EEL 4914 – Senior Design I

Smartphone-Based Surface Plasmon Resonance Sensor for Antibody Testing

Initial Divide and Conquer Documentation

Group 2

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1. Project description

1.A Defined Project

Surface plasmon resonance, or SPR for short, is an optical effect that can measure the binding of molecules in real time without labels. The SPR sensor is a biological sensor used to measure the kinetics and affinity of the interactions within the sample. These interactions can be seen through dips in spectral intensity as a light source interacts with a dielectric film layered with the analyte. Our goal with this project is to create a more affordable, easily readable, and portable sensor for commercial use that can be attached to a smartphone device.

1.B Motivation

There are various questions that exist that can be solved from the SPR detection method. Such questions include: Are pesticides lingering on produce? Is there contamination in a body of water? Does my food contain traces of salmonella? As mass production of perishables become more and more processed, these are important things to be aware of before consumption. Yet the challenge for many SPR sensors are their price and portability. Commercial SPR sensors can cost thousands of dollars and are not well designed for many remote and low-income locations. The need for low-cost yet high quality devices is crucial for the democratization of medical services. Therefore, we propose to develop a compact SPR sensor that can be attached to a smartphone to provide rapid, on-site detection while significantly reducing the manufacturing cost of the SPR sensor itself.

1.C Initial goals and objectives

The goal of this project is to create a portable and functional SPR sensor that can be attached to a smartphone. Many smartphone-based SPR sensors use optical fibers as their SPR sensor location by exposing the core of the fiber and binding a metal film and protein onto this surface. This process requires the optical fiber to be replaced after so many uses of the device, due to the SPR sensor being a disposable component on the device. This makes many of these devices an inefficient solution for consumers, as the optical fiber would need to be realigned after each replacement. For our project, we propose to design an SPR sensor that uses optical components such as a prism that will remain separate from the disposable components of the SPR sensor to allow for easy replacement by the user. The cell phone camera will be the only component necessary for operation while the rest of the optics will be inside of a 3D printed attachable case. This case will consist of an LED, two lenses, a bandpass filter, a linear polarizer, three mirrors, and a prism where an SPRi sensor chip can be glued onto the base and easily removed when a replacement is required. Through our research, we determined an SPRi sensor chip would be more optimal for detection as well as being more consumer friendly compared to affixing a gold film onto the base of the right-angle prism ourselves. The chip would allow for easy removal when replacement is required, making it suitable for long term use. An SPRi sensor chip is a manufactured chip that contains a metal on one side and a bound protein or coating on the other that allows for molecular binding to occur under the proper circumstances. The SPRi chip will be located in an accessible sample chamber for testing our various solutions. A mobile application will be developed to monitor the binding in real time through an analysis of the light spectrum detected by our smartphone's camera.

2. Requirements

2.A Requirement Specifications

This project is primarily optical, with some systems and electrical engineering to create a fully functional SPR sensor. A green LED will be connected to a microcontroller that will allow the smartphone application to communicate with the system and determine when the light turns on or off. A battery-powered power supply will be used as a power source for our LED and microcontroller. The light from the LED will be manipulated by a 532 nm bandpass filter and linear polarizer, which are used to narrow the range of the LEDs wavelength spectrum and change our incident light into a transverse magnetic wave respectively. This ensures our incident light is monochromatic and transverse magnetically polarized so that the wave may resonate with the wave created by surface plasmon excitation. Two mirrors will then be used to direct the light onto a right-angle prism. This is where the surface plasmon detection occurs. By angling our incident beam to a 45-degree angle using mirrors, we can create the phenomenon called total internal reflection as the beam hits the right-angle prism. This coupling of the light using the prism creates a perfect situation where surface plasmon excitation can occur as most of the energy from our incident light will be absorbed by the metal/dielectric interface on our SPRi chip. This leads to a decrease in intensity of our received light onto the smartphone's CMOS camera. The decrease in intensity of our received light indicates that excitation occurred, and molecular binding took place.

For our experiment, we will observe the molecular binding of Staphylococcus Protein A (SPA) and bovine immunoglobulin G (IgG). Due to the interactions between SPA and IgG, SPA is commonly used to for antibody testing and disease diagnosis. The SPA will be previously immobilized to an SPRi chip that will be purchased from a manufacturing facility, while the IgG will be in various liquid concentrations with the buffer solution phosphate-buffer saline. Phosphate-buffer saline (PBS) is a common salt solution used for cell culture applications to remove the molecular binding in an SPRi chip. The IgG concentrations will be placed into the sample chamber which contains our Protein A immobilized SPRi chip glued to the base of our prism. The purpose of testing various concentrations of our IgG solution with PBS is to provide an accurate representation of the sensitivity of our SPR sensor as molecular binding occurs. PBS is used to clean an SPRi sensor after use by removing the molecular binding that occurred on the sensor surface. As the concentration of IgG is increased, we can gain a better understanding of our SPR sensor's sensitivity to the molecular binding occurring with SPA and IgG. The expected outcome of our experiment is to see an increase in our relative intensity of the SPR sensor's response as we increase the concentration of IgG in our solution, which indicates its sensitivity to detecting IgG being bound to SPA.

An Android application will be developed to turn on the SPRi sensor and analyze the captured images from the smartphone camera. The application will control both the external LED and the smartphone camera to take multiple images of the reflected light from the SPRi sensor during a certain timeframe while surface plasmon excitation is occurring. A custom-programmed application will be used to map the relative intensity profile of the received images and display them in a graphical form, providing the user with the change in relative intensity over time. Initially we will use MATLAB for testing the image processing methods then transition to an Android-based application with processing methods influenced from the MATLAB functions. The application will be able to analyze the increase or decrease in relative intensity and provide the user with information on what time interval molecular binding begins, ends, and if no binding occurred at all. The application will also allow the user to test various concentrations of the same sensing element to then provide a graph containing the various relative intensity changes over time for the different concentrations. This would easily allow the user to determine which concentration created the most molecular binding from their experiment. The user will also be allowed to test multiple times the same concentration levels for a more accurate reading. The application will take the data from these various tests and calculate the mean and standard deviation of each concentration and provide them in a graphical format.

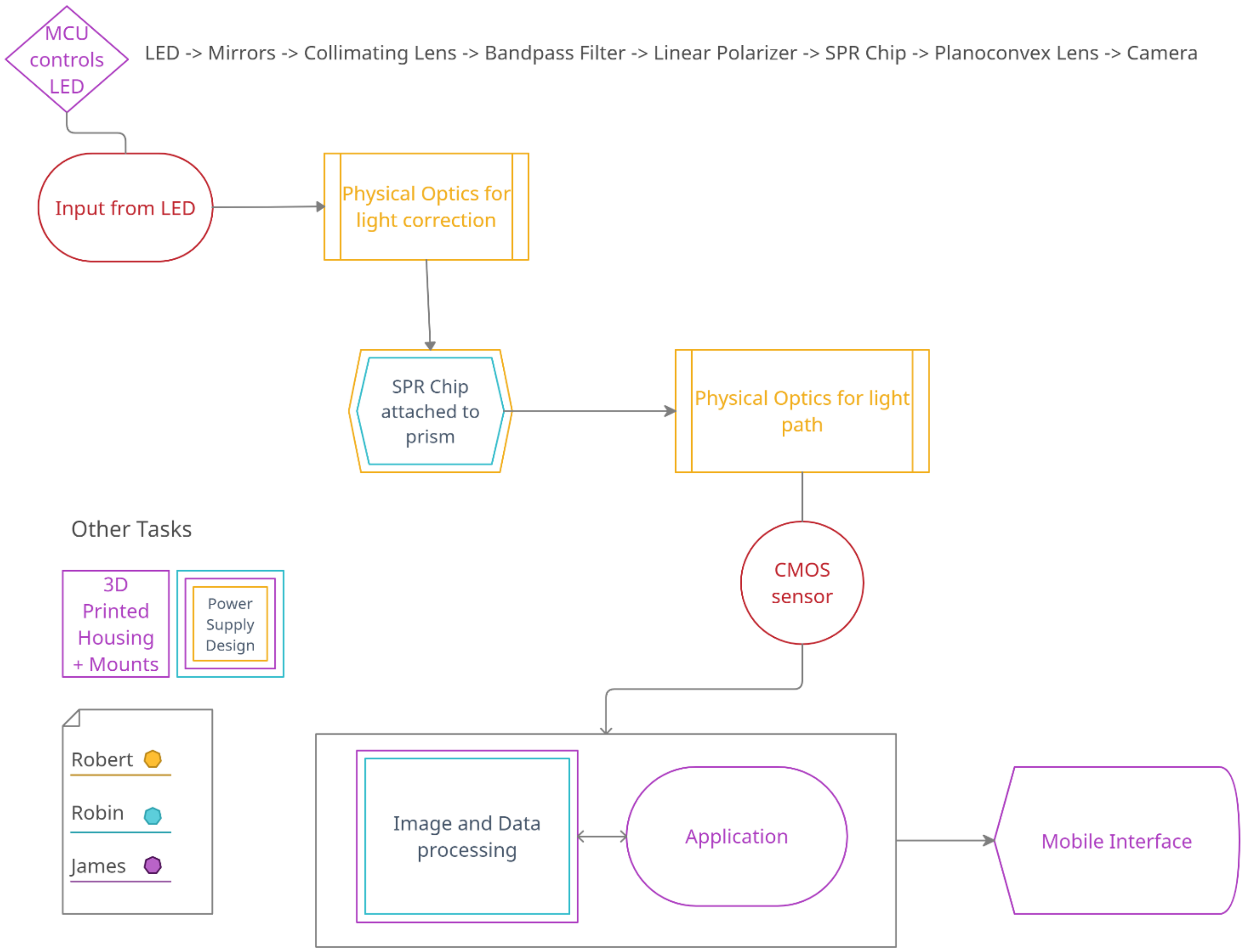
2.B Constraints

The main constraints for our SPR sensor are budget and time. Our initial design schematics may change depending on how we want to configure the optical system, the pricing, and the time constraints. As of right now, our configuration includes 3 mirrors to direct the incident light onto the SPR sensor and camera, but a multimode fiber may provide more ease when it comes to beam propagation. The project will take two semesters for completion. The first semester will be spent determining the best optical components for proper beam propagation as well as designing the optical setup for presentation at the end of July. The second semester will be spent building the 3D printed case and further electrical and optical components required for the final product.

3. House of Quality

			Engineering Requirements				
			Install Time	Accuracy	Power Draw	Dimensions	Cost
			-	+	+	-	-
Marketing Requirements	Weight	-		↓		↑↑	
	Quality	+	↑↑	↑↑	↑↑	↑↑	↑↑
	Accuracy	+		↑↑	↑		↑
	Installation Ease	+	↓	↓			
	Cost	-		↑↑		↓	↑↑

4. Block Diagrams



5. Prototype Illustration

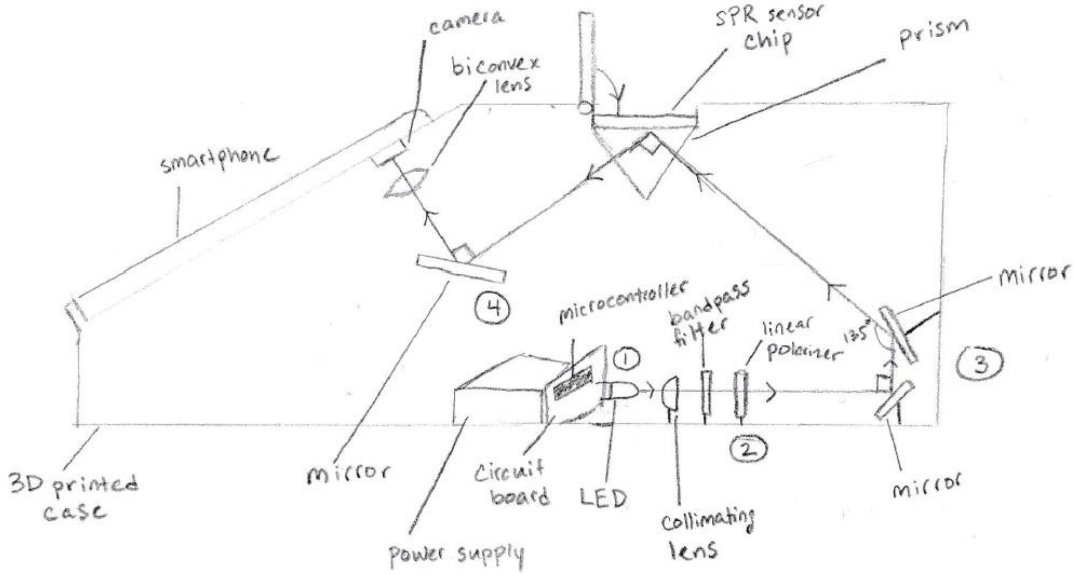


Figure 1. Illustration of SPR Sensor Prototype. (1) A green LED is powered by microcontroller that is connected to a battery-powered power supply. The emitted light travels through a collimating lens. (2) The collimated light travels through a 520nm bandpass filter and a linear polarizer. (3) The light's direction is controlled by directing it onto one mirror turned 45-degrees and another turned 135-degrees. This allows for the light to hit a right-angle prism at a 45-degrees angle to make contact with the SPRi sensor. (4) A third mirror directs the light onto a biconvex lens which focuses the light onto a smartphone CMOS sensor.

6. Project Financing

Part Description	Quantity	Price	Characteristics	Provider
SPR Chip	3	~$250	9x9x0.3mm	Sofchip.com
Prism (crown glass)	1	~$20	Right angle, 10x10x10	3rd party vendor
Mirror	3	~$10	12mm, plano	3rd party vendor
LEDs	1 (?)	< $5	Green	A bin in my garage
Microcontroller	1	< $50		
3D Printed Housing	~		Phone friendly	James
Collimating Lens	1	~$10	Planoconvex	3rd party vendor
Biconvex Lens	1	~$10		3rd party vendor
Linear Polarizer Sheet	1	~$10	25mm diameter	3rd party vendor
Bandpass Filter	1	~$20	Filter for 532nm, 25mm diameter	3rd party vendor
Total		**$395**		

7. Milestones

Week	Description
1-12	**Senior Design I**
1	Project Inception
2 - 3	Research and Role Discussion
4 - 5	Initial Project Documentation Draft
5 - 6	More Research
7 - 8	Initial Project Documentation Final
9 - 10	Order Parts
11 - 12	Build and Present Project Demo
	End Of Summer Session
13-27	**Senior Design II**
13 - 14	Build Prototype
15 - 16	Testing and Redesign
17 - 18	Finalizing Design
19 - 20	Fine Tuning
20 - 21	Peer Presentation
22 - 26	Finish Report
27	Presentation

8. Conclusion

Smartphone-based SPR sensors provide an effective tool for analyzing substances outside of traditional lab settings. The simple yet highly sensitive process that SPR sensors use allow for real-time antibody testing that can provide tools for disease detection to remote and lower income locations across the globe. Unlike many smartphone-based SPR sensors, our device allows for easy replacement of the disposable SPRi sensor chip without requiring realignment of the optical components, as is needed for optical fiber-based SPR sensors. This provides our device with a longevity that previous SPR sensors lacked. While our experiment will prove the sensitivity of our SPR sensor to molecular binding of SPA and IgG, our device can be repurposed to detect various other substances such as salmonella and pesticides by simply changing the SPRi sensor chip to one that contains the necessary bound protein for molecular binding to occur with these other substances.