20mA
	2	Transistor	3.3V	2mA
Sample & Hold	1	Transistor	3.3V	2mA
	1	OpAmp	5V	520uA
DC,Filtering,Amplifying	1	BandPass OpAmp	5V	.9mA
	1	Amplifier	5V	520uA
	1	Ref OpAmp	3.3V	750uA
Bluetooth	1	BLE Module	5V	4.9mA
Embedded Processesor	1	ATMega	3.3V	0.2mA
		Passives		5mA
Total Current Consumption				101mA
3.3V Branch				60mA
5V Branch				41mA

Total power consumption:

$$101\text{mA} * 10 \text{ seconds} * 10 \text{ runs} = 2.81\text{mAh}$$

Processing System (PCS)

The Processing System (abbreviated PCS) consists of the embedded processor, and the spectroscopy processing algorithm which will calculate the SpO2 from the spectroscopy data provided by the spectroscopy subsystem, as described more fully in [2].

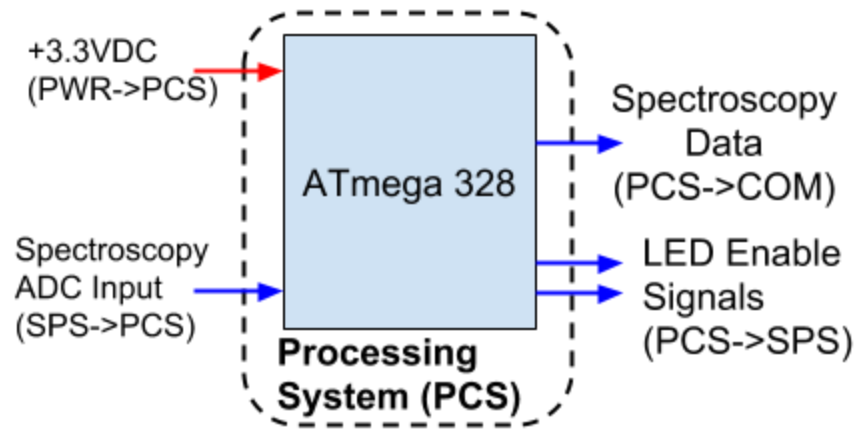


Figure 3: Block diagram of the processing system

Communications System (COM)

The communications system (abbreviated COM) will facilitate the transmission of pulse oximetry data obtained by the Spectroscopy Subsystem to the Client System, so it can be processed and shown by the Diagnosis Indication System.

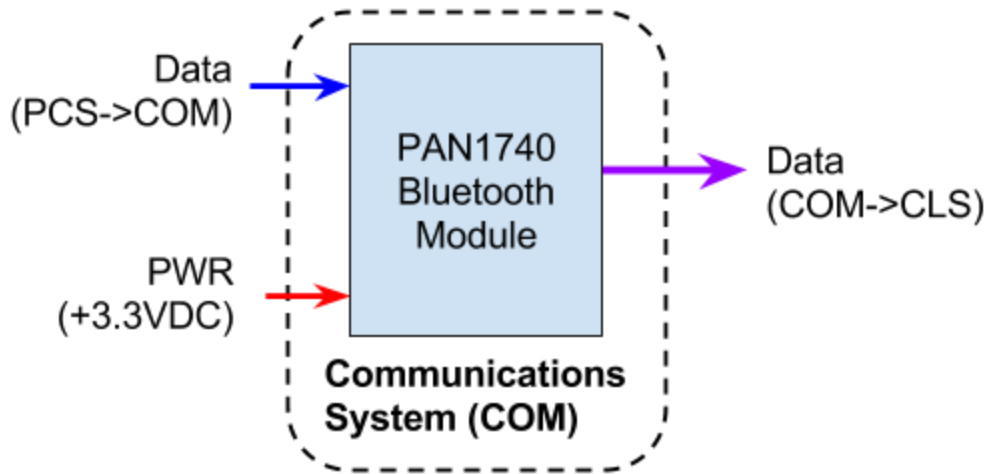


Figure 4: Block diagram of the communications system

Spectroscopy Subsystem (SPS)

The Spectroscopy Subsystem (abbreviated SPS) is one of two subsystems that comprise our Detection System, the other being the Imaging System within the Client System. It will excite the finger of the patient with red (660nm) and infrared (940nm) light on a 50% duty cycle, which will then be captured by a photodiode and filtered before being sent to the processing system for further refinement. The design of our pulse oximetry system is heavily influenced by a reference design given in [6].

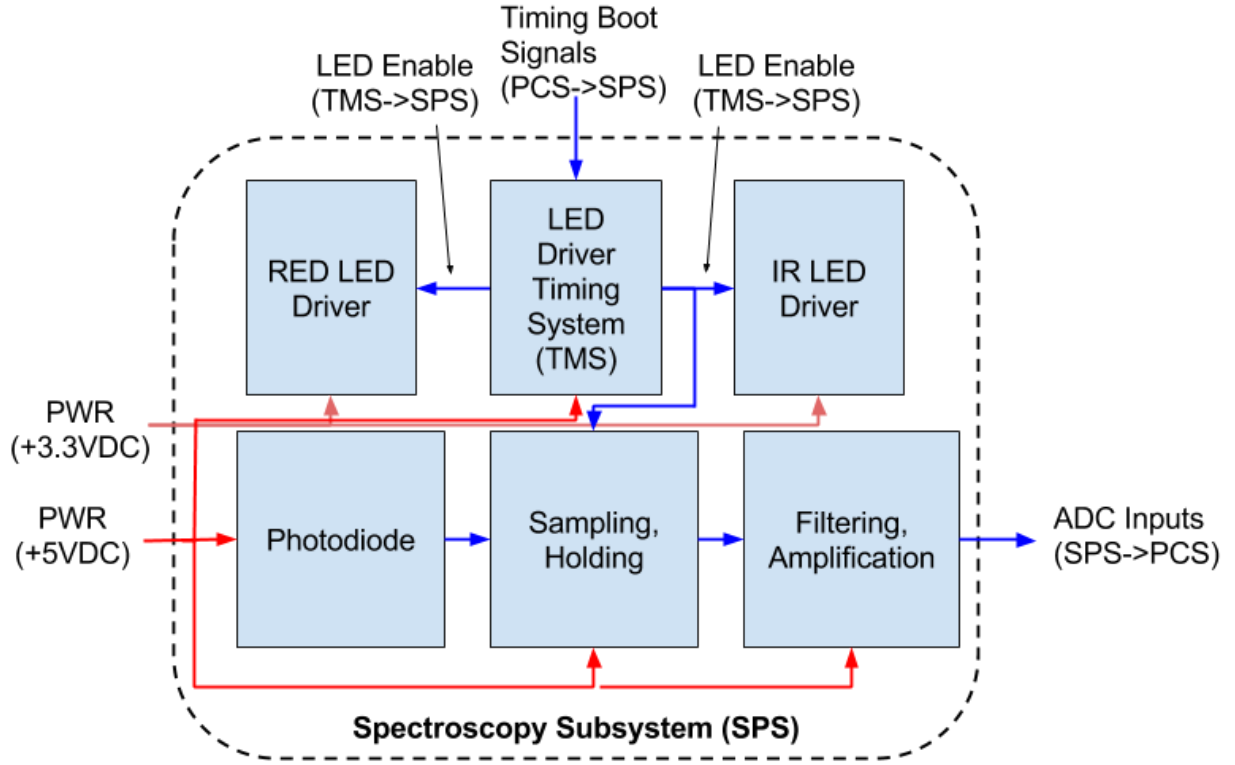


Figure 5: Block diagram of the spectroscopy subsystem

We choose to add a series of hardware timers (based on the 555 design) to more tightly control the sequencing and timing of the pulses. We also introduce an analog sampler that is tied to this timing circuit in order to ensure that there are no timing issues in processing the ADC input. Using an analog sampler, we can ensure that what the ADC samples is the data we want, and not the data from a different channel.

Using the automated gain control (abbreviated AGC), we will control the DC voltage of the output of our spectroscopy subsystem to be 2V. According to [6], the pulsatile amplitude of the heartbeat (which we aim to detect) is about 1% of the DC voltage. To ensure proper detection of minima and maxima, we need to resolve differences of half of that, or 0.5%. Our chosen processor has an ADC with 1024 distinct values, ranging from 0V to the supply voltage V_{cc} . To calculate the minimum detectable step voltage ΔV_{step} , we simply substitute our chosen supply voltage and divide through by the number of distinct values.

$$\Delta V_{step} = \frac{V_{cc}}{N} = \frac{3.3V}{1024} \approx 0.0032V$$

To verify that our detectable step voltage is below what we want to detect, we must show that 0.5% of our chosen DC voltage is greater than the minimum step voltage:

$$\Delta V_{step} < 0.005 \cdot 2V = 0.01V \rightarrow 0.0032V < 0.01V \checkmark$$

From the minimum amplitude to the maximum amplitude, we will have the full 1% voltage change, implying we will have at least 5 and at most 7 different values on the ADC.

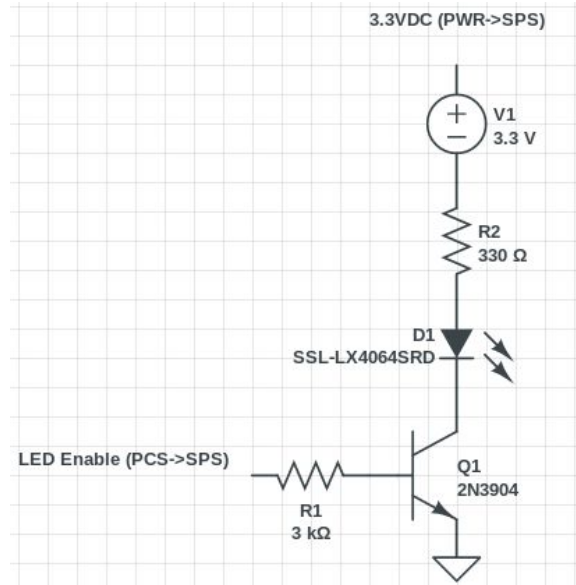


Figure 6: Simple LED Driver (660nm LED pictured). The Enable signal comes from the TMS, not the PCS

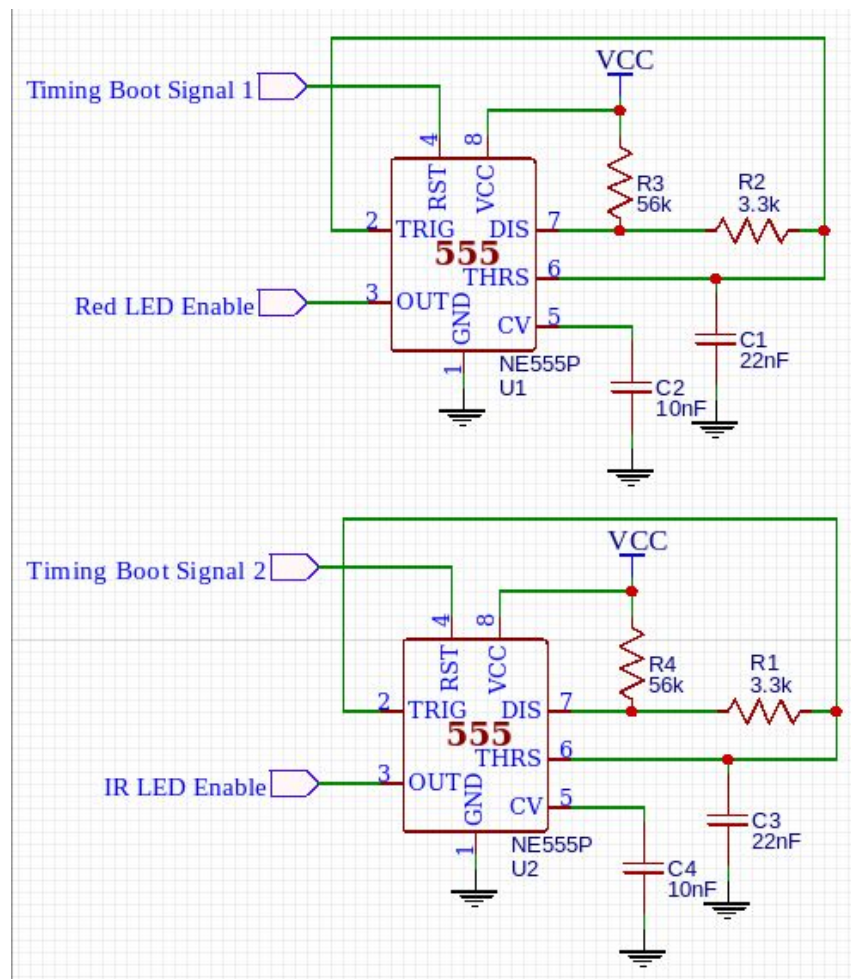


Figure 7: LED Timing Circuit (50us pulse, 1ms period)

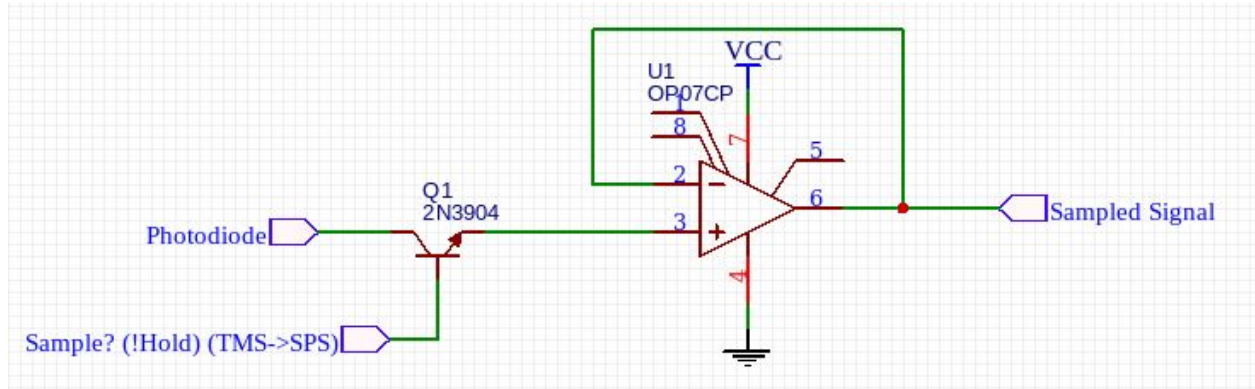


Figure 8: Sample/Hold Circuit. Enabled using the LED Enable. Two used in practice.

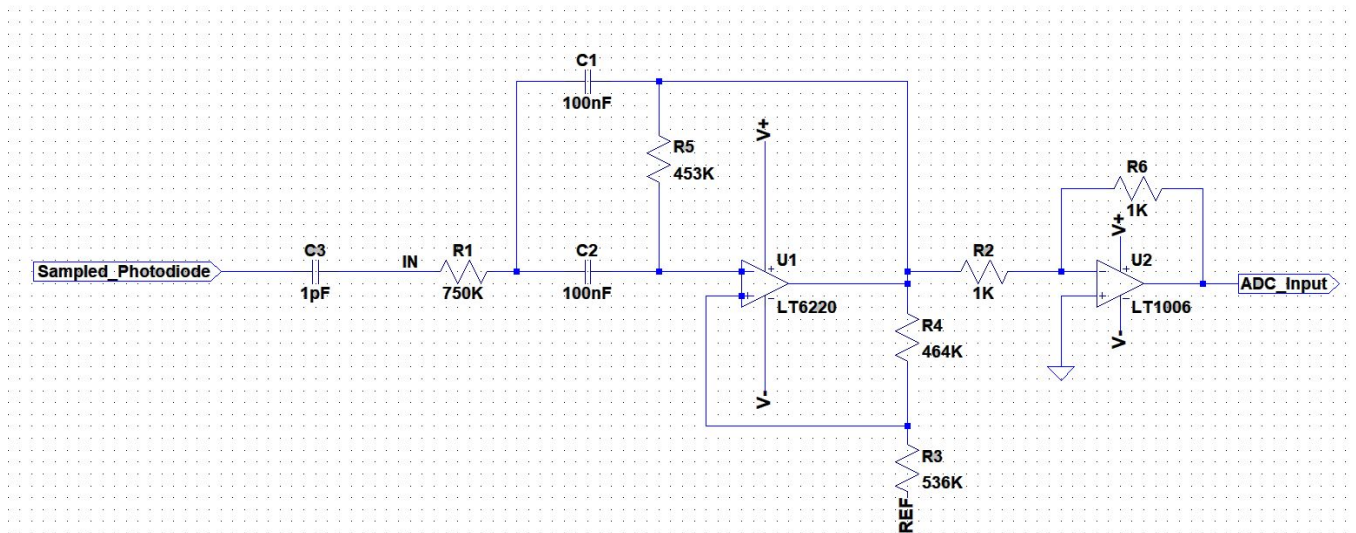


Figure 9a: DC Blocking, Active Bandpass Filtering, and Amplification.

*note: $V+ = +3.3V$ and $V- = 0V$

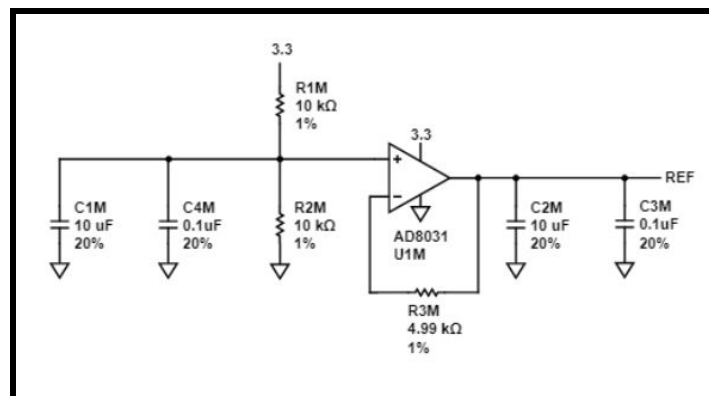


Figure 9b: Active Bandpass Filtering and reference voltage generation

Notes on the active bandpass filter:

Our intention is to hone in on frequencies shown by the pulsatile signal relating to heartbeat and blood flow. These frequencies fall between 0.5Hz and 5Hz, so we chose to use a 2nd order

butterworth filter centered at 2.75Hz. The filter has a passband bandwidth of 4.5Hz with a 0.25Hz rolloff, and mitigates frequencies 3db below the maximum signal amplitude.

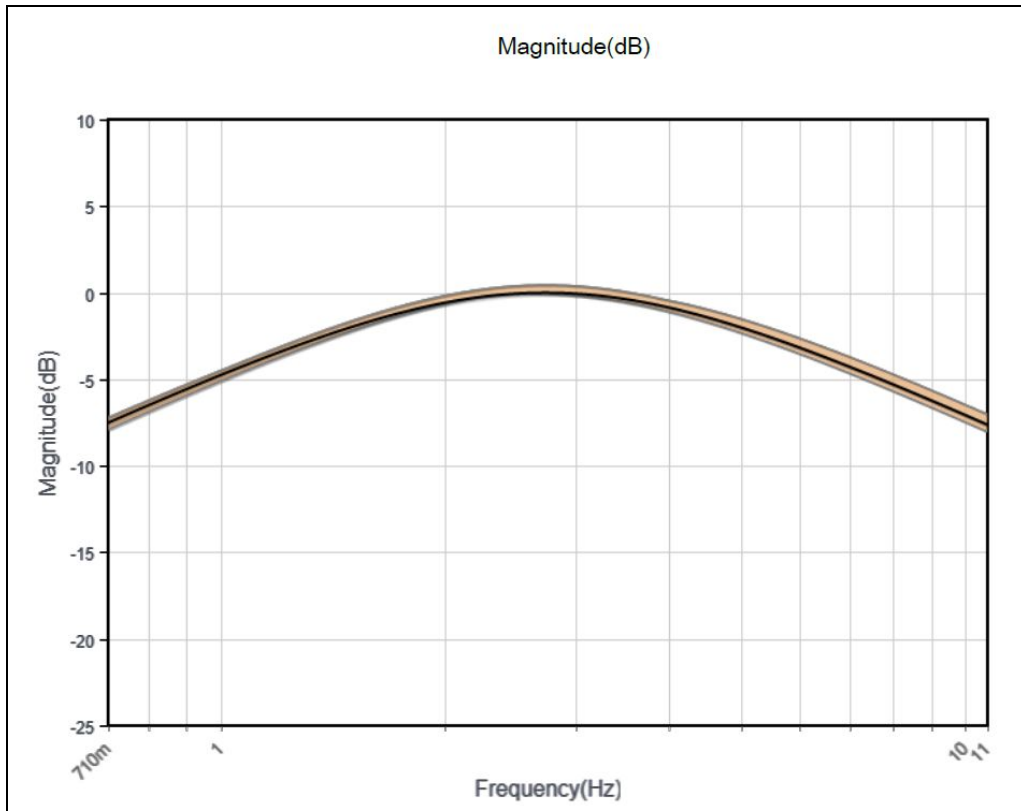


Figure 9c: Frequency response of active bandpass filter.

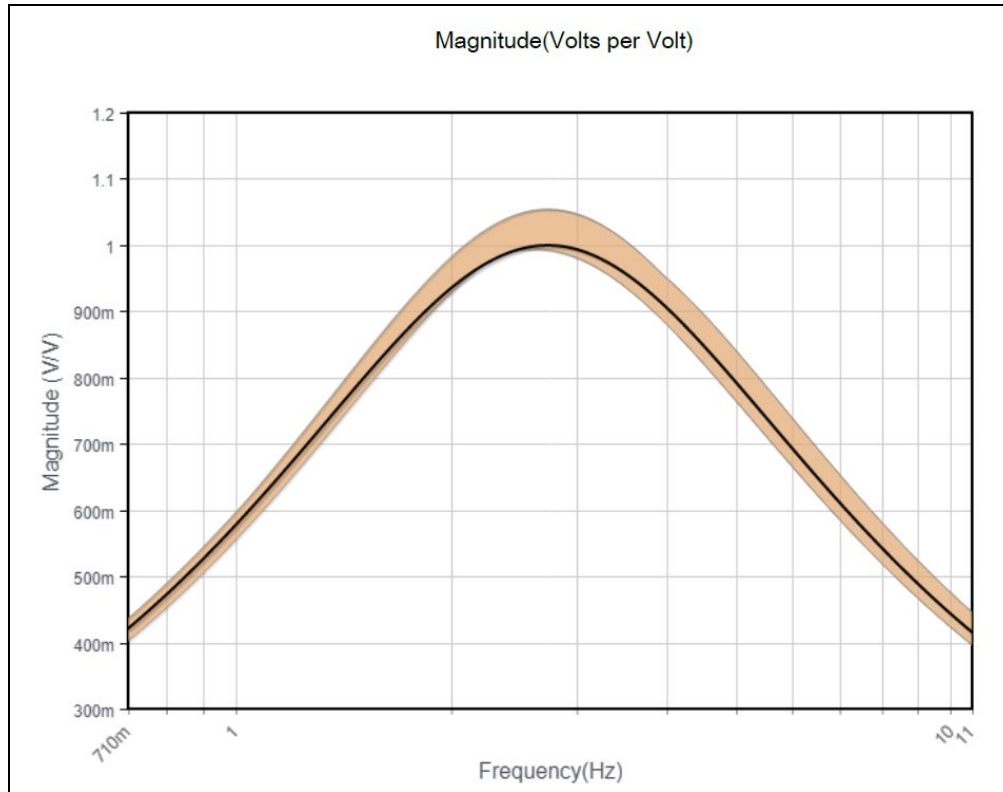


Figure 9d: Magnitude of signal from active bandpass filter

Client System (CLS)

The client system (abbreviated CLS) consists of the image capture, image processing, and diagnosis indication systems. It combines these systems through use of complex software systems that are exposed to the user via a smartphone application. The block diagram shown in the High Level Block Diagram is sufficient to show the function of this system.

Image Processing Subsystem (IPS)

The Imaging Processing Subsystem (abbreviated IPS) consists of the smartphone camera of the client system, and an image processing algorithm that will identify the redness of the conjunctiva to arrive at a partial diagnosis. As this system contains no hardware, it does not have a block diagram.

Diagnosis Indication System (DIS)

The Diagnosis Indication System is where the user will read out their final diagnosis. This diagnosis will be implemented in software and shown through an Android application. As this system contains no hardware, it does not have a block diagram.

Anemia Detected

Please align the conjunctiva and the pupil using the provided crosshairs.

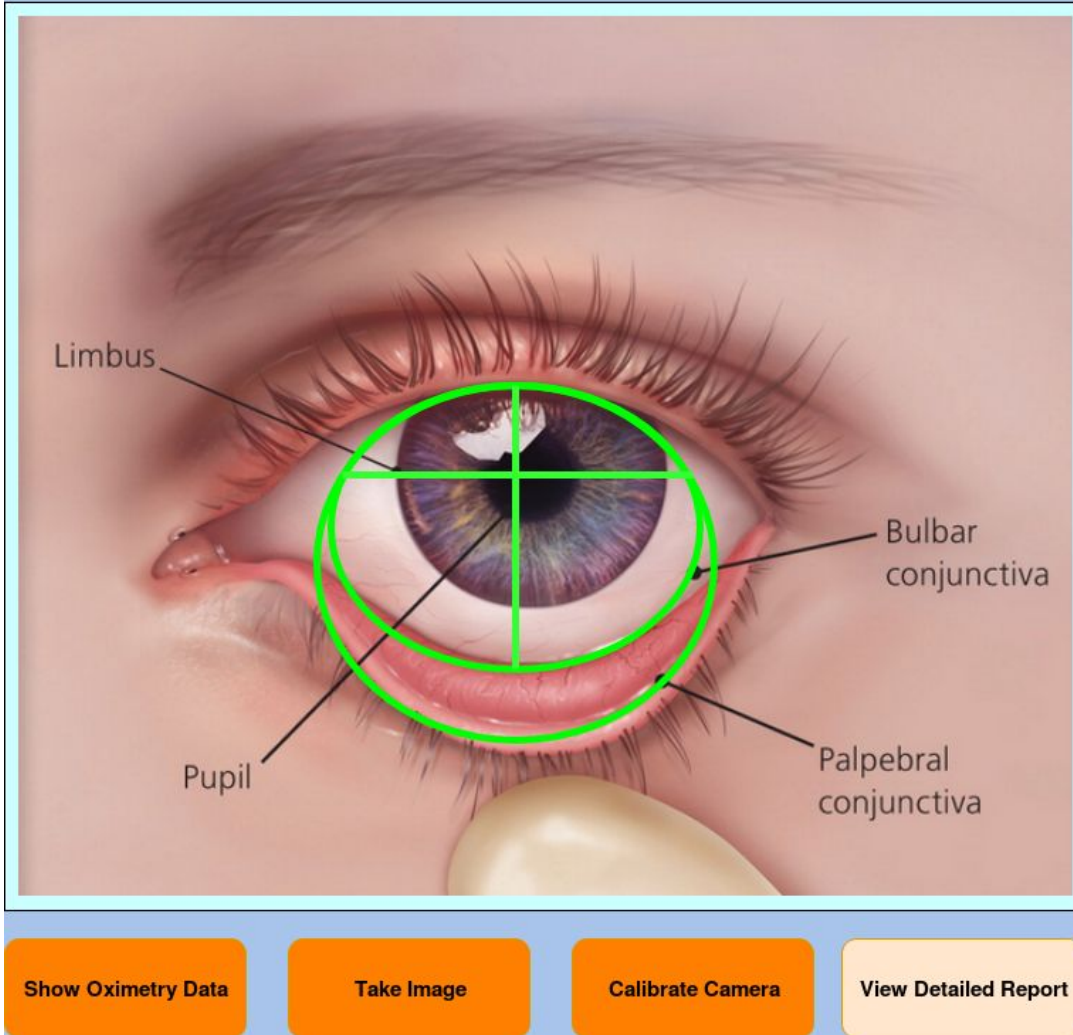


Figure 10: Mockup of Android application

External to these requirements, we may extend the Diagnosis Indication System to do the following:

- Show measured SpO2 from the SPS
- Show EI value from the conjunctiva image

Requirements and Verification

Block	Requirement	Verification
Power System	Rechargeable battery pack must have minimum capacity of 20mAh of charge.	Discharge battery pack through known resistance, measure current over time using oscilloscope to calculate overall energy storage.
	Power system should be able to supply current of 150mA sustained and 200mA peak.	Discharge battery into programmable load box drawing 150mA and 200mA.
	5V and 3.3V outputs must be within a $\pm 1\%$ tolerance after filtering and isolation.	Record waveforms for 10 seconds of 5V bus and 3.3V bus to make sure output voltage meets tolerance.
Processing System	The embedded processor must have an ADC that operates from 0 to 3.3VDC, $\pm 1\%$, with a resolution of better than 0.005V.	Calculate gain error, offset error, and non-linearity error given by
	The embedded processor must be able to drive an LED by pulsing a DAC.	Reference datasheet to ensure existence of programmable output pins whose voltage is greater than the gate voltage of the LED driver circuit's BJT.
	The embedded processor must be able to run on 3.3VDC, $\pm 1\%$.	Connect embedded processor to 3.3V power supply and run read/write C code example given by manufacturer
	The embedded processor must have a UART to send spectroscopy data to the communications system.	Send 1000 bytes to the ATmega UART, increment all 1000 bytes within the ATmega, send back the incremented byte over UART and verify that all byte were properly incremented, and thus properly received and re-transmitted.
Communications System	The communications system must be capable of running on 3.3V provided by the power system.	Communication system powers on and transmits data when powered by the 3.3V bus.

	The communications system must be capable of transmitting at a rate of at least 9600 bits/sec, and support up to 115200 bits/sec.	Send data with baud rate set to 9600bps and then 115200bps.
	The communications system must consume no more than 40mA during transmission, and no more than 200uA during idle mode.	Record current waveform through bluetooth module during operation and ensure that peak current draw is less than 40mA. Record current waveform once again during idle mode and ensure that current draw is less than 200uA.
	The communications system must interface with the processing system over UART.	Communication system can full read full range of output data from embedded processor UART.
Spectroscopy Subsystem	The photodiode must be capable of detecting both the red and infrared outputs of the two LEDs.	The spectrum of the selected photodiode includes both the 660nm and 940nm wavelengths.
	The final output sent to the processing system must be between 0 and 3.3V.	Pulse both LEDs at full brightness for a period of 10 minutes and measure output waveform on oscilloscope. Collect voltage statistics and verify that the output voltage is between 0VDC and 3.3VDC over the entire test period.
	The spectroscopy subsystem must run on 5VDC and 3.3VDC.	For each individual component in the spectroscopy system, verify through the datasheet that the chosen part can operate using either 3.3VDC or 5VDC.
Client System	The client must support data transfer from the communications system.	The client system can transmit to and receive from the BLE radio employed by the communications system.
	The client must be capable of running the image processing subsystem.	The software developed for the image processing subsystem will be developed and tested against an Android phone.
	The client must be capable of displaying the final diagnosis.	The Android application shows the final diagnosis on the main screen.

Image Processing Subsystem	The image processing algorithm must feature some type of feature detection to identify different sections of the image.	Image processing algorithm must detect the following features: 1. Conjunctiva 2. Eyeball 3. Periorbital (under eye) area
	The image processing algorithm must run on an Android device.	Image processing algorithm is able to detect features using an Android phone.
	The image processing algorithm must use less than 250MB of RAM on the client.	Memory usage will be recorded as image processing algorithm runs start to finish, and statistics will be run to ensure the usage never exceeds 250MB.
	The image processing algorithm must give a binary diagnosis (anemia/no anemia) in no more than 5s.	User will externally time image processing algorithm run time on Android phone. Result of diagnosis should appear in either the form of displaying the word 'anemic' in red or green the words 'not anemic'.

Risk Analysis

The block that poses the greatest risk to the completion of our project is the Client System. The client system contains an as-yet unspecified image processing algorithm that will need to provide feature detection, classification, and diagnosis capabilities. To mitigate this risk, we will be scoping the features of the image processing algorithm such that the identification of the features of the image is part of the image capture itself, so as to decrease the complexity in the most complicated portion of the algorithm. One potential manifestation of this is using an image template that all images must conform to, such that features exist in a known location of the image.

Ethics and Safety

Both ethics and safety are of great importance to us while pursuing this project.

Because we will be working with a 120V AC line and stepping it down to a lower DC voltages, we will be sure to abide by the following safety precautions when working in lab. First and foremost, we will always be aware of any damaged or frayed equipment, and work without bringing food or water into a lab setting. When testing, we can take precaution by placing one hand on our back or in our pocket to prevent a closed loop current passing through the body. Additionally, using proper grounding methods, working with a partner, and wearing PPE will ensure that any safety risk regarding electrical shock is minimized.

In addition to safety, our group will also hold ethics in high regard as this project may require us to work with medical/patient data. When working with others, our group will stand by the IEEE code of ethics, and follow the appropriate methods set out by the IRB if working directly with patient data.

Lastly, we promise to attribute any research or information taken from a source to the source itself, and never pass off the work as our own.

References

- [1] <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3685880/>
- [2] <https://www.nxp.com/docs/en/application-note/AN4327.pdf>
- [3] <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1497067/>
- [4] <http://ieeexplore.ieee.org/document/8249080/>
- [5] <http://epomedicine.com/clinical-medicine/clinical-examination-pallor/>
- [6] https://www.robots.ox.ac.uk/~neil/teaching/lectures/med_elec/notes6.pdf