Low-Cost Spectrophotometer

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Statement of Need

Clinicians and technicians in the developing world cannot run laboratory tests using current spectrophotometers due to their inability to function in third world countries. These tests are important because they provide vital information that can be used to diagnose a patient. The factors that contribute to this issue are a result of current spectrophotometers being expensive and fragile. This is due to their use of highly complicated optics and electronics. Additionally, the infrastructure is inadequate to provide a stable power source for medical environments thus preventing the running of needed diagnostic test. Therefore, the team will design a system that is accurate, low-cost, durable, and incorporate various power options. The design will focus on the most commonly requested tests, considering the reagents will be obtainable in the developing world. Ideally, the system would be designed using local and sustainable materials with a reduced number of parts, and provide useful results for its target audience.

Introduction, Overview, and Requirements

Introduction

Spectrophotometry is a measurement of the transmittance of a material or solution, based on wavelength. UV-Vis Spectroscopy measures between 200 and 400 nanometers for UV light measurements, and up to approximately 750 nm in the visible spectrum. According to Beer Lambert's law, the amount of light absorbed by a medium is proportional to the concentration of the absorbing material or solute present. In a clinical setting, spectrophotometry can be used to determine the presence of certain compounds in the body by using serum from the patients' blood. For example, there are elevated levels of the enzyme creatine kinase (CK) in the blood, following a heart attack. Spectrophotometer can be a valuable tool for comparing a patient's CK levels to a normal baseline. Currently there are two types of spectrophotometers being used in medical laboratories, single-beam and double-beam. Single-beam spectrophotometers consist of a light source, monochromator, the sample area and the detector. Single-beam is mainly used on ground of cost. Double-beam spectrophotometer sends a beam through a sample and reference positions using a chopper wheel at any one time. Double-beam gives a higher resolution; however, there is an increase in cost. For the scope of this project, a single-beam spectrophotometer will be designed.

Overview

The low-cost spectrophotometer will provide a platform for diagnosing bilirubin, hemoglobin, and glucose in the serum of the blood. These three tests were determined the most useful in the clinical settings of developing countries. Testing hemoglobin levels can determine if that individual is anemic. Iron deficiency is the most common and widespread nutritional disorder in the world. Two billion people – over 30% of the world's population are anemic due to iron deficiency. Iron deficiency and anemia reduce work capacity of individuals and entire populations; bring serious economic consequences and obstacles to national development. Another major disease in the developing countries is hyperbilirubinemia, which is a condition in which there is too much bilirubin in the blood. When red blood cells break down, a substance called bilirubin is formed. Babies are not easily able to get rid of the bilirubin and it can build up in the blood and other tissues and fluids of the baby's body. Because bilirubin has a pigment or coloring, it causes a yellowing of the baby's skin and tissues. This is called jaundice. Around sixty percent of newborns develop jaundice, and if it is not treated, large amounts can circulate to tissues in the brain and may cause seizures and brain damage. Lastly, there are 366 million people that are suffering from diabetes and of that 80% live in third-world countries. Glucose levels can be measured to determine if the patient has diabetes. Considering these statistics and relevancy of anemia, hyperbilirubinemia, and diabetes in developing countries, our team will be focusing on these three diseases. Furthermore, current spectrophotometers are expensive and fragile and require frequent calibration. The solution provided in this project will be low cost and provide a more durable and reliable diagnostic option. The device will easily be repairable and will require little maintenance.

Prior Art

1.) *Spectrophotometer built in Nicaragua*

Device was constructed for less than $100, which provides a frame of reference for our device cost.

2.) *DIY Spectro II*

Simple spectrophotometer made with arduino microcontroller, lead us to determine arduino as an option.

3.) *A Low cost LED based Spectrophotometer*

Helped us determine LEDs as a light source to help eliminate a diffraction grating. Our design will be unique from this one in that it has the option to be battery powered for up to 10 hours, where this design requires a consistent wall power to operate.

4.) *Camera Phone used as a spectrophotometer*

While an interesting option, due to phones being readily available in our target country. The design is not well packaged or durable.

Requirements

1. [high] The prototype shall be capable of analyzing bilirubin, hemoglobin, and glucose levels in blood; level of necessary precision to be determined based on experiments and further research.

Motivation: The team investigated which diseases in the developing world are in most need of diagnosis. Prevalence of disease and urgency of diagnosis varied slightly depending on the article or resource referenced. However, most resources cited a core group of pathologies in need of diagnosis: malaria, diabetes, HIV/AIDS, and tuberculosis (TB). Ultimately, our consultation with Dr. Amin Mohammad, professor of pathology at the TAMUHSC, provided the most useful source of information. His input helped to narrow our considerations down to hyperbilirubinemia and diabetes. Hyperbilirubinemia will be diagnosed by measuring levels of one or both of the following from a specimen: bilirubin and hemoglobin. Diabetes will be diagnosed by measuring blood glucose levels.

2. [high] The final manufactured product shall be affordable for our customer (<$100).
Motivation: It is common that large devices, namely spectrophotometers, are too expensive for use in hospitals in the developing world. Reducing the cost of our devices is a necessity that must be accomplished for our customers to acquire the device.

3. [high] The device shall be robust considering local conditions (humidity, dust, heat, etc.) and long lasting. It would be able to withstand rough use, electrical components would all be able to operate within local climate conditions (12˚ C to 27˚ C), and an enclosure to limit effects of humidity and dust.
Motivation: Devices in developing world settings need to be robust and durable due to lack of skilled technicians to repair their equipment. A device that does not break easily under local conditions will be more reliable, and therefore more effective at diagnosing patients.

4. [high] The device must be self-sustainable in its power use. It should be able to operate for 10 hours minimum independent of external power.
Motivation: About 1.6 billion people in developing countries have no access to electricity, and some have unreliable electricity service. Power in developing world hospitals is often unreliable with power surges and power outages being commonplace. A device that is self-sustainable in its power usage, such as those using a battery, would be ideal for this application.

5. [medium] The device must be able to report a useful reading for the clinician in a user-friendly way (determined by a clinical expert).
Motivation: The device needs to report its values to clinicians, so a proper diagnosis can be made. Equipment that is complicated and hard to use is typically discarded and left in storage. The output of the device must present results in a fast, consistent and easily readable way that would be useful to the clinician.

6. [low]The device should be able to be repaired locally, and by low skilled technicians.
Motivation: While the device should be robust as mentioned previously, but if a failure should occur it would be beneficial for the device to be repaired locally. The issue with using an intricate medical device in a third world country hospital is that the parts are often not available locally, so it would be impossible to repair. In addition local technicians would not be able to repair complicated equipment, because specific knowledge that may not be available would be required. However, if our device is constructed to be low maintenance as defined in requirement #5, this requirement becomes unnecessary.

Constraints

1. Available budgets of developing hospitals are typically low
2. Local availability of (replaceable) parts are limited
3. Local manufacturability is limited
4. The device must be able to withstand extreme weather conditions sometimes present in developing world hospitals
5. Lack of skill technicians to repair or operate on equipment

Concept/Design Selections

- Case Study I: SLIM
    - Simple, Low-power, Inexpensive, Microcontroller-based
    - Replace parts in traditional designs with alternatives for developing world
    - Total cost is ~$25
    - Design seems feasible for use in resource-limited settings
    - Concerns: SLIM design is noisier and has lower resolution than conventional models. We team must address these issues in our design.

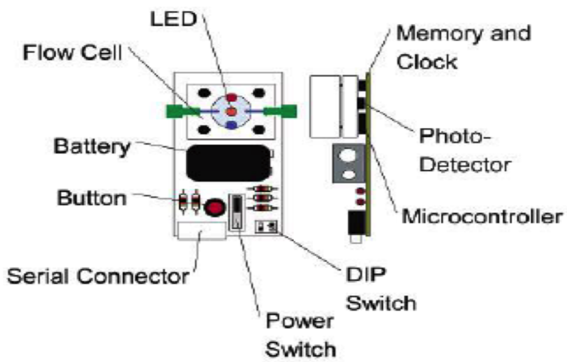

Figure 1- SLIM

- Case Study II: Spectuino
    - Spectruino replaces an expensive monochromator with an arduino board to make it robust
    - Two simple buttons to choose from the "learning" and "identify" mode make it user friendly
    - Total cost is less than $100

- Much of the cost comes from the case and serial display used

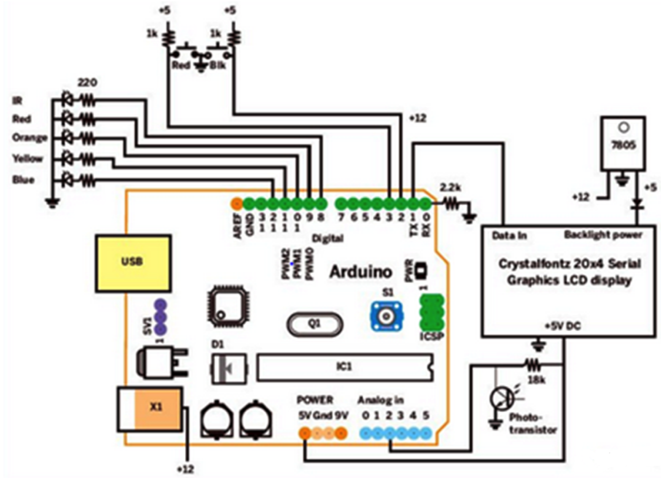

Figure 2- Spectruino

Previous Design

Previous prototype built on spectruino design

- Used same phototransistor detector circuit
- Used shift-registers to output to 4 7-segment displays
- Could be powered using 8 AA NiMH batteries or 5 V USB

Advantages

- Easily programmable and customizable
- Simple Design

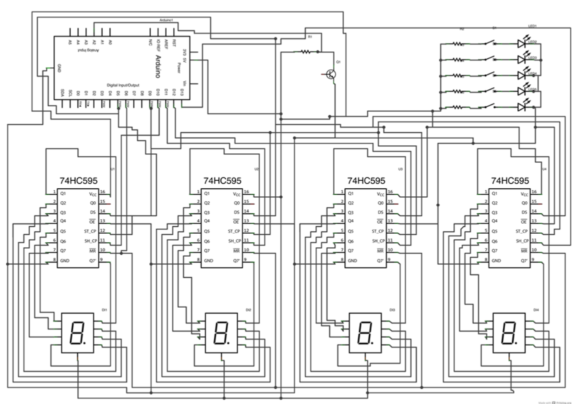

Figure 3-Circuit Schematic of Previous Device Design

- Battery life minimal
  - 3 hours when relying on batteries due to overly complicated and wasteful display circuit
  - Unneeded functions on Arduino consumes power
- Limited Dynamic range/Resolution
  - Phototransistor circuit needs to be calibrated in order to use full dynamic range
  - Limited resolution on AD converter

Current Prototype

- Current Design:

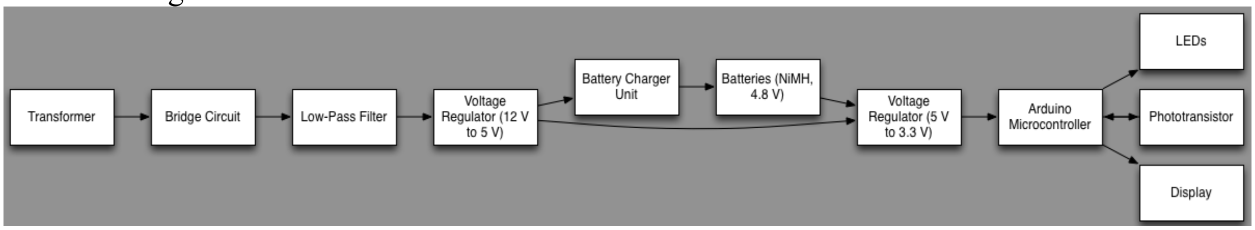

Figure 4- FlowChart for electrical Design

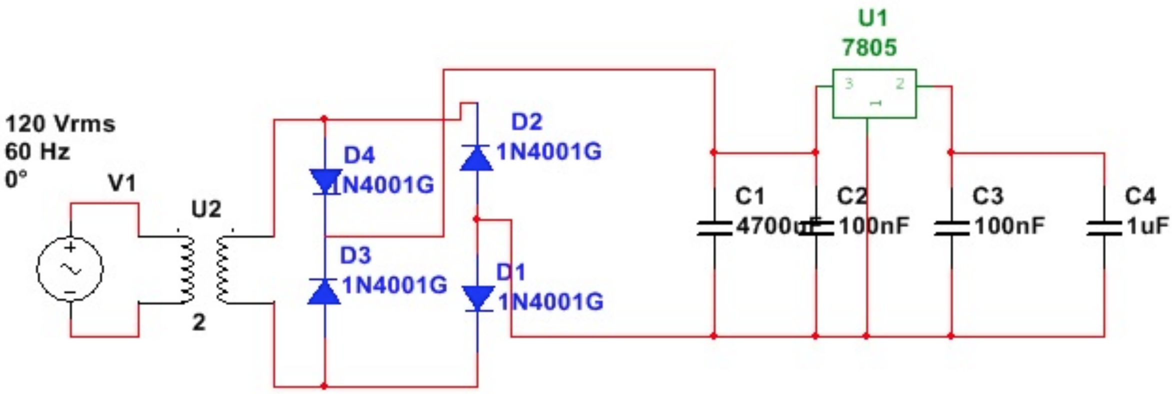

Figure 5- Circuit Schematic of Power Supply Circuit

- Device will be able to operate on both battery power and wall power
  - A power supply circuit controls input voltage and current
  - NiMH rechargeable batteries
    - 4 Batteries provides a fairly consistent 4.8-5.2V over the batteries charge cycle.
    - Batteries last 2 to 5 years before losing ability to hold charge.
  - Battery Life
    - The device will consume between 30 and 60 mA.
    - Batteries have 2000 mAH capacity
    - Device should operate properly for 25 Hours without main power supply

- Power Supply Circuit
  - Power from main converted down to 5 V DC from 120 V
    - Transformer - 120 V, 60 Hz AC to 12 V AC
    - Bridge Circuit/
      Low Pass Filter - 12 V AC to 12V DC
    - Voltage Regulator - Steps down 12V DC to 5 V DC
  - Next Steps would be to ensure device can operate from a 240 V AC output at 50 Hz, which is the standard in Rwanda.

            - Most other African countries operate at 220-240 V 50 Hz

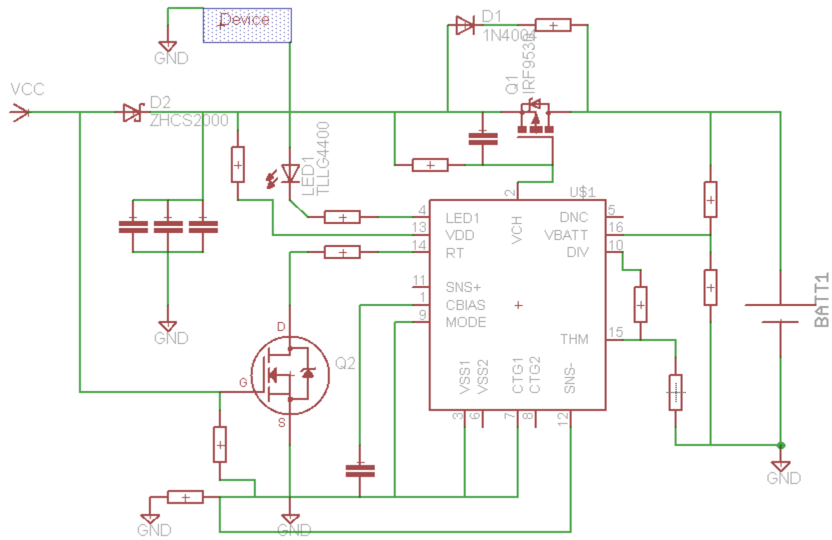

Figure 6: Battery Charging Circuit

- Battery Charging
    - Charging of batteries must be regulated in order to maintain their capactiy
        - Running a high current(>3A) through a fully charged battery causes permanent damage
    - Charging through an integrated circuit from Maxim Integrated
        - DS2715
        - Regulates the current through the batteries via three methods
            - Temperature through a thermistor
                - Semetic 103AT-2
            - Voltage - IC regulates voltage across a sense resistor
                - R = (Fast Charge Voltage)/(Fast Charge Current)
                - .27 Ω Resistor
            - Time - Additional resistor regulates voltage from RT pin to ground
                - t(minutes) = 1.5 x R(ohms) / 1000
                - 178K Ω provides 266 minutes of charging time.
        - Transistors in conjunction with the IC regulate the to and from the battery.
        - Four states of charging Pre-Charge, Fast Charge , Top-Off and Done
            - Fast Charge provide .5 A current
            - Roughly 4 hours to charge completely
    - Interfaces easily with device
        - Operates during all three Cases
            - Plugged into wall and charging
            - Plugged into wall and done charging

        - Not plugged into wall(running on battery)

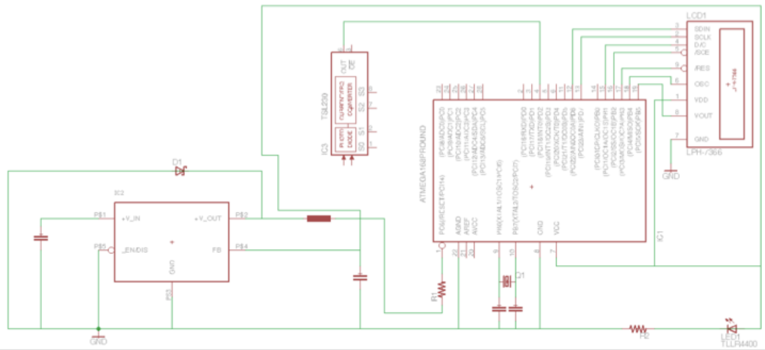

Figure 7- Circuit Schematic of Microcontroller

- Switch-Mode Step Down Converter
    - Power conversion is more efficient than linear regulator (75% - 98% efficiency)
    - Converts 5V to 3.3V
    - Component Parameters
        - L = 220 mH inductor
        - Cin = 100 uF Capacitor
        - Cout (LPF)
            - must minimize voltage limit (~5V to 8V)
            - higher capacitance desired to minimize ripple
            - Tradeback on higher capacitance?
        - Diode
            - >120 mA
            - 6.5V reverse voltage rating
- Custom Arduino
    - Minimal arduino design build around the ATMEGA328 microcontroller
        - Allows for us to add/subtract components that we find useful/not useful
        - Minimizes power consumption
    - Utilizes 3.3V operating voltage for digital logic
        - Reduces power consumption
    - Minimizes physical presence on PCB
        - Less space => smaller cost
- Software/Hardware Limitations
    - ATMEGA328 has only 2KB of ram
        - Limits on sampling storage and signal processing algorithms
        - Also has 32KB of flash memory storage
        - Runs at 16 MHz
    - Limited to C implementation for software due to the Arduino platform being used on the microcontroller
    - To save space, the software stores signal values as Boolean variables
        - Smallest variable type available
        - Boolean Variable = 1 byte
        - Can only store True or False Values (1 or 0)
    - Maximum sampling frequency is 1 MHz due to limitations on the delaymicroseconds function

        - E.g. Delaymicroseconds(1) = 1MhZ, Delaymicroseconds(2) = 500 kHz, etc.
    - Example: Sampling at 200 kHz with a 1024 sampling window would require a delay of 5 microseconds, and 1024 bytes of space in ram.
- Signal Processing
    - Signal from the Light-to-Frequency Converter needs to be sampled and stored in the microcontroller.
    - Frequency of signal needs to be determined, this can be done through two main methods:
        - Fast Fourier Transform
            - Find frequency by Fourier transforming the signal, excluding the D.C component and finding the first highest peak for the frequency of the square wave.
            - Fast Fourier Transform library for Arduino has a maximum capacity of 256 bins
            - Extra memory consumption due to requirements in processing data: 1376 bytes for 256 bins
            - Can reduce the memory consumption to 888 bytes for 256 bins by utilizing the Fast Hartley Transform
            - Advantages: Works reliably and is accurate, mathematically easier
            - Disadvantage: Uncertain if 256 samples will be enough resolution for our signal, computationally more difficult
        - Auto-Correlation
            - Uses the correlation operation on the signal (with itself as the kernel) to find the period of the signal.
                - First local maxima gives the period of the signal, the inverse of the period will give the frequency of the signal
            - Advantages: allows for higher sampling windows (only limited by ram memory), computationally easier
            - Disadvantage: uncertain about accuracy, since only looking at one period of signal. Could be improved by averaging multiple periods measured in the signal, mathematically difficult
- Testing the resolution of the Light to Frequency Converter

Sample: Blue LED, blue food coloring

- Blank sample: 30 kHz
- 2 microliters: 33 kHz
- 3 microliters: 28 kHz
- 4 microliters: 27 kHz

Sample: Red LED, blue food coloring

- Blank 8.33 kHz
- 2 microliters: 1.7 kHz
- 3 microliters: 1.51 kHz
- 4 microliters: 700 Hz

Scope
This project will develop a platform for current clinical tests. Novel tests will not be developed for specific diagnostic purposes. The device will be independent of preparation of samples. However, the means to analyze these samples will be provided with this device. The device should not exceed requirements designated in the requirements section listed in this document. This project is intended to provide a design for a low cost spectrophotometer, which will include a printed circuit board, compact enclosure, and a method for cuvette sample input. This design should be a reproducible product so it can be distributed largely to our target customer. A prototype will also be built based on the design that is generated. The prototype, however, may or may not resemble the final product to be produced on a large scale. A user manual should also be generated to accompany the final design, so that it can be used with minimal barrier to entry.

Deliverables
1. Code of Cooperation
2. Project Statement
3. Project Presentation
4. Design Review Reports
5. Progress Report Presentations
6. Prototype (iterations and final)
7. Device test results using the reagent kits (Drabkins Method, Evelyn-Malloy Method, Glucose Oxidase)

Stakeholders
Engineering World Health Organization
The idea of designing a low-cost spectrophotometer came from Engineering World Health. Engineering World Health is a non-profit organization mobilizing the biomedical engineering community to improve the quality of health care in hospitals serving resource-poor communities of the developing world. Kristen Duckworth is the representative for Engineering World Health for Texas A&M University as well as the graduate student on the project.
Dr. Kristen Maitland- Sponsor/mentor
AggiE-Challenge - Is a program designed to actively engage undergraduate students with multidisciplinary team projects related to the engineering challenges facing our society. Our project is listed in Engineering World Health: Projects That Matter. Funding is also provided by the AggiE-Challenge program.

Texas A&M University
The University provides the educational and research resources for our project. All members of our group are representatives of Texas A&M University.

Biomedical Engineering Department

The department provides the facilities and technical resources needed for our project. Members of our group are also representatives of the Texas A&M University Biomedical Engineering Department.

Lab Technicians and Nurses

The low-cost spectrophotometer will impact the nurses and lab technicians working in developing world hospitals by giving them an accurate tool in diagnosing the patient's disease. These stakeholders will have to be trained on how to use the device as well as be able to analyze the results.

The patients that will be diagnosed

The motive behind designing the low-cost spectrophotometer is to ultimately diagnose diseases that the patient may be suffering from. Once the type of disease is known, the patient can be treated more accurately.

Appendix I

The figure below shows a previous low-cost spectrophotometer based on the Arduino microcontroller platform. From this previous design, we created a functional prototype that was later altered to better fit the requirements and constraints of the project.

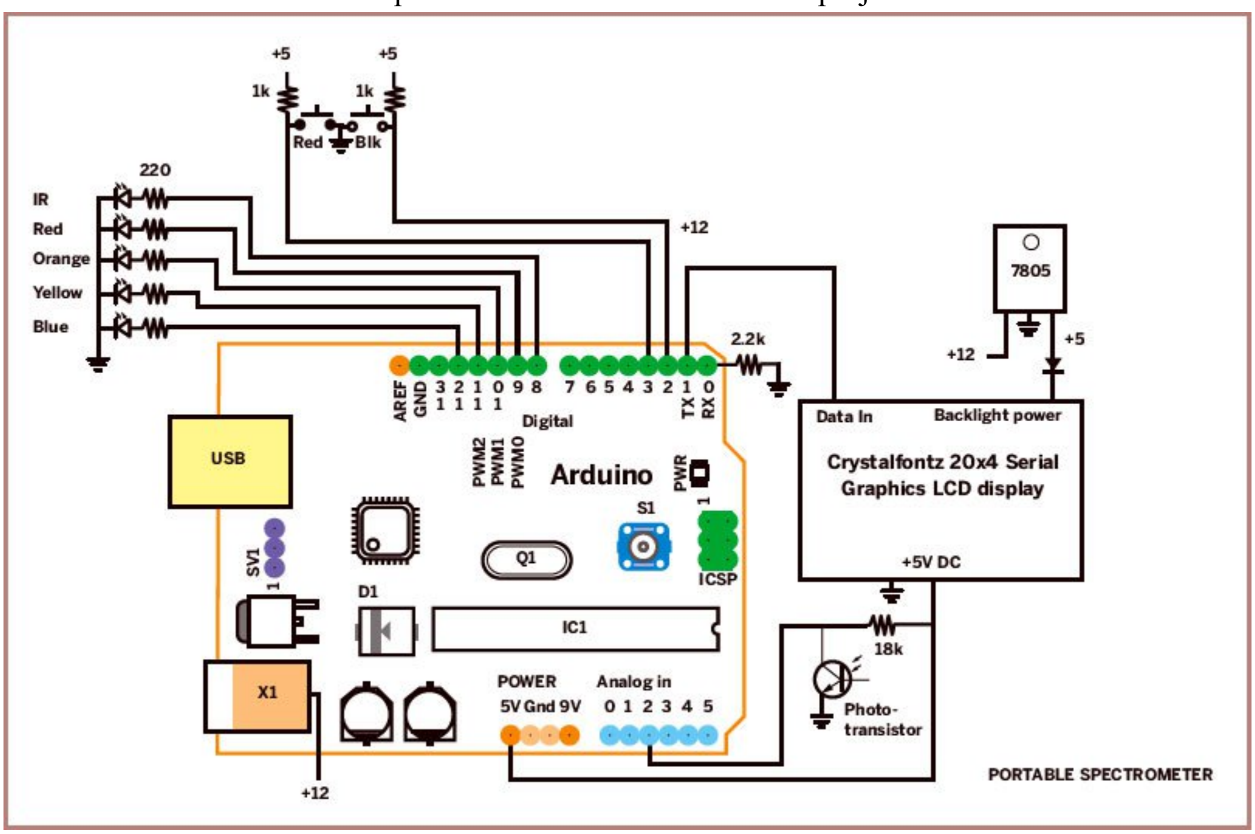

Figure 2 - Schematic of a low-cost spectrophotometer using Arduino microcontroller

Appendix II

Questions throughout the semester

1. What diseases are relevant for diagnosis in the developing world?

- hyperbilirubinemia, Anemia and Diabetes; See requirement 1 for detailed answer

2. What low-cost spectrophotometer designs have been used in the past?

- Spectrophotometer built in Nicaragua - http://iihlab.wordpress.com/2011/08/20/
  Device was constructed for less than $100
- MEDIkit Spectrophotometer dissected -http://vimeo.com/21725936
- DIY Spectro II - http://arkfab.org/?p=195
  - Simple spectrophotometer made with arduino microcontroller; lead us to determine arduino as an option.
- A Low cost LED based Spectrophotometer
  - http://diyhpl.us/~bryan/papers2/A%20low-cost%20LED%20based%20spectrometer.pdf
  - Helped us determine LEDs as a light source to help eliminate a diffraction grating.
  - Our design will be unique from this one in that it has the option to be battery powered for up to 10 hours, where this design requires a consistent wall power to operate.

5. Camera Phone used as a spectrophotometer

- http://www.wired.com/gadgetlab/2010/10/in-high-school-chem-labs-every-camera-phone-can-be-a-spectrometer/
- While an interesting option, due to phones being readily available in our target country. The design is not well packaged or durable. Our device will need to be able to handle an extended wear and tear.

3. What are the environment(s) in which our device will be used?

- Target area is Rwanda where the environment is harsh. The temperature is very hot and humid. Dust getting into the device is a concern.

4. How to select capacitors for a low pass filter? What are the tradeoffs with the different values?

- Large capacitors act as a "reservoir" to store energy from the rough DC out of the bridge rectifier. The larger the capacitor, the less ripple and the more constant the DC. Large capacitors are good to use for low frequencies. Small capacitors are good to use for high frequency.

5. How long will the reagent kits last after they have been opened?

- The reagents have a shelf life up to the expiration date if they have not been opened and stored correctly. Once the reagent is reconstituted, it should be stored in an amber container and is stable for 30 days.

6. Can the lab technicians order reagents with ease?

- It varies with different hospitals. Some hospitals order reagents a great deal while others do not. Our team has decided to not focus too much on the reagents, but instead on designing the device.

7. How will we charge our batteries without damaging them?

- We will need to design a circuit that will charge the battery. Look into cell phone batteries.

8. Would a light-to-frequency converter be a better option than a phototransistor (light-to-current)?

- In theory the light-to-frequency converter may provide better resolution at the cost of complexity. Experimentation needs to take place to decide this.

9.) Is there a lab safety training that will be completed before we use bovine blood?

10.) Looking at our current options, what would be the best method to sample our signal?

Other Activities

During the spring semester of 2013, our team took a field trip to Scott & White Hospital in Temple, Texas to meet with Dr. Amin Mohammad who is over the clinical laboratory. The team gained valuable information about how a clinical laboratory functions and what point-of-care devices are being used currently in hospitals. Dr. Mohammad also gave the team helpful feedback when it came to the design of the device. The team participated in the AggiE-Challenge Showcase exhibit at Texas A&M last spring semester to showcase the work completed. During that exhibit, the team displayed how the voltage is altered depending on the amount of concentration of food coloring in a cuvette of water. On Friday, September 20th, the team will participate in the fall semester meeting with the College of Engineering Advisory Council.

Notes

Project Timeline:

Task Name	***Duration***	***Start***	***Finish***
Project Preferences	1 day	Mon 8/26/13	Mon 8/26/13
Code of Cooperation	1 day	Wed 9/4/13	Wed 9/4/13
Order Parts	5 days	Mon 9/9/13	Fri 9/13/13
Project Statement	1 day	Wed 9/11/13	Wed 9/11/13
Design Review Presentation	1 day	Wed 9/25/13	Wed 9/25/13
Visit 305 Lab to learn about power supplies	1 day	Wed 9/25/13	Wed 9/25/13
Find statisitcal data for project statement need	1 day	Sun 9/29/13	Sun 9/29/13
Design Review Reports	1 day	Wed 10/2/13	Wed 10/2/13

Find reagents from wholesale suppliers	1 day?	Fri 10/4/13	Fri 10/4/13
FMEA	1 day	Mon 9/9/13	Mon 9/9/13
Risk Respone Plan	1 day	Mon 9/9/13	Mon 9/9/13
Rebuild Arduino/Power Supply	21 days	Mon 9/30/13	Mon 10/28/13
Test resolution and dynamic range of device	15 days	Mon 10/7/13	Fri 10/25/13
Software	20 days	Mon 10/21/13	Fri 11/15/13
Tests/Calibration/Design	100 days	Mon 10/21/13	Fri 3/7/14
Progress Report Presentations	3 days	Mon 11/11/13	Wed 11/13/13
Design Review Report	14 days	Wed 11/13/13	Mon 12/2/13
Review/Prepare for next semester	6 days	Fri 12/6/13	Fri 12/13/13
Finalize Design (PCB/Enclosure)	55 days	Mon 1/20/14	Fri 4/4/14

Budget

The goal for the total cost of the spectrophotometer will be less than $100.00. Our total budget to design the low-cost spectrophotometer is $1,500.00 and is funded by AggiE-Challenge.

Part Name	Date Ordered	Date Received	Description	Price	Quantity	Total
Compact ABS Electronics Enclosures	**2/12/13**	**3/1/13**	**Enclosure is for the casing of the spectrophotometer. Made of lightweight, impact-resistant ABS plastic and have a lift-off cover. Steel screws to secure the cover are included. Color is black. 6.9" Height X 4.9" Width X 2.5" Depth**	**$11.14**	**1**	**$11.14**
Polystyrene	**2/18/13**	**3/1/13**	**As far as I can tell, these cuvettes should do for our**	**$18.00+10 for shipping for 100**	**1**	**$28.00**

cuvettes			application. The price seems pretty reasonable compared to Sigma-Aldrich. I went ahead and asked for a sample just in case so we can see what we will get before we buy a bunch	cuvettes		
Eneloop Batteries(8 pack)	2/12/13	3/1/13	Rechargeable batteries were ordered, so we could power our inital prototype, while also being able to recharge those batteries for future use.	$19.10	1	$19.10
Wall charger for enloop AA batteries	9/19/13	9/26/13	Charge the batteries externally, when we use up the battery's charge.	$11.54+shipping	1	$11.54
Breadboard	9/19/13	9/30/13	Used for prototyping our device	$8.00	2	$16.00
Schottky Diode (Need this)	9/18/13	9/23/13	Needed for step-down voltage regulator	$0.15	1	$0.15
Clock Crystal (16 MHz)	9/18/13	9/23/13	Sets clock speed for microcontroller	$0.95	1	$0.95
Button	9/18/13	9/23/13	Reset button for microcontroller	$0.50	1	$0.50
Breakout Board for FT232RL USB to Serial (Used to program board)	9/18/13	9/23/13	USB interface for microcontroller	$14.95	1	$14.95
ATmega328 with Arduino Optiboot (Uno)	9/18/13	9/23/13	Microcontroller	$5.50	1	$5.50
Nokia 5110 LCD Black on Blue	9/18/13		Display for our device	$4.50	1	$4.50
Transformer 120V to 12V	9/19/13	9/30/13	Initial voltage conversion	$7.99	1	$7.99
1N4001 Diode	9/19/13	9/23/13	Used for bridge rectifier in power supply	$0.10	4	$0.40

Heavy-Duty-3-Wire Replacement Male Electrical Plug	10/2/13	10/3/13	10/14/13		$5.29	1	$5.29
Light-to-frequency Converter TSL23R	10/2/13	10/3/13		10/7/13	$2.95	1	$2.95
USB mini-B cable	10/4/13	10/4/13		10/11/13	$0.49	1	$0.49
pin header strip	10/4/13	10/4/13		10/7/13	$0.25	2	$0.50
solderable breadboard	10/4/13	10/9/13			$3.99	1	$3.99
10K resistor	10/11/13	10/11/13		10/11/13	$0.02	1	$0.02
Weller Soldering tip D-series	10/11/13	10/11/13		10/11/13	$3.69	1	$3.69
Display for our device	10/14/13	10/15/13		10/20/13	$9.95	1	$9.95
Total Bilirubin Reagent Kit	10/23/13	10/23/13		10/25/13	$39.11	1	$39.11
Glucose (OX) Liq 120 mL	10/23/13	10/23/13		10/25/13	$29.60	1	$29.60
Hemoglobin 120 ml	10/23/13	10/23/13		10/25/13	$26.43	1	$26.43
Thermistor for battery charging circuit	10/28/13	10/28/13		10/29/13	$2.25	3	$6.75
Transistor 2N7002	10/28/13	10/28/13		10/29/13	$0.23	1	$0.23
IRF transistor	10/28/13	10/28/13		10/30/13	$2.06	1	$2.06

Schottky diode (B340A-13)	**10/28/13**	**10/28/13**	**11/14/13**	**$0.15**	**2**	**$0.30**
0.27 ohm resistor for battery charging circuit	**10/28/13**	**10/28/13**	**11/4/13**	**$1.09**	**2**	**$2.18**

Currently we have spent $254.26 on the parts listed above. Overall the budget is expected to be $320.00.

Plans for Spring Semester

-Finish writing software for device based on dynamic range, precision, and accuracy measurements.
-Design/3d-print the enclosure for device
-Run tests on bovine blood
-Design/Build LED Selector
-Write user manual
-Run tests to verify that device satisfies requirements
-Design/Print printed circuit board