Dr. Drowsy

<u>Final Report</u>

EECE 4512

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1. Introduction

According to the National Highway Traffic Safety Administration, every year about 100,000 police-reported crashes involves drowsy driving. Drowsiness is a state of tiredness that affects all demographics and is often the result of medication, sleep deprivation, or disturbance. Individuals who are most disposed to the repercussions of drowsiness include students (ages 14-25), drivers at night, truckers, doctors, nurses, or anyone who is in a profession that demands long hours. When students are feeling overworked, their cognitive ability and mental health are affected. Doctors who continue to work long hours while sleep deprived put their patients at risk. Many serious surgeries last over 8 hours and being meticulous throughout the procedure is straining for surgeons. Drowsiness in doctors and other healthcare practitioners can lead to false diagnosis, treatment, and surgical mishap. This leads to a greater medical expense for the patients and the situation can sometimes be dire. Thousands of medical negligence claims are also filed every year and result in compensations up to millions.

This report aims to present the design of a pair of drowsiness detection glasses and to document a pilot study conducted using the device, aiming to investigate the correlation between the effect of blue light and state of drowsiness. The report summarizes the hardware and software considerations of the device. We also looked at the value that Dr. Drowsy would bring to the market while comparing to other competition of commercial drowsiness detection devices. We also discuss how a pilot study is conducted and the methodology used to test Dr. Drowsy's performance.

2. How it works

Dr. Drowsy is a pair of glasses which serves as both detection and a responsive device. It will first detect drowsiness in the user, and then activate an alert system which will not only awaken the user but also, cause the drowsiness level to drop.

Figure 1: Dr. Drowsy Glasses on Khoy

2.1 Drowsiness detection

Dr. Drowsy detects drowsiness in the user by calculating the blink rate. It achieves so by using an IR LED placed on the center of the frame of the glasses and a photodetector on the side of the frame. The LED and photodetector are positioned in such a way that the emitted IR will pass in between the open eyelids and then reach the phototransistor. By closing the eyelids, the IR transmitted will be obstructed and will not reach the phototransistor, causing the resistance of the latter to increase. The difference in intensity of the received IR in the phototransistor can then be used to calculate the blink rate of the user.

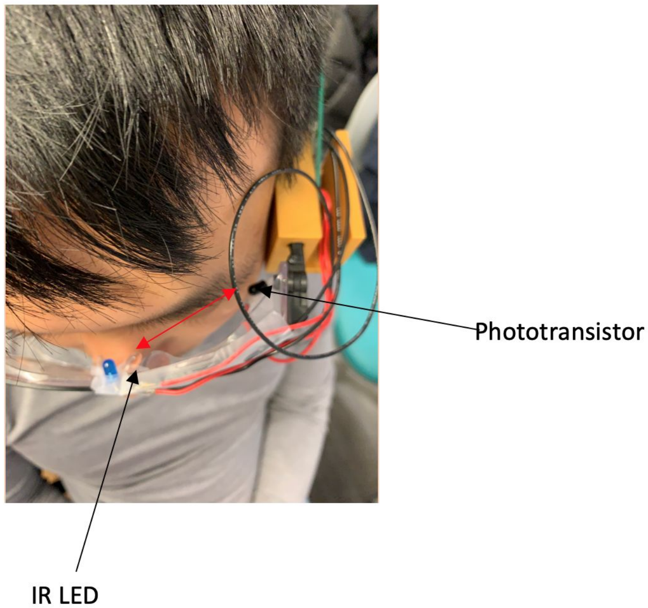

Figure 2: How blink detection takes place (red arrow shows path of IR to the phototransistor via in between the eyelids)

2.2 Anti-drowsiness response

The response to drowsiness detected is the lighting on of a blue LED placed on the frame of the glasses. A blue LED is chosen since the blue wavelengths in natural and artificial light has been proved to boost attention and mood, helping the user to stay awake. Exposure to blue light can also delay the process of the brain releasing melatonin, a hormone which regulates the sleep-wake cycle. (Tuck, Light, and Sleep) .

3. Hardware Considerations

Dr. Drowsy consists of the glasses, a 3D printed mount, and a solder board with all the circuitry. The circuit includes a phototransistor, blue LED, infrared LED, trinket/ microprocessing chip, battery pack, and resistors.

3.1 Glasses

The glasses used for this first prototype is a pair of glasses used in the lab by students of the university. The various components (LEDs and phototransistor) have been secured onto the glasses with tape. The wires connecting the components to the solder board have also been taped along the frame of the glasses.

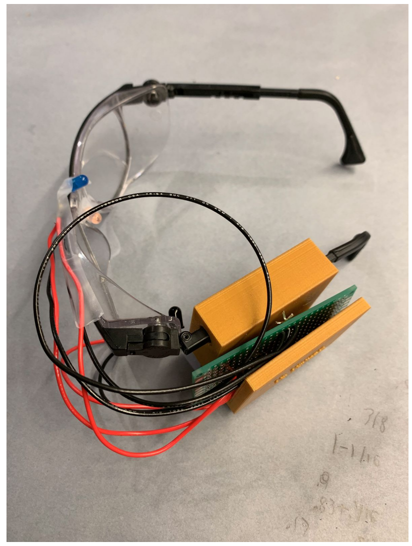

Figure 3: Dr. Drowsy Finished Prototype

3.2 Mount design

The mount was designed using SolidWorks and then 3D printed to precise specifications based on the glasses. The design of the mount effectively holds all the necessary circuitry (solder board with components on it and batteries). The mount also has a hole which enables the temples of the glasses to be inserted through. Measurements of the Solidworks design is depicted in assembly drawing below.

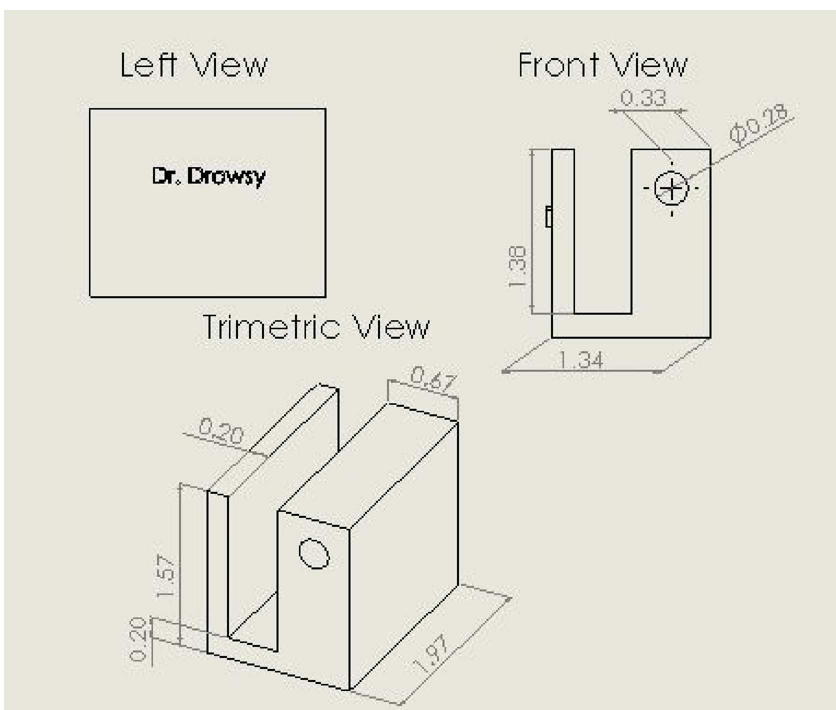

Figure 4: Assembly Drawing of the Mount on SolidWorks

Note: Measurements in the assembly drawing are in inches.

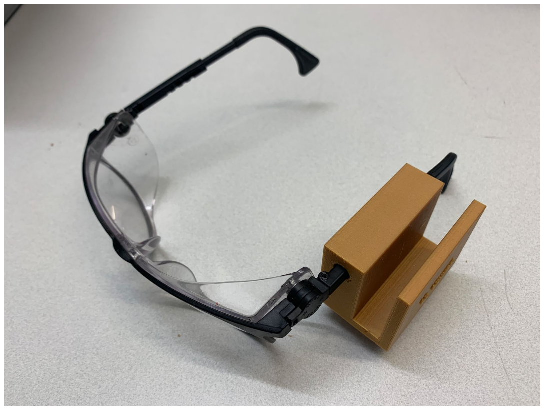

Figure 5: 3D Holder/ Mount Fitted on Lab Glasses

3.3 Circuitry

All the necessary components required to power and operate the glasses have been soldered on top of a solder board, which then sits on the mount. The actual circuit design is pictured below in figure 3.

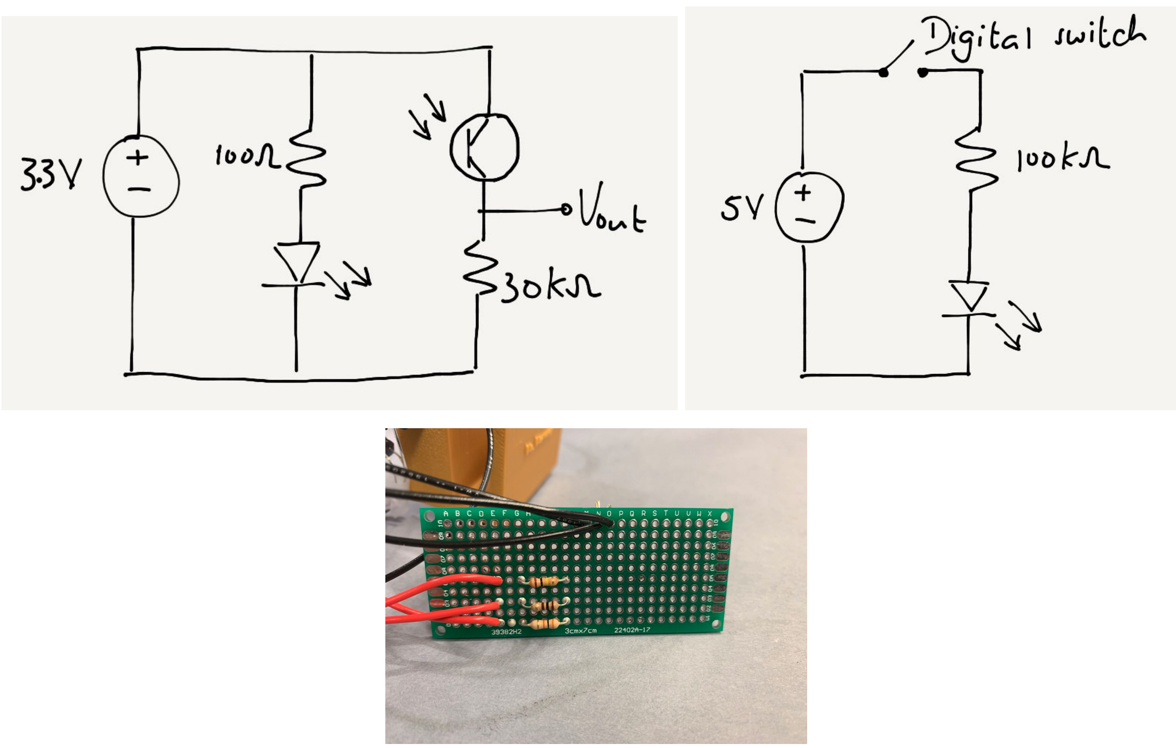

Figure 6: Circuit Design

The circuit was designed to have an output of 5V from the microprocessing unit. The 5V would go to the phototransistor and infrared LED that run in parallel. Simultaneously, the MPU would have a 3.3V output that feeds a blue LEDs that are also in parallel. The measured signal from the phototransistor then feeds back into the MPU. A ground port is also be present in the MPU, which grounds the LEDs, IR sensor, and phototransistor.

3.3.1 Microprocessing Chip

Our primary microprocessor on the device is an Adafruit Trinket M0 chip. We chose this microprocessor because of its compact size, ease in prototyping, and ability to read and provide signals within our desired range. Since the board measures only 27 mm in length we're able to mount on the side of the glasses without causing strain to the wearer. The Trinket is also capable of delivering a 3.3 V current up to 500mA from the 3.3V output pin, making it capable of driving our low-intensity LEDs without any additional circuitry.

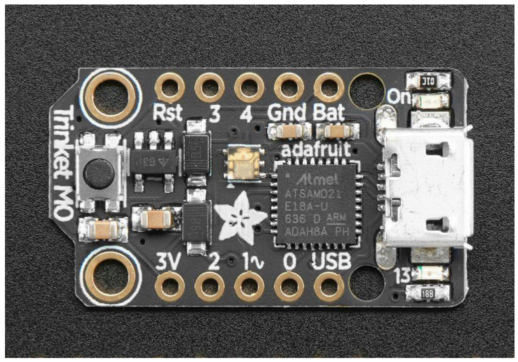

Figure 7: Adafruit trinket M0

3.3.2 LEDs and resistors

Taking into account the harm that IR can cause to the eyes at high intensity, a resistor of 100Ω has been connected in series with the LED to limit the intensity of IR exposure to the eyes.

Similarly, a resistor of 100kΩ has been connected in series with the blue LED [4] to limit its intensity to avoid harm caused to the eyes, especially for users who are sensitive to light.

3.3.3 Phototransistor

An IR phototransistor has been used to detect the IR emitted by the LED. This is has been chosen over a normal phototransistor since it eliminates the need to filter out rays of other wavelengths over than IR. In order to measure the difference in resistance of the phototransistor when different intensities of IR are directed towards it, a resistor of 30kΩ is connected in series with the phototransistor. This will act as a potential divider. This resistor value has been chosen since it is approximately the same as the upper limit of the resistance of the phototransistor. This will cause a significant change in the voltage drop across the phototransistor when its resistance decreases (IR intensity absorbed increases). The voltage at the point between the resistor and phototransistor is recorded and based on the value recorded, it can be determined whether the resistance of the phototransistor has increased or decreased and subsequently whether the intensity recorded has increased or decreased.

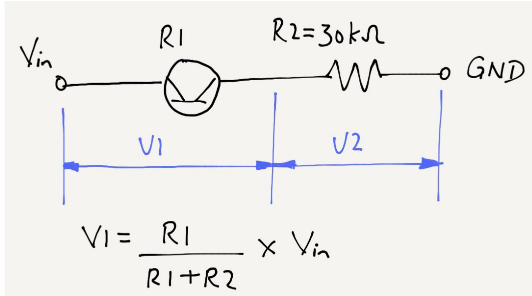

Figure 8: Potential Divider Circuit Diagram

4. Software Considerations

The software on the microcontroller chip is written in an extension of standard CPython called CircuitPython, which allowed for rapid prototyping. However, the Trinket board has only 50 KB of flash memory available, and even less at runtime once the program is compiled. Thus, design of the software was coupled strictly with considerations about memory usage. For these reasons, we use rolling windows on almost all data collection, so that whenever a data store exceeds a certain size, the software automatically discards the oldest 25% of data points (we let the fraction of data points be a parameter so that we could tune performance vs. aggressive memory management as needed).

4.1 Program design

At a high level, the software on the device has an execution flow that runs three detection loops iteratively, and in parallel. We illustrate a simplified version of the program logic here.

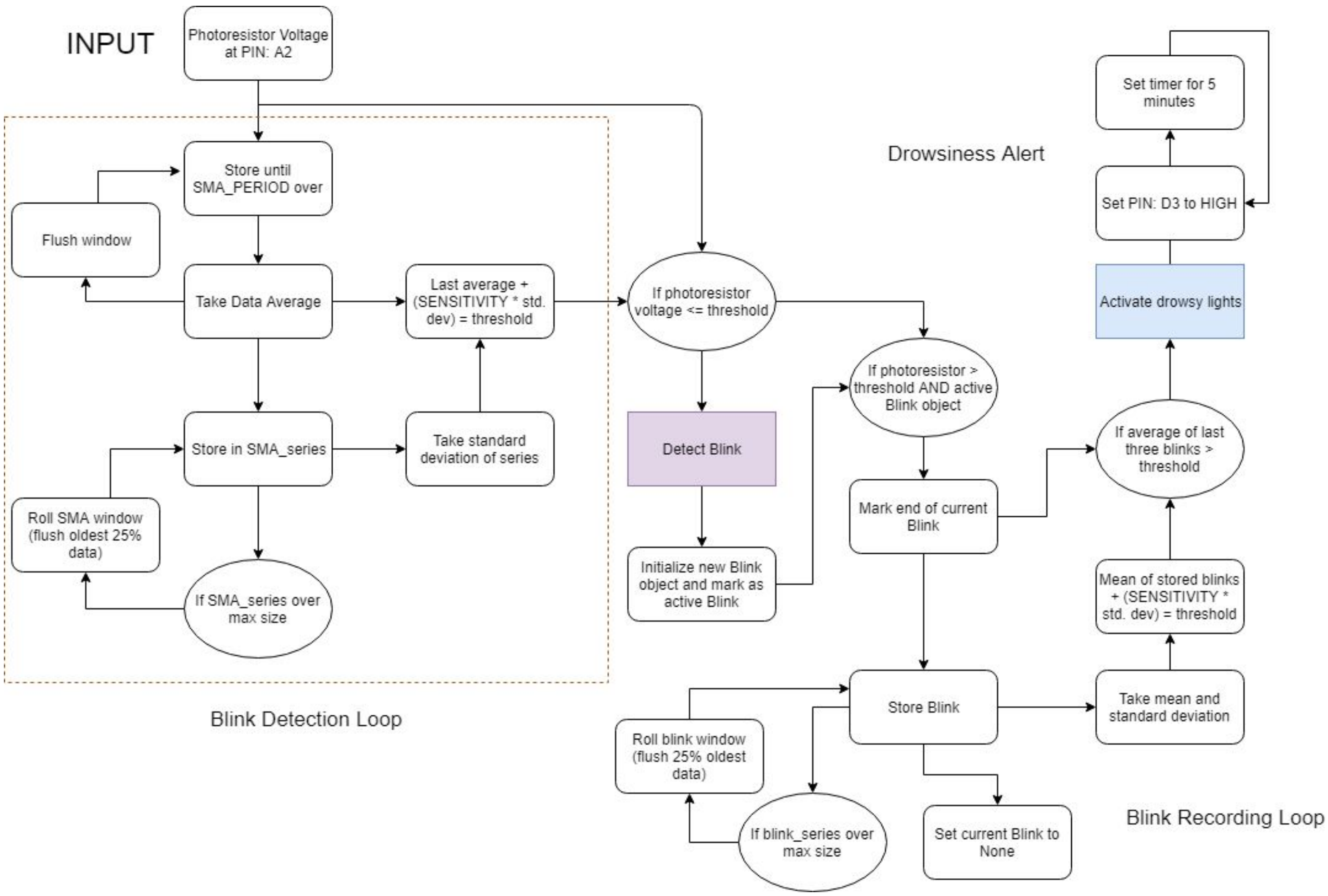

Figure 9: Python Code Flowchart

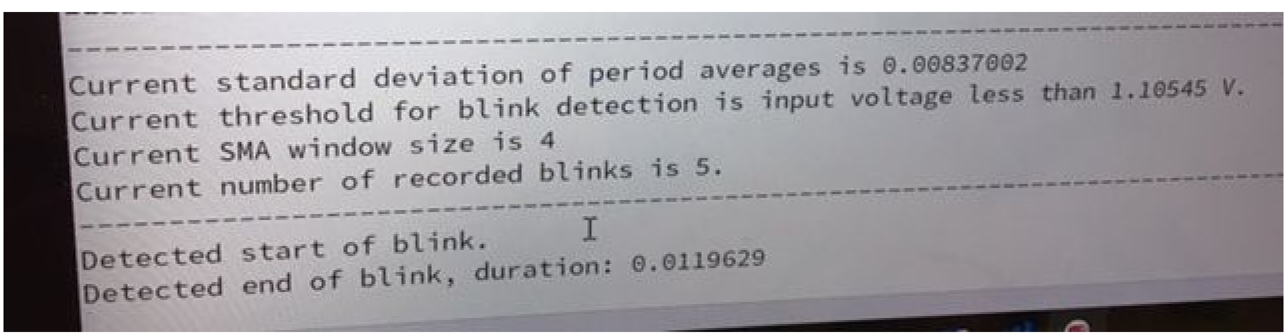

Figure 10: Code Output

4.2 Noise filtering

Our software first collects the voltage across the photoresistor directly and streams it into memory. To eliminate the baseline, we take a simple moving average on the photoresistor data over a sufficiently long (relative to the period of a blink) interval. This allows us to record a dynamic voltage level, indicative of an open eye, which can respond if the wearer moves to another room where there may be more or less ambient infrared light. From the series of averages stored, we compute a voltage threshold at which we will mark a blink as being detected. This is the last average taken, minus the standard deviation of the average series time some gain (the “sensitivity”). In practice, we have found best results with sensitivities between 5 and 10, for standard fluorescent-lit rooms. We use the falling edge of the raw voltage stream, compared against the threshold, to mark the start of a blink, and we use the rising edge to detect the end.

4.3 Blink rate management

Performance testing our software, we're currently able to detect blinks as fast as 70 ms, a great target since the average human blink is 100-150 ms. Due to the controlled setup of the IR LED and photoresistor system, our system is highly resistant to ambient noise creating false blinks, as the LED beam is by and far the biggest source of IR light near the photoresistor. In software, we avoid further errors by comparing most recent data to a rolling average always, and never any static figure. This allows our software to be adaptable to a variety of real world conditions.

4.4 Blue LED activation

Blinks are averaged and compared similarly to the photoresistor voltage input. When the software detects that the most recent (3) blinks are much longer than the calculated threshold, the blue lights on the device are activated. Threshold is calculated as before, except the standard deviation times gain is added to the mean instead of subtracted. After the blue lights are activated, they are designed to stay on for a period of at least five minutes, or more if blinks are still detected to be longer than average.

5. Testing

5.1 Precision, Accuracy, Sensitivity and Specificity

When we designed the Dr. Drowsy glasses we wanted to target a high specificity over sensitivity since we did not want the Dr. Drowsy glasses to turn on the blue light when the user did not need it. This could provide as a distraction and if the glasses turn on unnecessarily the users will throw it away quickly. In their current state, the Dr. Drowsy glasses have very high timing accuracy and precision, but accuracy with blink detection could be improved. In our testing, using simulated blinks by running our finger between the IR beam path, 22 out of 30 blinks were detected, an accuracy of 73.3%. However, our precision for the detected blinks was very high. Using a photogate borrowed from the Introductory Physics Laboratory at Northeastern, we were able to record the duration of the simulated blinks and compare them to the durations that our device measured. Over a set of 30 data points, Dr. Drowsy was, on average, within 2.3 milliseconds of the photogate recorded value. This indicates that the device is sufficiently capable of measuring blink time once a blink is detected, but still needs work in making sure that all blinks are detected. However, it's worth noting that throughout our testing, Dr. Drowsy *never* recorded a false positive blink (only false negatives). This is a good position to be in for us, as it's much more important to not accidentally turn on the blue light from a falsely recorded blink than it is for us to miss a blink.

5.2 Testing Dr. Drowsy

The experiment will take place at 80 Forsyth Building (FR), Room 201, Forsyth Street, Boston. It will include one session for each participant, and one hour for each session.

In each session the participant will do 3 trials. To begin the trial, participants will be directed to sit in a chair and will be outfitted with the Dr. Drowsy glasses. Participants will be asked their to gauge their comfort level on a scale of 1-10. When they are satisfied with the fit the researches will help to adjust the LEDs if necessary. Participants will be tested in trials of about 12 minutes. A trial will consist of 5 phases that includes 3 pre-phases.

- Phase 1: Blink normally for 2 minutes.
- Pre-Phase 2: A researcher will use a stopwatch to count ½ second, for the participant 5 times by saying out loud "Start" when they start the stopwatch and "Stop" when ½ seconds passes. They will do this 5 times in order to train the participant what ½ second feels like.
- Phase 2: The participant will blink when the participant feels necessary and hold the blink for approximately ½ a second. This phase will last 2 minutes.
- Pre-Phase 3: A researcher will use a stopwatch to count 1 second, for the participant 5 times by saying out loud "Start" when they start the stopwatch and "Stop" when 1 second passes. They will do this 5 times in order to train the participant what 1 second feels like.
- Phase 3: The the participant will blink whenever the participant feels necessary and hold the blink for approximately 1 a second. This phase will last 2 minutes.
- Pre-Phase 4: A researcher will use a stopwatch to count 1 second, for the participant 5 times by saying out loud "Start" when they start the stopwatch and "Stop" when 1 second passes. They will do this 5 times in order to train the participant what 1 second feels like.
- Phase 4: The participant will blink whenever the participant feels necessary and hold the blink for approximately 1.5 seconds. This phase will last 2 minutes.
- Phase 5: Blink normally for 2 minutes.

After every main phase, not pre-phase, thus every two minutes the participant will be asked their comfort level. The data collected will then analyzed in order to see how well the processing board picked up the two types of blinks.

6. Why Dr. Drowsy?

6.1. Value to Consumers

Our value is calculated by the equation " Q x C / $". The Q represents the objective quality. From the point of view of customers, Dr. Drowsy glasses would make them feel secure about their working environment. Knowing that there is "someone", the glasses, looking out for them they would know that they could not get sued by patients or or fired by their employer. Dr. Drowsy glasses provide an alternative to coffee and drugs in order to keep them up. Since many people do not like the taste or feeling or being awoken by caffeine or drugs, Dr. Drowsy would help keep them awake more naturally. The C represents the subjective convenience of the product. One of the best parts of the Dr. Drowsy glasses is the convenience of them and mobility. The glasses can be worn anywhere and on the go. The $ represents the cost to the customer. The costs as perceived by the customer could include the price tag which plans to be priced at $50. For doctors this cost may not seem like a pocket-buster but for college students many would not want to pay this price. For the average driver commuting to work or feeling tired after lunch, the amount of time they spend in the car and at the after lunch period every day, they would consider it a small price.

6.2 White Space

Currently the customers that could benefit from Dr. Drowsy glasses are endless. Doctors, college students, night-shift workers, and drivers all over the world in all countries could benefit from the product. It is capable of detecting drowsiness and even better, it can awaken users with a blue light. Currently, we do not have competition since Optalert glasses are not in the market and the StopSleep Ring is only available in Europe and has barely attracted any customers. Our product is the only drowsiness detection device that has the potential to keep users awake by targeting the production of the sleep hormone, melatonin. This means we have found our white space where we can operate and grow. If we patent our glasses then no one in the US could produce it without having to pay.

6.3 Beachhead & Consumers

Doctor, drivers and college students are some of the targeted consumers that would have the most potential benefits from Dr. Drowsy. The glasses can prevent surgical mishap and thus, the financial burdens of lawsuits from medical negligence. For drivers, Dr. Drowsy would ensure that they stay focused on the wheel and protect their lives as well as others. Students would benefit from not wasting precious time in class. We are in a place that can sell this value and we do it best by using a simple design and does not require users to ingest chemicals in order to stay awake.

6.4 NABC

6.4.1 Need

Dr. Drowsy glasses fill the need of customers to detect drowsiness in order to prevent physical, mental and financial injuries to themselves or others. The glasses are needed because surgeons can be fined millions in lawsuits if they are on the job and are become too tired to work at the highest level. Hospitals can go out of business and ruin doctor's careers, so get Dr. Drowsy glass. Millions of people are on the road every day and it is normal to get sleepy and pay less attention to the road. Falling asleep on the road is just as dangerous as drunk driving. It can cause car crashes, injuries to oneself, friends, family, and other drivers. As a student, it is important to stay awake during class in order to maximize their valuable time and money.

6.4.2. Approach

We started this project by brainstorming ideas using many different methods. One method we used was diving into a health condition or disease that already exists and trying to apply our knowledge to that problem. We also brainstormed by thinking of the sensors we could use and trying to solve a problem with that particular sensor. We approached the problem of drowsiness by looking at what biomarkers signaled drowsiness. We explored ideas such as using posture, gait, speech detection, facial imaging or blink detection in order to track drowsiness. We choose blink detection and analysis since a person who is drowsy may not be moving around or speaking while gets sleepy. We also found that facial imaging and posture imaging/detection via cameras was not in our expertise. Thus we landed on blink detection. We started by looking at how blinks could be detected. One could use camera to look at the coloration changes, the velocity of the eyelid opening, shining a light into the eye and measuring the reflection and the one we picked, shining an IR beam from the nose area to the temple side. The beam would not go into the eye, it would be placed such that when the eyelid closed, the beam would be cutoff. Out first sketch was on the chalkboard in Ryder Hall. Nabeel started the drawing and then the other group members with more circuit knowledge moved around the components to make it electrically logical. After figuring out our components we went to the breadboard with a voltmeter in hand. Then we needed a way to put the board on the glasses, so we ordered soldering boards to attach it to the glasses. The circuit went through many iterations as we were debugging over several weeks. We assumed at first that we needed a gain and filtering, but it turned out that the IR light was just not on and only Harmony's phone could detect it was on. Thus, we were able to get rid of the gain part of our circuit by changing the resistor values. In order to minimize the components on the glasses we were also able to implement filtering through software.

6.4.3 Benefits/Cost

Dr. Drowsy glasses will benefit its users by keeping them awake to enjoy their day and keep themselves and others safe. Dr. Drowsy Glasses will give users the benefit of knowing they are safe and keeping other safe around them. Our product uniquely detects the user starting to fall asleep and will awaken them in order for them to keep being productive. The only cost of the Dr. Drowsy glasses is having to wear the glasses and $50, a low price for the security of the thing most important to you, your life.

6.4.4 Competition

When compared to other competition such as the the Optalert glasses or the StopSleep Ring, no other competitor uses blink detection in order to detect sleepiness and blue light to awaken its user. We currently have a monopoly on this sector of sleep detection and we intend to keep it this way.

6.4.5 Comparison with existing products

Despite being only a prototype, Dr. Drowsy has been compared to several products on the market.

	Optalert glasses	Stopsleep
		

Product description	Pair of glasses which tracks the blink rate using a LED-based technology, similar to Dr. Drowsy.	A ring-like device which measures drowsiness via the electrical conductivity of the skin, which is affected by the level of brain activity.
Alert system	Does not have any alert system implemented.	Vibration & sound-based alert system
Price	Currently not available for purchase, prototype in the making	$189

As compared to the existing products, Dr. Drowsy glasses are a more affordable and viable option for everyday use. Our device is ready to be introduced into the market as opposed to the Optalert glasses and will be selling for a third of the price for the Stopsleep product. Dr. Drowsy's portability allows consumers to use the glasses whenever and wherever. Unlike the Stopsleep, which has a sound alert system, the Dr. Drowsy glasses alerts the user without disturbing other individuals in close proximity. The device is also more effective, taking measurements directly from the blink rate while the Stopsleep device measures skin conductivity, which can easily be interfered by the environment. The Stopsleep ring device also limits the user's mobility, making it less practical for many consumers like surgeons and students, who would make up a huge market. Dr. Drowsy is the only drowsiness responsive device that not only awakens the user with a blue light but also keeps the user awake by suppressing the production of the sleep hormone.

7. Risks

Dr. Drowsy being a device which directs EM waves into the user's eyes comes with certain risks. Both IR and blue light, at high intensity, can be harmful to the eyes. For IR[1,2,3], for exposure times of over 1000 seconds, the limit for spectral irradiance is of the magnitude of around $300 W\text{-}m^{-2}$. As a result, we have chosen to put a resistor of 100Ω in series with the IR, so that when supplied with 3.3V, it draws a forward current of 18.89 mA. This gives us a total power output of 62.21 mW for the IR LED. Calculating the irradiance as a function of distance from the eye, we find that the IR LED is safe for **direct** long term exposure to the eye at distances further than 10.8 cm. However, due to the construction of the device, it is extremely unlikely that the IR LED, would ever be pointing directly into the eye; at worst, it could glance off the lens of the eye and perhaps scatter internally, at a much lower power. As for the blue LED, we have put a resistor of 100kΩ in series when supplied 3.3V. Measuring a current of 75µA in the circuit, the power of the blue LED is therefore 0.247 mW. This power is always negligible to the human eye, even if the LED were to be held directly in front of the cornea, and so poses no harm to the wearer.

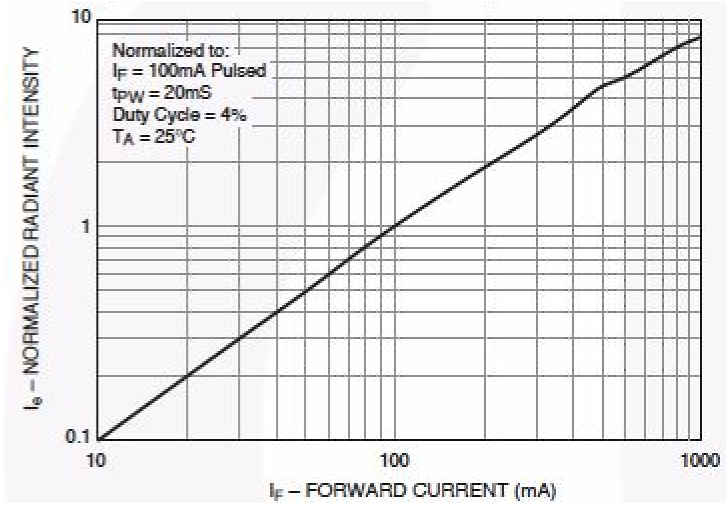

Figure 11: Normalized Radiant Intensity vs. Forward Current from Datasheet[6]

As seen in Figure below of the radiation of the IR LED, the beam is confined to only 20º from the top of the LED. Thus the IR light would not be hitting the eye with full intensity unless it was pointed directly at the eye.

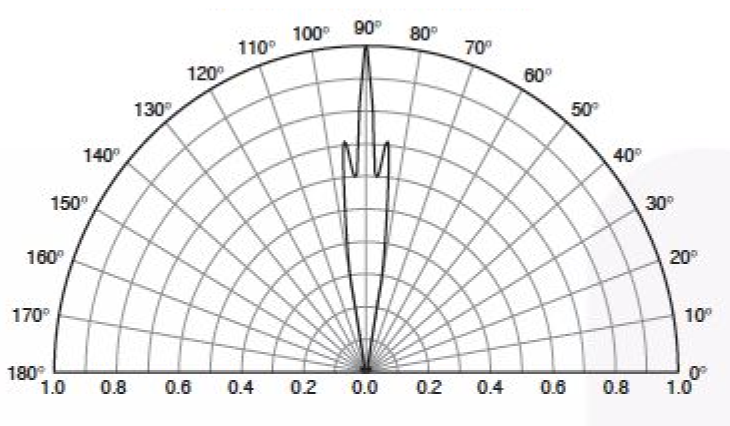

Figure 12: Radiation Diagram of IR LED from Data Sheet[6]

8. Pricing

8.1 Prototype Estimate

For this first prototype, we made the best use of the resources available to us. Apart from the Trinket board, which costs around $10, all other components were either obtained for free or were bought at a low price. The list of material used, along with the prices are summarized in the table below:

Budget estimate for prototype

Item	Quantity	Cost
Lab glasses	1	Free
Blue LED	2	Free (from 1st year Engineering Center)
Adafruit Trinket board	1	\$10.54 each
QSD123-ON semiconductor phototransistor	1	\$0.54 each
QEC123 IR LED	1	\$0.59 each
Wires	∞	Free (from Nabeel)
3D printed holder	1	Free
Battery	1	\$7.99
Soldering Board	1	\$0.65
	Component Total:	\$20.31
	Shipping	\$21.00
	Total	\$42.31

8.2 Pricing for Future Orders

With the possibility that Dr. Drowsy will enter the market, the cost of material for the product when mass produced has been anticipated and summarized in the table below.

Budget estimate assuming bulk pricing and PCB

Item	Quantity	Cost
Lab glasses	1	\$2.00
PCB (already populated)	1	\$28.89
Adafruit Trinket board	1	\$7.16 each
3D printed holder	1	\$2.00
Battery	1	\$7.49
	Total:	\$48.59

In future orders as a final product we will include a battery with an on and off switch as well as a PCB all in one. The user would be able to open their box, turn on the switch and be able to use the product immediately. Further development will also include the option to implement prescription lenses in the glasses for customers who are visually impaired.

9. Conclusion

Our product, Dr. Drowsy is the glasses you need to stay awake! Previous studies have proven that blue light effectively suppresses the production of melatonin, the major sleeping hormone. Our product incorporates this phenomenon by using a blue light to prevent drowsiness in users around the globe. Dr. Drowsy operates by detecting changes in the user's blink rate as the drowsy detection system and turns the blue light on when a dynamic threshold of blink time is reached. The use of IR light and phototransistor is our new and has never been commercialized. Our customers are the commuters who need to stay awake while driving home, doctors who must perform many surgeries in a day, university students who need to effectively listen to lectures and all other populations who have trouble staying awake and don't want to consume food, drugs or beverages in order to stay awake.

10. References

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