Smartphone Based Nano-device for Human Breath Sensing

FINAL DESIGN DOCUMENT

Team Number: 20
Client: Prof. Long Que
Adviser: Prof. Long Que
Team Members/Roles:
Jared Smiley-Team Leader
Zhaobo Huang-Webmaster
Mengzhou Sha-Communication Leader
Xin Chen-Concept Holder
Team Email: jcsmiley@iastate.edu
Team Website: may1720.sd.ece.iastate.edu
Team Email: may1720@iastate.edu

Revised: 4/23/2017 V3

Contents

1 Introduction

1.1 PROJECT STATEMENT

The goal of this project is to provide a non-invasive test for diagnosing pathogens in a portable, cheap, user friendly package. Our portion of the project is to determine how the spectrum emitted by nano-devices responds to changes in its environment. Our method for analyzing these spectrum changes can be used to determine how the nano-device responds to pathogens. Additionally we developed an app that can perform spectral analysis on a smartphone. The end goal of our professor is to develop a spectrometer that can fit over a smartphone to intake a patient's breathe and determine the bacteria or virus causing a patient's illness using spectral analysis. Once the professor develops the spectrometer, our app can be tested and its spectrum analysis can be matched to the spectrums of pathogens to determine what a patient is sick with.

1.2 PURPOSE

A smartphone based spectrometer that can diagnose illnesses will benefit society because it could replace more invasive forms of medical diagnostic testing such as blood tests. This means lower cost to diagnose, greater portability, greater patient comfort, more efficient use of doctor's time, and puts greater information into the hands of patients by allowing for self-diagnosis. All these factors give patients a better option for diagnosis than is widely used now. It could also allow third world countries with poor health care access to accurate diagnoses that had previously been too expensive or logistically impossible to achieve. This could save countless lives.

2 Deliverables

-Data that details how PDMS material responds to different concentrations of ethanol in its environment
-An equation that intakes an intensity vs wavelength spectrometer graph of PDMS material and can predict how much gas concentration is around the PDMS
-An app that takes images from the camera and plots intensity vs wavelength in the same way as a commercial spectrometer

3 Design

3.1 SYSTEM SPECIFICATIONS

3.1.1 Non-functional
-An app that can run on any Android capable device

3.1.2 Functional

-Android application capable of taking an image from camera for analysis
-Android application must include capability to determine all frequencies of light entering camera
-Android application must include capability to determine the intensity of each of these frequencies
-Android application must include capability to graph frequency vs intensity spectra
-Equation that details how different spectrums resulting from different levels of PDMS engorgement predict different gas concentrations
-Process to determine how PDMS responds to environment to use for determining how PDMS responds to pathogens

3.2 DESIGN/METHOD

The nano-device we used for our project was made of Polydimethylsiloxane (PDMS). This silicon based substance can be used to determine if pathogens are in the air surrounding it by using a spectrometer to see changes in the PDMS structure. We developed an experimental process to determine how the PDMS responds to substances in its environment. We used 99% pure 2-propanol (rubbing alcohol) in our experiments at different concentrations to determine how the PDMS responded. We used this because it is easier to work with than pathogens and the same process can be used.

In order to predict how much gas concentration was around the PDMS, we performed signal analysis on the output of a commercial spectrometer pointed at the PDMS to detect differences from the base case PDMS to the exposed case.

The PDMS consists of tiny holes and expands in the presence of different gas concentrations. A diffraction grating is stuck to the surface of PDMS so it expands along with the PDMS and changes the intensity of light reflected as it expands. A wavelength vs intensity graph can be plotted over time and the intensity goes down over time as more gas is absorbed. After obtaining a base case graph and several graphs at different concentrations, regression analysis can be performed to determine what intensity decrease from the base PDMS corresponds to which gas concentration. This equation can be used to predict concentrations in the future. Step by step instructions are given in Appendix I for how to determine how the PDMS responds and how to use the response equation to predict gas concentrations. Below is an intensity vs wavelength graph with the base case at the top and the waveforms from different concentrations below.
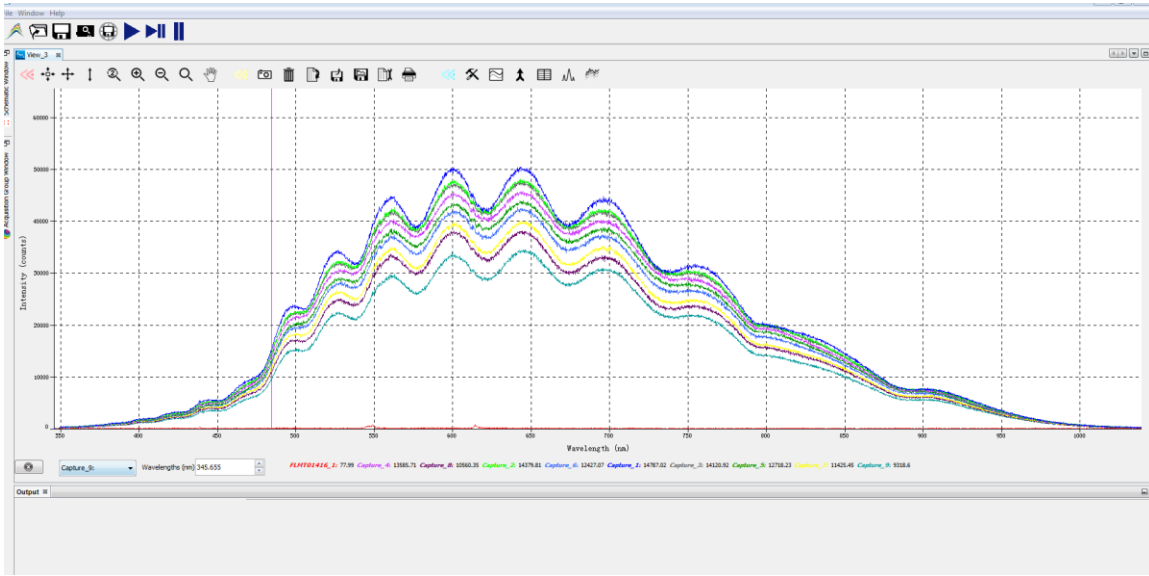
For the app portion of our project, we decided to build an android app rather than an iOS app due to the fact that we have more experience with Android and because Android is more prevalent worldwide.

Our app allows the user to take a picture and then plots the wavelength vs intensity on the screen. Once our client develops the spectrometer it will work like the image below:
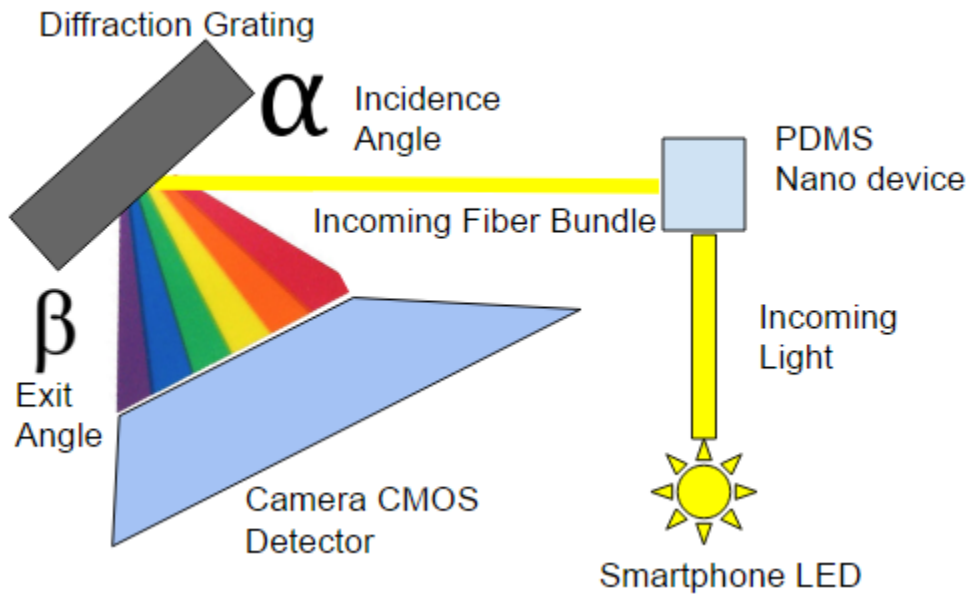
First, light from the smartphone LED goes through a fiber optic cable and is used to light up whatever you want to analyze. The light reflects off of the object you are analyzing and goes through another fiber optic bundle. It is then pointed at a diffraction grating which splits the light into its different wavelengths. The light gets reflected onto the smartphones camera with different wavelengths hitting different pixels on the camera. Which pixel corresponds to a specific wavelength on it can be calculated using the equation below. Depending on what diffraction grating our client picks for his design and the distance from the diffraction grating to the camera's

CMOS detector, each pixel corresponds to a different wavelength. For our app we programmed it to believe that the leftmost pixel corresponded to a wavelength of 500 nm and each pixel to the right was 1 nm more. These parameters in the app can be easily adjusted after our client develops his spectrometer to fit over the smartphone camera.

$$N\bar{\lambda}=d(\sin \alpha - \sin \beta)$$

N: diffraction order (use 1)
λ: wavelength (nm)
d: grating groove space (nm)
α: incidence angle on grating
β: exit angle

After determining the wavelength of each pixel, we calculate the intensity of each pixel and plot it with that pixel's corresponding wavelength. The RGB values are obtained for each pixel and intensity is found by calculating a weighted average of the RGB pixels using the following equation: Intensity = 0.2989 * R + 0.5870 * G + 0.1140. This equation is used because the RGB detectors have different sensitivities to light.

Our app can plot multiple wavelength vs intensity spectras on the same graph in different colors with a key detailing which capture is which. A step by step guide to using the app is in Appendix I.

4 Results/Testing

Because our client hasn't finished a spectrometer to fit over a smartphone, we just hard coded a wavelength spectrum into the phone the plotted the intensity vs wavelength of the image rather than obtaining an image from the camera. The image is shown below as well as the apps graph.
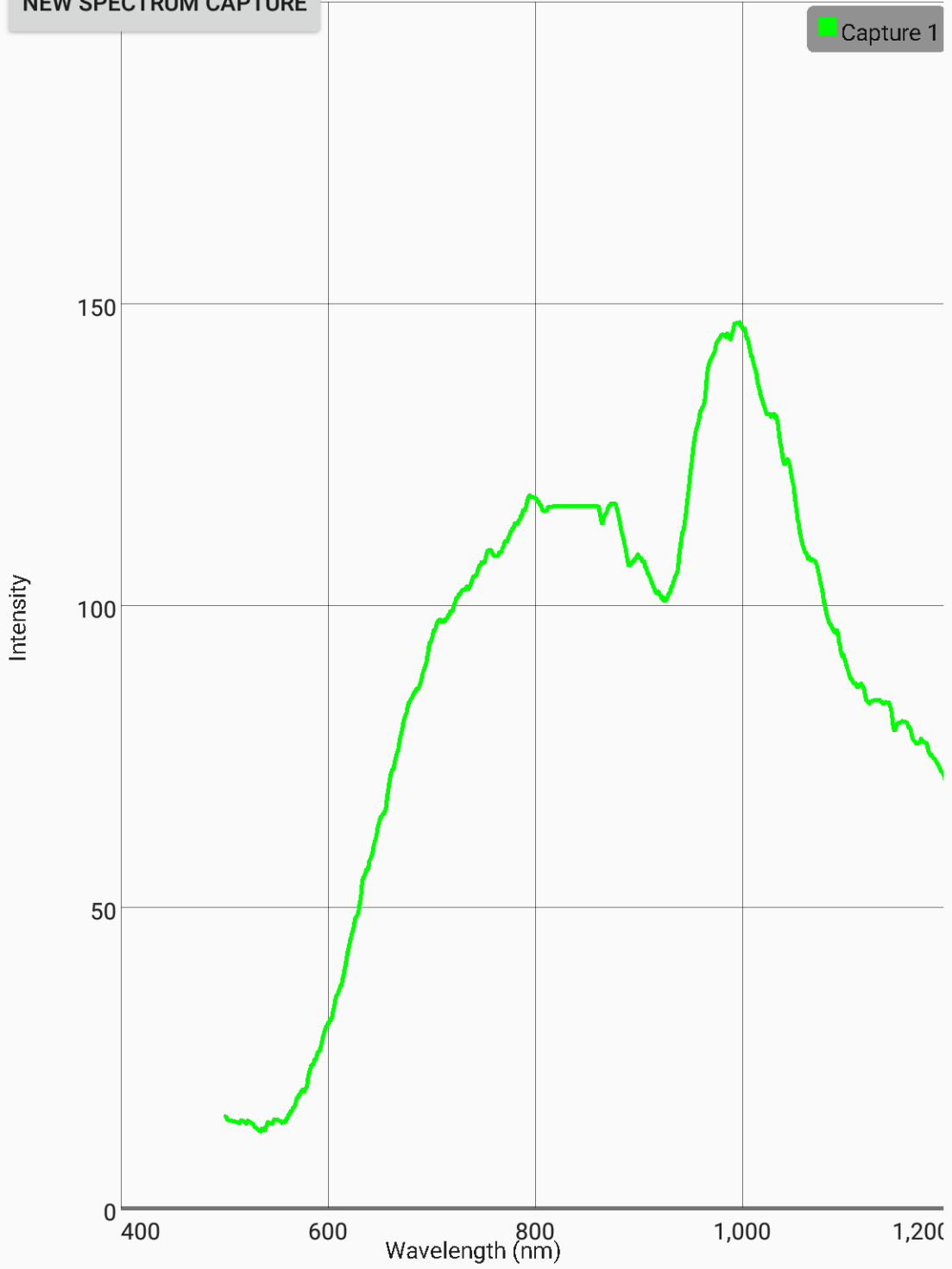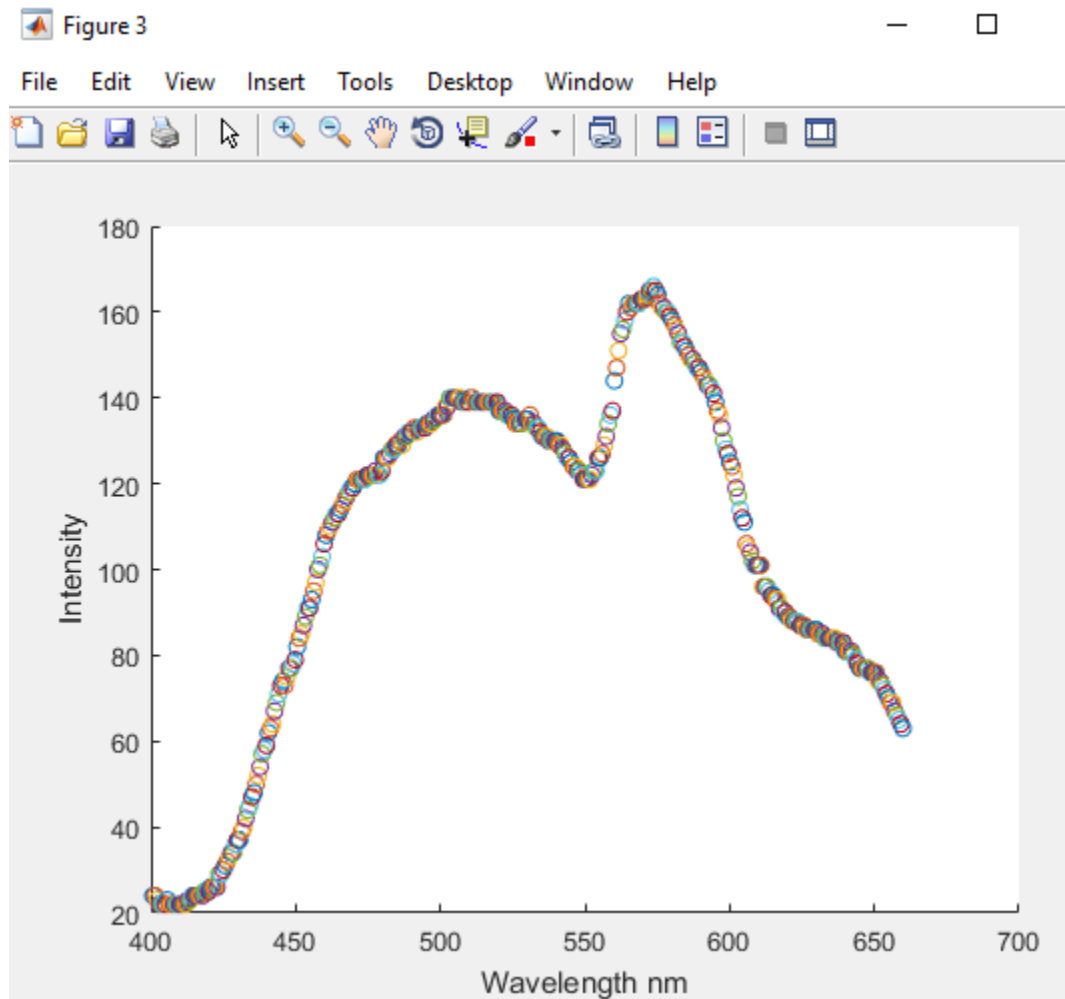
Spectrometer

Wavelength vs Intensity Spectra

NEW SPECTRUM CAPTURE

🟩 Capture 1

Intensity

150

100

50

0

400   600   800   1,000   1,200

Wavelength (nm)

◁   ◯   ▢

This is the same as the graph we obtained using Matlab to plot the spectra of the image and similar to a scientific paper's spectrum of the same image.

The wavelengths are a little off because we don't know which pixel on the camera will correspond to a certain wavelength. Using the diffraction equation we will be able to develop an equation to determine wavelength on each pixel of the camera after our professor develops the smartphone spectrometer.

For our nano-device after many experiment attempts with bad data, we obtained the following intensity vs frequency spectra. We plotted the base case of the spectra and then added 100uL to a flask 9 times and plotted the spectra after each previous 100uL had evaporated. You can see that each plot goes down. We were able to find that each 1% decrease in intensity is due to an additional 14.14% 2-propanol concentration. Using this data we can predict concentration based on how much intensity has decreased over the base case. To test our equation we ran the test again and tried to predict what intensity corresponded to what concentration. We were able to do so with 84% accuracy. Our methods are shown in Appendix I.
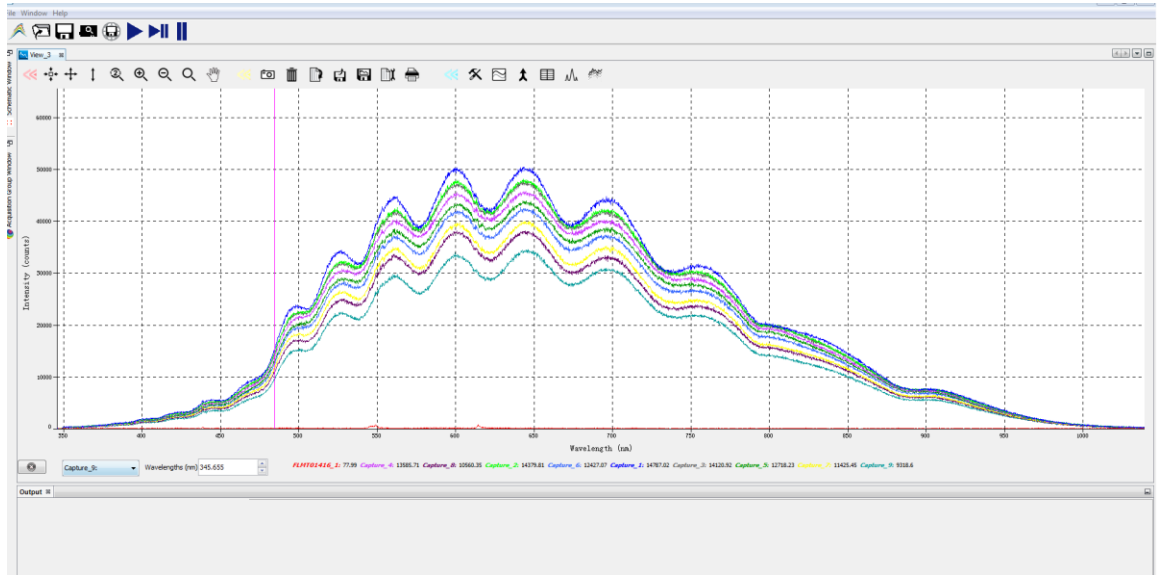
5 Appendices

Appendix I: "Operation Manual"

To set up the nano-device to determine the gas concentration:

1. Mix Dow Corning Slygard 184 PDMS with Slygard 184 hardener at a 10:1 ratio in a test tube for 5 minutes.
2. Dump mixture into petri dish and place into vacuum chamber for 1 hour to get rid of air bubbles.
3. Put petri dish at 100C for 45 minutes to cure
4. Remove from petri dish and cut out a 1cm by 1 cm square.
5. Stick diffraction grating to one surface.
6. Tape to the inside of a top half of a petri dish but hanging down slightly so that it has some exposure to air around it.
7. Drill hole in top of petri dish and superglue tube that attached to syringe in
8. Place tap on inside of top half of petri dish and place on slightly smaller beaker (we used 100mL) so that tape gives a seal.
9. Place the spectrometer probe pointed at the PDMS material. The setup is below.

10. Open the OceanView Spectrometer software.
11. Move PDMS beneath spectrometer until you see a graph that is close to a sin wave like the red line in this graph.
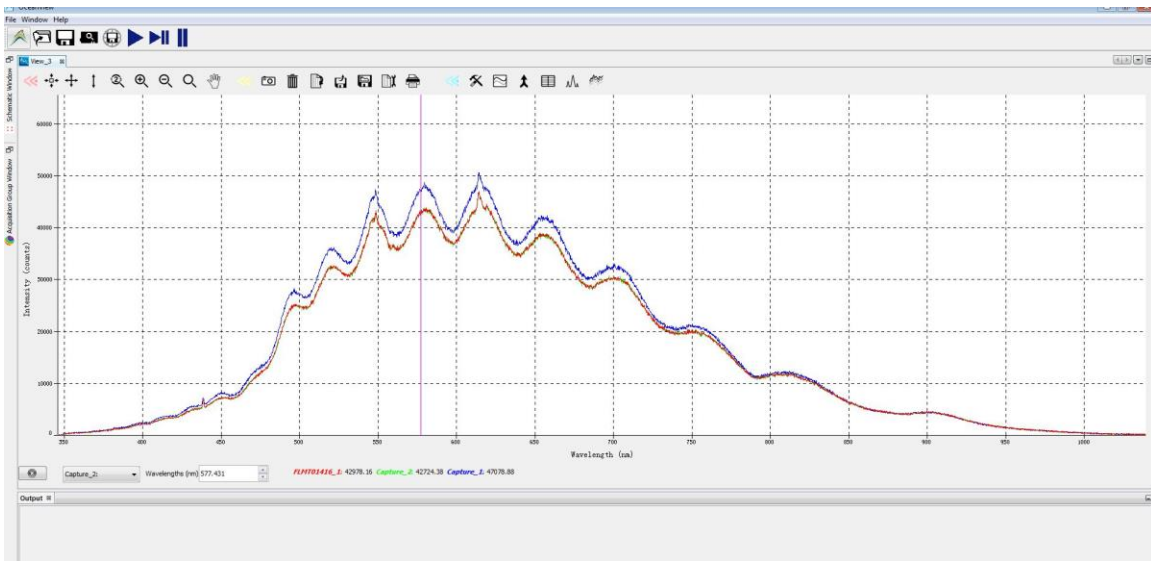
12. Under acquisition group window, hit automatic to auto scale the graph.
13. Hit the camera icon at the top of the graph to capture the base PDMS waveform.
14. Use a syringe to insert a given amount of propanol-2 into the pipe and beaker (We did 100uL).
15. Wait until you can see that all of the propanol is evaporated and press the picture icon to capture the new waveform after the PDMS absorbs some of the propanol-2 in the air.
16. Repeat several times (we did it 9 times) and you should get a graph similar to the one below. You can see that every increase of concentration in the beaker leads to a decrease in intensity in the graph.
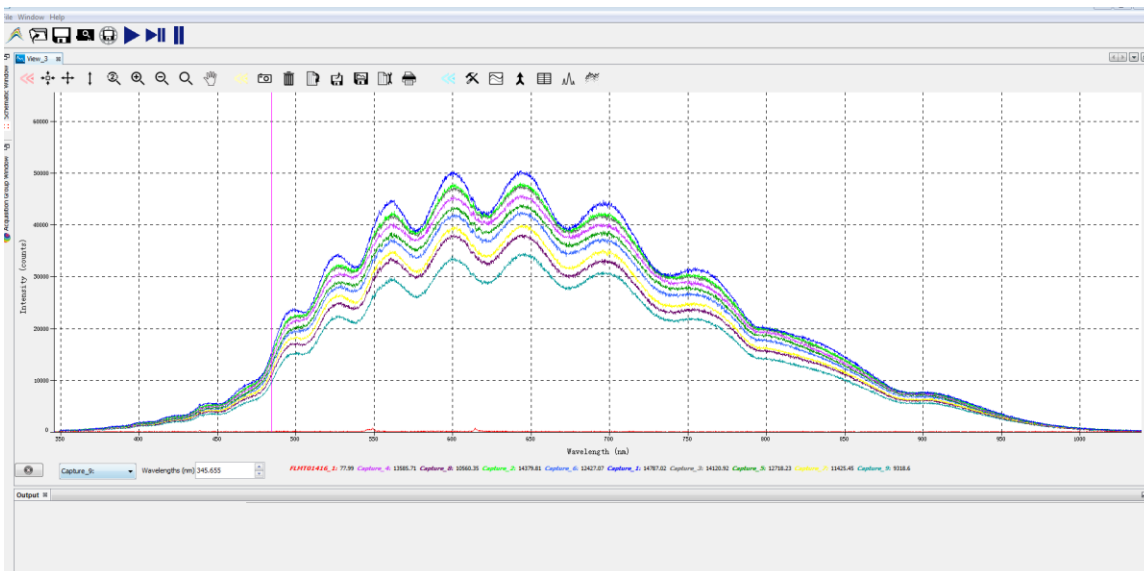
17. Click the floppy disk icon to export data for each waveform to text file.

18. Transfer data from text file to excel.
19. Find the average intensity difference from each waveform capture to the base case.
20. Divide the difference by the base case average intensity to find % drop in intensity
21. Perform a regression with the intensity difference % as the independent X variable and the gas concentration as the dependent Y Axis. Use a 0 intercept regression you can calculate concentration by dividing volume put into the beaker by the size of the beaker. For the first run of 100uL in to a 100mL beaker concentration is 1% (100uL / 100mL) after evaporation.
22. We find that each percentage decrease in intensity is due to an additional 14.14% propanol-2 concentration. Below is the regression

% Concentration	% Decrease in Intensity							
1	-0.184269107							
2	-0.233094265							
3	-0.258586921							
4	-0.275514875							
5	-0.294472145							
6	-0.312936409							
SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.955728101							
R Square	0.913416203							
Adjusted R Square	0.713416203							
Standard Error	1.255318728							
Observations	6							
ANOVA								
	df	*SS*	*MS*	*F*	*gnificance F*			
Regression	1	83.12087	83.12087	52.74753	0.001909			
Residual	5	7.879126	1.575825					
Total	6	91						
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
% Decrease in Intensity	-14.14039456	1.946975	-7.26275	0.000773	-19.1453	-9.13553	-19.1453	-9.13553

To test equation's predictive power and accuracy

1. Perform experiment again and find the percentage intensity decreases each time. Multiply each percentage decrease by 14.14% to find what percentage concentration your equation predicts. Regress actual concentration as the dependent Y variable and predicted concentration as the independent X variable. Perform a regression without an intercept. The adjusted R^2 tells us that our equation is 84% correct when predicting gas concentration. Greater accuracy can

be obtained by using more data points in your regression to create your equation. Below is the regression.

% Concentration	% Decrease in Intensity	Predicted Concentration * -14.14
1	-0.06728287	0.951406334
2	-0.084129391	1.189622785
3	-0.151647451	2.144354785
4	-0.233731833	3.305060339
5	-0.302150695	4.272530044
6	-0.422288032	5.971319395
7	-0.496715015	7.023746303
8	-0.646921794	9.147729417

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.990896258
R Square	0.981875395
Adjusted R Square	0.839018252
Standard Error	0.7267756
Observations	8

ANOVA

	df	SS	MS	F	gnificance F
Regression	1	200.3025806	200.3026	379.2153	1.19E-06
Residual	7	3.697419414	0.528203		
Total	8	204			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	ower 95.0%	pper 95.0%
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
X Variable 1	0.989038244	0.050789057	19.47345	2.35E-07	0.868941	1.109135	0.868941	1.109135

App User Guide:

1. Open the app and it will look like this. Click New Spectrum Capture
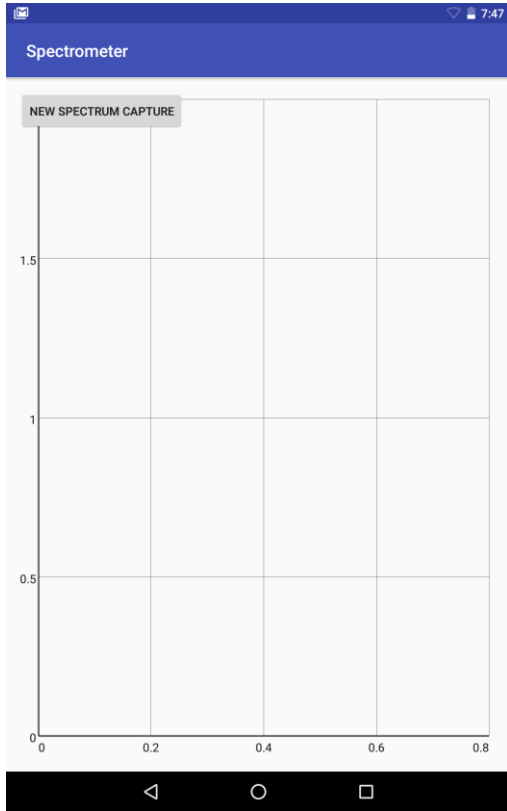
2. It will take you to a picture page. You should see a rainbow if a spectrometer is attached.

3. Once you take a picture you will go back to the graph page and the intensity vs wavelength spectrum will be plotted.
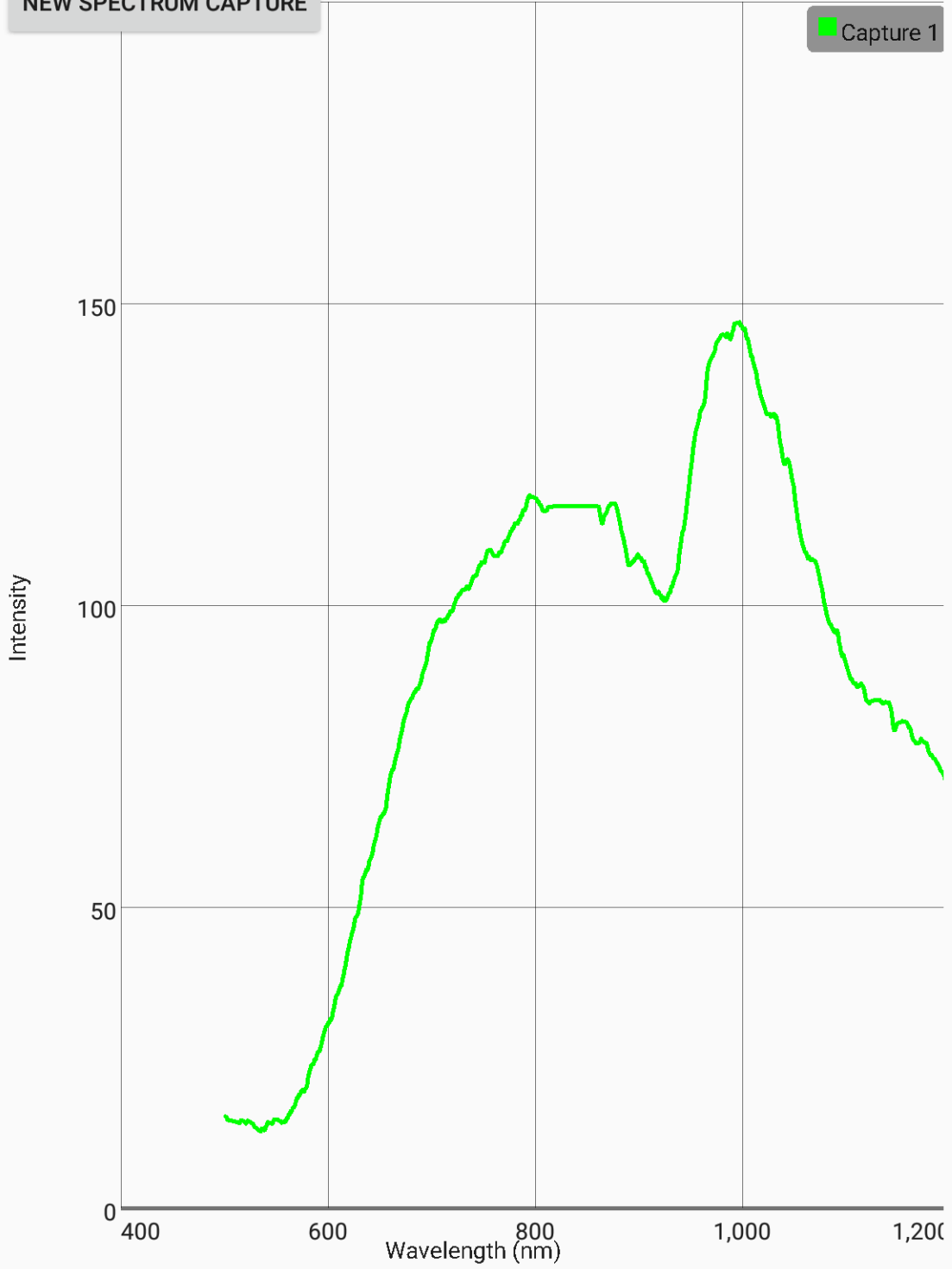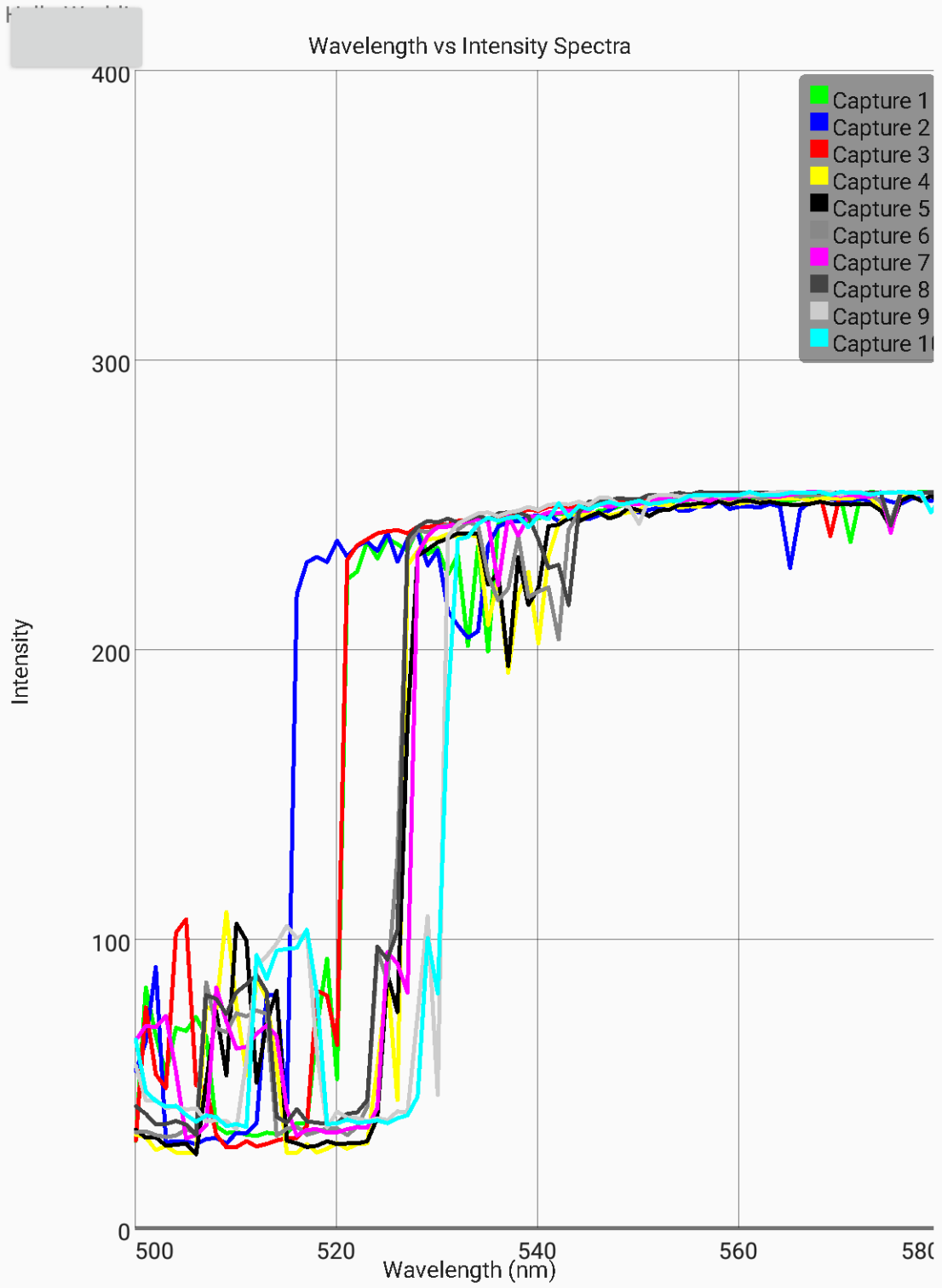
Spectrometer

Wavelength vs Intensity Spectra

NEW SPECTRUM CAPTURE

■ Capture 1

Intensity

150

100

50

0

400   600   800   1,000   1,200

Wavelength (nm)

4. To plot multiple graphs hit NEW SPECTRUM CAPTURE

graph2

Hello World!

Wavelength vs Intensity Spectra

Appendix II

Our original plan was to develop an app that could take a spectrometer image and match it to a graph generated by a pathogen. However our project was changed to doing more with nano-devices. This is our original plan.

Our app will have several different capabilities. First the app will have a calibration section that allows you to utilize the app on any Android phone regardless of camera size and resolution. This section will obtain a video feed from the camera and instruct the user to adjust the spectrometer until the spectrum fills the whole screen. This will ensure that the spectrum fills the whole camera and gives the phone the ability to calculate frequency of the image based on the distance from the edge of the camera each pixel is. The spectrometer will have a dial measuring the distance to the camera and this distance will be input to the calibration portion of the app to form the frequency calculations which are described in greater detail later.

The next activity in the app will instruct the user to point the spectrometer at a patient's mouth and click a button to take an image when ready. This image will be retrieved from the camera and stored. The image will be displayed on screen and another button will appear to calculate the frequency vs intensity spectra.

After obtaining a frequency vs spectrum graph, the app will then compare the graph to saved graphs representing the spectrum of known viruses and bacteria. It will find a match if there is one and display the virus or disease on screen that the patient has.

We have decided to put all the calculations on the phone in case there is no cellular access. We may need to reassess if we can't store enough spectrums to match against to make the device capable of finding most diseases.