STRE&M: LED Absorption Spectrometer ECE 445 Project Proposal - Spring 2023

Project #52 Gage Gulley, Adrian Jimenez, Yichi Zhang

> Professor: Arne Fliflet TA: Abhisheka Mathur Sekar

Problem

Urine tests are critical tools used in medicine to detect and manage chronic diseases. These tests are often over the span of 24 hours and require a patient to collect their own sample and return it to a lab. With this inconvenience in current procedures, many patients do not get tested often, which makes it difficult for care providers to catch illnesses quickly. The tedious process of going to a lab for urinalysis creates a demand for an "all-in-one" automated system capable of performing this urinalysis, and this is where the STRE&M device comes in.

The current prototype is capable of collecting a sample and pushing it to a viewing window. However, once it gets to the viewing window there is currently no automated way to analyze the sample without manually looking through a microscope, which greatly reduces throughput. Our challenge is to find a way to automate the data collection from a sample and provide an interface for a medical professional to view the results.

Solution

Our solution is to build an absorption spectrometer that is capable of measuring and plotting the absorbance of casts, bacteria, and cells that may be present in the sample. Since each protein that we are trying to detect absorbs light at a particular wavelength, we need to emit this wavelength of light. Our approach is a low-cost, scalable, and effective spectrometer that can emit these wavelengths of light corresponding to the proteins we desire to detect and measure the absorption at the desired wavelengths.

Visual Aid



High-Level Requirements List

- The spectrum analysis and data transfer must be completed in less than 30 seconds
- Our system must be able to produce an absorbance spectrum for a sample with known absorbance in our desired range (380-480nm), and generates no response for a sample with known absorbance in the range (600-800nm).
- The device must be capable of performing absorbance spectroscopy with a resolution rate of ~10 nm for the light source emitting lights ranging from 380 nm to 480 nm.

Block Diagram



Subsystem Overview

Subsystem1 (Lighting)

The lighting subsystem will serve to produce light at wavelengths that are of interest in the field of urinalysis. The light is needed so that we can detect the change in light intensity and determine how much absorbance there is at a given wavelength of light. To prove the design is functional, we will focus on emitting at wavelengths between 380-480 nm with intervals of ~10 nm. This is done to maintain a higher level of resolution compared to more dispersed values of wavelength. Our design will be scalable so that more LEDs can be added in the future without major design changes. The lighting subsystem will be connected to the microcontroller to control which LED will be illuminated.

Subsystem2 (Detection)

To detect the absorbance, we will use a photodiode to produce a current that corresponds to a given light intensity captured after passing through a sample. We will collect the light after passing through the sample. The design will focus the light on the sample, which then will absorb some light that the photodetector will be nearby to detect. The current produced will be converted into a voltage output and be inputted to our microcontroller's internal ADC converter.

Subsystem3 (Control Unit)

The control subsystem is programmable. The control subsystem is connected to the lighting subsystem, the detection subsystem, and the power subsystem. It will talk to the peripheral subsystems (the lighting system and detection subsystem) to get the measurement data and then calculate the final spectrum. After it gets the final spectrum, it will wirelessly send the result to the PC and a server using its built-in wifi capability. There's also an ON/OFF button for us to start the system for testing. Since now, our system is detached from the urine collection system designed by another senior design team previously, the start-to-test signal should be sent by their microcontroller. For this design, we will use the ON/OFF button to launch the testing process.

Subsystem4 (Power system)

The power subsystem will provide power to all the subsystems. It will convert AC power from the wall outlet to DC power and then adjust the DC power to different voltage levels due to the demands that different components need different drive voltages. The power subsystem needs to connect to all subsystems. The power subsystem will begin with a 12V wall-connected power supply that will connect to our PCB via a standard barrel jack. The 12V must also be reduced to 3.3V for our microcontroller, and 5V for our photodiodes and LEDs. To accomplish this, we will use two linear voltage regulators.

Subsystem Requirements

Subsystem1 (Lighting)

The lighting subsystem will include an array of LEDs with peak wavelengths at values corresponding to the proteins we are trying to detect. These LEDs will be laid out and can be turned on and off from our MCU. A LED driver will be used here to assist the microcontroller to control the LEDs since the microcontroller cannot provide sufficient power to the LEDs. The LED driver will provide a very steady current to drive the LEDs. To make the LED driver work, we need to provide a 5V voltage supply. Additionally, the LEDs will need to be focused by a lens so that the light can be directed across the sample as directly and focused as possible. Note that our first stage goal is to make the spectrophotometer function correctly as proof of concept. We will focus on the wavelength range from 380 nm - 480 nm with a wavelength spacing of ~10 nm first.

Subsystem2 (Detection)

The observing window is used to examine the sample. Note that the observing window is made of quartzite since quartzite won't block UV lights. The photodiode needs a -5 voltage supply to reverse bias it. Depending on the bias voltage, it will produce a current based on the light intensity in a nearly linear relationship. Note that due to quantum efficiency, the photodiode absorbs light with different wavelengths differently. We need to take that into account when we compute the spectrum produced by the photodiode. The current value will then be converted to an analog voltage value that our MCU can discern through a current-to-voltage converter. This current-to-voltage converter is composed of an op-amp, a high pass filter, and a buffer. Figure 4 below shows our design idea. The op-amp converts the current signal into voltage. The high pass filter filters out the DC biasing voltage. The buffer circuit takes advantage of the high input impedance of the op-amp to make the input voltage for the photodiode is -5V. The op-amps are biased at -3.3V to 3.3V. These values will ultimately (after ADC) be interpreted by our MCU as absorbance at a given wavelength.

Subsystem3 (Control Unit)

The microcontroller will indirectly get data (analog output) from the detector (photodiode) and compute the corresponding absorbing spectrum of the sample. Note that to get the absorption spectrum of the sample, we need to know the passing spectrum (How much light could pass through the observing window) of the blank observing window first. This blank passing spectrum will serve as the control spectrum. When we get the passing spectrum of our sample later on, we then take the difference between the passing spectrum of the blank observing window and the passing spectrum of the sample to get the absorption spectrum of the sample. Furthermore, due to the effect that the photodiode will have different quantum efficiency at different wavelengths and the effect that LEDs on the edge of the arrays may not be able to transmit all its output light to the sample, we need to somehow normalize the result.

Subsystem4 (Power system)

We will use the wall outlet to power the whole system. The plugin can convert 120V AC power to 12V DC power. Then, two separate voltage regulators will turn the 12V DC voltage to 3.3V and 5V DC voltage. We plan to first step the voltage from 12V down to 5V, then input the 5V into the 3.3V regulator to avoid any unnecessary heat generation from inputting 12V into the 3.3V regulator. The microcontroller requires a power voltage of 3.3V, and we will need a steady voltage supply of 5V for our LED driver, so a stable regulator will be necessary.

Tolerance Analysis

For our tolerance analysis, we demoed our photodiode and amplifier circuit in LTSpice. We wanted to confirm that our output would not reach the 3.3V max threshold of our microcontroller.



Our LED will generate a photodiode current in the low microampere range. To calculate the gain resistor necessary for our circuit we took the Voltage max minus the Voltage min divided by the max current. $(3.3V - 0.1V)/100uA = 32k\Omega$. We then swept the current over the range of possible current values the photodiode could generate to confirm the voltage range we would be outputting.



This has confirmed the functionality of our photodiode and amplifier circuit. It also has confirmed the values of components we will need to have a usable output voltage range for our microcontroller.

Ethics and Safety

Safety concerns will arise as we build our device to work with liquid samples. Some of the LEDs we are working with for the spectroscopy are in the UV range of wavelength. UV light can be extremely dangerous, causing damage to one's skin and/or eyes. We will need to avoid direct exposure to this light source as well as direct viewing to avoid any injuries. We have completed the DRS Laser Safety training so that we are adequately educated on the procedures of handling UV lights. Anytime that UV LEDs are lit, we will be wearing protective equipment for our eyes, as well as placing an acrylic shield between us and the light. We will uphold IEEE Code of Ethics #9 to assure we are not harming ourselves or the school and the labs they provide us. Since we are working with a team for our pitched project as well as the class TAs, the IEEE Code of Ethics #5 will be crucial in working on our project as we make sure to receive feedback from and credit the others working on this project.