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Electronic Dive Mask: A Heads Up Display for Deep Diving

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Electronic Dive Mask:

A Heads up Display for Deep Diving

By

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Report Summary

The top five dangers in diving are marine life, malfunctioning equipment, asphyxiation, pulmonary embolism, and nitrogen narcosis. These risks exist even with the current standards of diving equipment. Most of these risks can be attributed to a lack of information, either due to inattention or because the information is not accessible to the diver. The current solution to these risks are dive computers, wearable devices around the diver's wrist which provides numeric displays of various information. One value the devices do not display is orientation. These devices also have insufficient methods of warning the user. As such a device is proposed to work in tandem with dive computers to both provide a measurement of orientation and a better method of warning the diver.

This proposed method is a device placed inside the diver’s dive goggles. This allows the device to constantly warn the user by always being in the diver’s peripheral vision. The proposed solution uses an accelerometer to provide values for orientation, a value not present in dive computers. By constantly displaying orientation to the diver, the diver will know where to go even if they become disorientated due to nitrogen narcosis. This solution also uses the accelerometer to measure vertical acceleration to provide a warning for pulmonary embolism, as well as uses a timer found in the processor to warn the user if they are running out of oxygen. These values are then displayed using a series of multicolored LED’s around the dive goggles. After initial testing it was found that using the accelerometer to measure vertical acceleration is not a valid option. This is due to the vertical acceleration limit heavily depending on the depth of the diver as well as the time spent at each depth.

For the final design, a constant LED display of orientation as well as time remaining was successfully implemented in a dive mask with a price point reasonable to work in tandem with the current dive computers. This resulted in a device that can mitigate the risks of nitrogen narcosis, the most dangerous risk of diving not that the current dive watches ignore, as well as asphyxiation. While not being fully tested for underwater use, due to all the necessary components fitting inside the dive mask, it should be possible to create a fully waterproof electronic dive mask.

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1. Introduction

Deep-sea diving can be a dangerous activity. Every year about 100 diving accidents are reported to have happened in North America alone.[1] Many of these deaths can be attributed to five specific reasons: marine life, malfunctioning equipment, asphyxiation, pulmonary embolism, and nitrogen narcosis.[2,3]

Marine life can refer to any form of sea life including sharks and dangerous plants. Marine life only tends to become an issue for divers who are actively interfering with the environment and is a common issue for any underwater activity.

Malfunctioning equipment and asphyxiation are often closely related. Most instances of malfunctioning equipment refer to broken oxygen regulators or depth gauges, altering the amount of oxygen produced from the tank. This can lead to the tank depleting quickly or just not producing the necessary amount of oxygen needed at a given depth. These reasons, combined with simply losing track of how long the user has been diving, are to blame for the majority of the dangers involving asphyxiation.

Pulmonary embolism, also known as the bends, is a type of decompression sickness caused by ascending quickly. As the diver descends, the body often absorbs oxygen and nitrogen. These gases take the form of small bubbles in the bloodstream and in the lungs. As the diver ascends these bubbles can expand due to the change in pressure. Depending on the rate at which the person ascends, the bubbles can cause a variety of problems including the diver's lungs exploding.

Nitrogen narcosis is similar to decompression sickness. The aforementioned nitrogen bubbles in the bloodstream can often act as a narcotic, impairing the driver's senses. Similarly, at deeper depths oxygen bubbles in the bloodstream cause a similar effect. The disorientation often causes the diver to get lost underwater resulting in either asphyxiation, or some type of decompression sickness.

It appears that all of these risks occur from a lack of crucial information, be it oxygen values, rate of acceleration, or which way is up. The objective of this project thus is to create a device to help mitigate as many of these risks as possible by providing necessary information, while not creating more risks from limiting visibility. The list of risks used are current meaning they exist even with the diver wearing the current accepted diving equipment. As a result, the device is designed to work in tandem with the equipment instead of replacing any of it.

The next section will be focused on assessing the problems with the current diving equipment and determining what needs to be included in this proposed solution. Due to the nature of the device, this will mainly be pertaining to the safety, manufacturability, and sustainability of the system. The section after will then consist of the design requirements of the device, heavily restricted due to the deep-sea environment it needs to work in. The fourth section will include the proposed design alternatives, including different ways to achieve what the current diving equipment cannot. The fifth section includes the preliminary proposed design, which includes the initial components chosen and the method used to mitigate the diving risks. After the preliminary proposed design comes the final design and implementation which includes any changes from the initial design. Then comes the results to compare how the device performed with how it was perceived to perform. The eighth section is a cost analysis of each of the components in the device. Following the cost analysis section comes a user manual for using the device. The remainder of the paper consists of a discussion and conclusion based on how the project went as well as any future work that should be done. Last comes a reference section, which includes any references used in creating this report.

2. Background

It is well known that diving is a dangerous activity. Due to this there exists a widely used piece of technology designed to provide constant information to the diver. This device is called a dive watch, also known as a dive computer. Dive watches were initially created in the 1930's and, as the name suggests, were an arm mounted device used as an underwater watch.[4] This allowed for divers to keep track of the time while diving. A picture of an early dive watch, the Rolex Submariner, can be seen in Figure 1 below.[5]

Figure 1: Image of a 1930's Dive Watch: The Rolex Submariner

This was the standard commercial diving tool until the 1980's when the first electronic dive computer was released, the Orca Edge dive computer, seen in Figure 2 below. [6] This device, which was also worn on the arm, allowed for the user to track depth as well as time. Since then, dive computers have become much more advanced, allowing the user to track numeric values of time, depth, temperature, and pressure. Some devices also connect to the oxygen tank to allow for a numeric display of the oxygen remaining.[7]

Figure 2: The First dive computer, The Orca Edge, Next to an Early Dive Watch

The amount of information the devices can display is often related to the price, with cheaper devices, ranging from 160-300$, only displaying time, depth, and oxygen, and expensive watches, from 700-2,000$ displaying everything above as well as oxygen toxicity and other warnings. [8]

While these devices provide a wide array of information on the diver's watch, they are not a perfect solution. Comparing the devices to the aforementioned five risks of diving, some of the flaws become clear. First, while the devices have ways of detecting oxygen remaining, depth, and time, only the expensive devices have methods of actually warning the diver in a way more than just showing it on the display. This can be an issue as the device is only useful when looked at, allowing for the diver to unintentionally ignore these warnings. Similarly, under an emergency situation the device can be difficult to see.

Lastly, and most importantly, these dive watches have no method of displaying orientation. This means the devices do little for a diver under the effects of nitrogen narcosis. This could be seen as a limitation of a wrist mounted device as measuring orientation becomes difficult on a constantly moving and rotating wrist. To work properly in detecting orientation, the device would need to remain reasonably still, which is difficult for a disoriented user.

Even with these flaws, the dive watches are a useful tool for displaying information. As a result any future device would benefit greatly from either working in tandem with the device or borrowing portions of the design. This is supported in the fact that dive watches and dive computers have been the only method of displaying diving information since they were invented.

Being a device pertaining to displaying crucial information in an underwater environment, safety is a concern. As a result, there does exist ISO standard 6425 for specifying what is a dive watch, published in 1982 and updated in 1996. The standard requires the device to be clearly readable at least 25cm away in total darkness and requires all readings to be clearly distinguishable. The device also needs to be shock resistant, magnetic resistant, and chemical resistant to be able to fully function in the most hazardous underwater environment. Lastly the device needs to clearly be able to give a warning when running out of battery life.[9]

This standard mainly was created with dive watches in mind, as opposed to more technically advanced dive computers, since more complex dive computers were yet to be invented. Despite this, the standard still applies for all dive watches and computers. Due to the wide variety of information new dive watches provide, it would then be difficult to rewrite the standard in regards to the current major risks.

As mentioned above, it would be fairly difficult to implement an orientation sensor in the current model and only expensive watches with capabilities to link with the oxygen tank can measure oxygen toxicity making it difficult to enforce any standard that addresses nitrogen narcosis.

However; it may be possible to update the standard regarding warning the diver. Currently only some types of dive watches have the capabilities to successfully warn the user of cases of pulmonary embolism, while most devices have the equipment to detect it. Instead of creating a new type of device to combat the risks of diving, a solution to some of the risks could be for the standards to be updated.

If the standards remain the same, then a new device will need to be created. As with the dive watches and the dive computers the device needs safety standards regarding the environment it is meant to be used in. For a standard dive this usually refers to 40m deep water.[10,11]

Any device also needs to not either exacerbate the current risks or create new ones unique to the device. For example the device’s method of warning the user should not affect the surrounding marine life. Similarly it should not affect the oxygen regulator. For new risks, the device should not inhibit the diver's ability to swim, or the diver's ability to see.

Manufacturability is also a concern with creating a device in a highly pressurized environment. As mentioned in the ISO standard 6425, the current dive watches need to be resistant to the surrounding environments. This needs to be true for any alternative.

The alternative should also be as readily available as current dive watches. Diving is an expensive activity, so for a device to work in tandem with a dive watch or computer, the device must be reasonably inexpensive. Similarly for a new device to be created, the device needs to be as expensive as the dive watches. More importantly than price, the alternative needs to be user friendly. The current wrist watch design is brilliant in this aspect.

The current design is also brilliant in terms of sustainability. Since the overall use of the device remains constant, any improvements to the concept of the dive watch have been due to an increase in sensor development. As can be seen in Figure 3 below, sensor development has been increasing steadily over the past 20 years.[12]

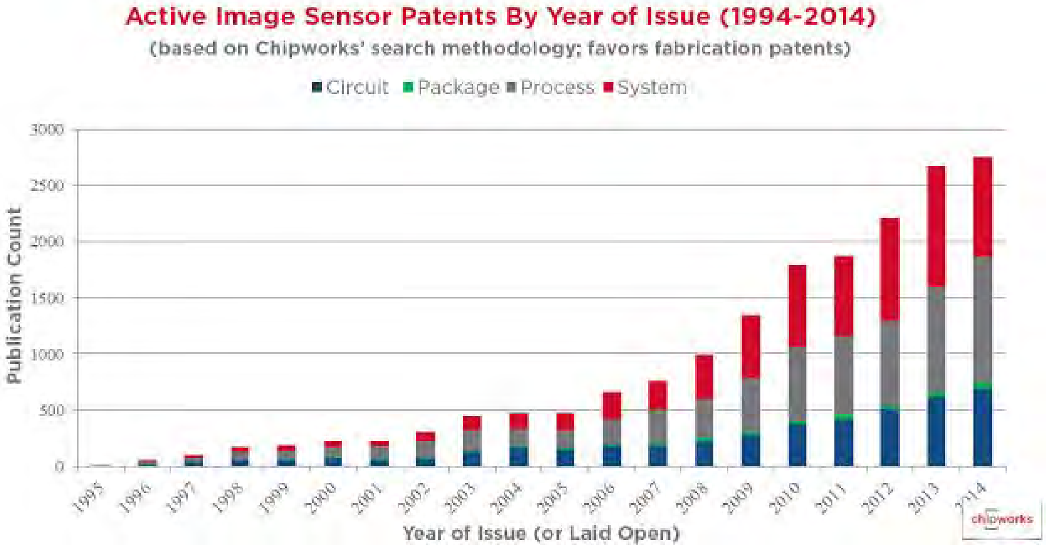


Figure 3:Active Image Sensor Patents By Year of Issue (1994-2014)

The current dive watches have seen to be following this trend. An example of this can be seen below in Figures 4 and 5 below by comparing the Mares Puck and the Cressi GOA dive computer. On release the Mares and the Cressi dive watches were 300$ and 350$ respectively. While the general design of the dive watches have not changed over the years, the difference comes from the amount of information the watches can display. Instead of displaying all information on one screen, the watch in Figure 5 has several modes to display oxygen toxicity, maximum dive depth, and the current time. These oxygen sensors are fairly new and have quickly become a standard in all reasonably priced dive computers.[13,14]

Figure 4: Mares Puck Dive Computer(2008)

Figure 5: Cressi GOA Dive Computer(2016)

The current solution, dive watches, is a reasonable solution to many of the dangers of diving. As a result the devices have become the standard tool for divers. Despite this, the five major risks marine life, malfunctioning equipment, asphyxiation, pulmonary embolism, and nitrogen narcosis, still exist. This is mostly due to the flaw in the wrist mounted design, that it is difficult to provide the user with a sense of direction. Similarly it is also difficult to provide clear warnings to the user. As a result any alternate design would be better off working in tandem with the current dive watch design.

3. Design Requirements

Due to the flaws present in the dive computers, a device chosen to work in tandem was designed. The device needed to be able to sense orientation as well as be able to warn the user at any time. These constraints mean that the device would need to be relatively motionless to the diver, but constantly be either in view or somewhere else to provide the user with a warning. Because of this the device was chosen to be placed inside the dive mask of the user. This provides a dry environment for components as well as an area that can allow for a visual warning.

At this point the device is projected to constantly display the user's orientation. Looking back at the flaws of the dive computers as well as the five dive risks, the device was also chosen to display a warning for pulmonary embolism and asphyxiation. This means that the device needs to be able to detect if the diver accelerates too fast and whether the diver has exceeded their projected dive time.

To detect orientation, acceleration, and time various sensors are seen to be chosen. These sensors then will send data to a microcontroller, which processes the data and sends it to a display. A block diagram of this rudimentary prototype can be seen below in Figure 6.

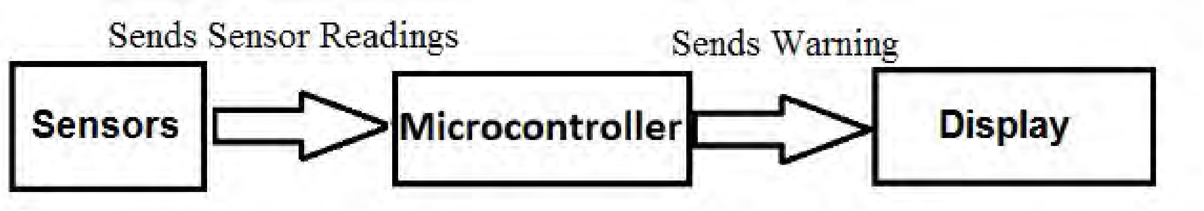


Figure 6: Basic Prototype Block Diagram

Before any of the components were chosen, the design requirements were listed. A full list of all design specifications can be seen in Table 1 Below.

Table 1: Design Specifications

	Need	**Want**
Depth	Work Underwater	Work 40m Underwater
Time	Work for 1 hour	Work for 1 Hour and 30 Minutes
Size	Must fit a Pair of Dive Goggles	Must fit in any Dive Goggles
Visibility	Must not Inhibit Visibility	-
Price	-	Must be Below 75$
Weight	Less than Dive Goggles (100g)	Half Dive Goggles (50g)
Precision	High for Orientation Sensor	High for All Sensors

The first specification is depth. The device is proposed to help divers. As a result it needs to be able to work underwater. Similarly it needs to be able to work at the typical maximum depth of a normal dive, 40m.[10] What this means specifically is that all the sensors in the device need to still provide accurate readings at that depth.

Similar to the depth restraint is time. The device needs to be able to last at least one dive without running out of power. Looking at average dive times, this was chosen to be 1 hour. Ideally the device also needs to last long enough for a long dive. This was found to be 1 hour and 30 minutes.[11]

Since the device needs to work underwater, any loose components can cause problems. As a result all components are restricted to fit inside a typical pair of dive goggles. While the device should fit in any pair of dive goggles, a specific pair was used for testing. The device must also not inhibit vision of the diver. Due to these constraints the far corners of the mask were chosen to store the device and its components. After measuring the sample pair of dive goggles used for testing, the maximum dimensions for any components were found to be 2”x1”.

Also due to the size constraints a small display may be difficult to read. As such the display was chosen to be a series of LED’s, something that provides a non-numeric display that the diver does not have to focus their eyes on to read.

Next, since the device is designed to work in tandem with more expensive equipment, the price of the device for it to be actually accepted in the market would need to be fairly cheap. As such the price of the device is aiming to be 75$, half the price of the cheapest dive watch available. With this price point in mind that leaves about 20$ for the microcontroller, 40$ for the sensors, and 15$ for a display. With that goal set, there is no formal spending limit, but the device should be as cheap as possible without sacrificing performance.

Even though the device is firmly attached to the diver's head so there is little risk of the device falling off, a heavy device can cause discomfort. As such the device is strongly limited to weigh only as much as the specified pair of dive goggles, measured to be about 100g. In total this would cause the goggles to weigh at most 200g. Ideally the less the device weighs the better, as such the device is aimed to be 50g, or half the pair of dive goggles.

While the dive computers provide accurate values for depth and air, they do not provide any information on orientation. As such the proposed device needs to have a high precision orientation sensor that can be able to accurately show which way is up at any point in time. Ideally it would also be possible for all sensors present to have the same level of precision, but it is most important for the orientation sensor to be held to a high priority.

Due to the above requirements, a very generalized functional decomposition was created, Seen in Table 2 below. Even with all the requirements, only the display method was chosen. All other functions did not have enough information to fully narrow down to a specific component. Deciding on specific components can be found in the following section, design alternatives.

Table 2: Basic Function Decomposition

Function	Device
Senses Orientation	Orientation Sensor
Senses Vertical Acceleration	Depth Sensor
Senses Time/Oxygen	Timer
Processes Information	Microcontroller
Displays Information	LED’s

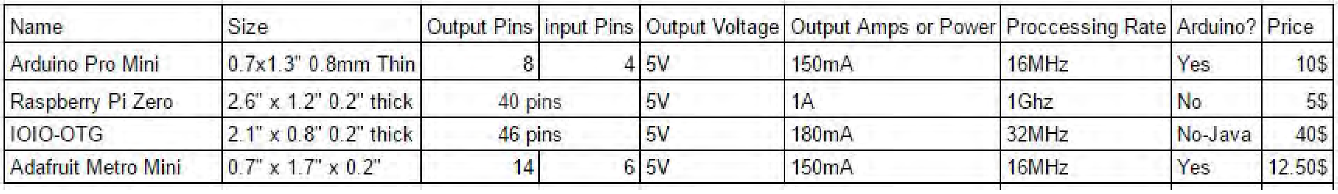
4. Design Alternatives

Since the design specifications did not provide strong enough constraints to narrow down a specific component for each function of the device, every component for each function was chosen using a decision matrix.

4.1 Microcontroller

The first component chosen was the microcontroller. This was chosen first because the software language the device runs on can be a limitation to the possible sensors used. The decision matrix for the microcontroller can be seen in Table 3 below.

Table 3: Decision Matrix for the Microcontroller



Name	Size	Output Pins	input Pins	Output Voltage	Output Amps or Power	Proccessing Rate	Arduino?	Price
Arduino Pro Mini	0.7x1.3" 0.8mm Thin	8	4	5V	150mA	16MHz	Yes	10$
Raspberry Pi Zero	2.6" x 1.2" 0.2" thick	40 pins		5V	1A	1Ghz	No	5$
IOIO-OTG	2.1" x 0.8" 0.2" thick	46 pins		5V	180mA	32MHz	No-Java	40$
Adafruit Metro Mini	0.7" x 1.7" x 0.2"	14	6	5V	150mA	16MHz	Yes	12.50$

Four microcontrollers were chosen to be considered based on their size, the Arduino Pro Mini[15], the Raspberry Pi Zero[16], the IOIO-OTG[17], and the Adafruit Metro Mini[18]. The Raspberry Pi-Zero was considered because it was the smallest model of the Raspberry Pi series of microcontrollers. Despite being familiar with that series, the size of the zero was too big.

Next the output and input pins were looked at. Since there were going to be three sensors, each with a projected 2 input pins, 6 input pins were thought to be needed. Similarly for the display at least 4 LED's, one for each cardinal direction, with 3 output pins each were used to calculate the amount of output pins needed. From these assumptions, the micro controller needed at least 6 input pins and 12 output pins. This resulted in the Arduino Pro Mini to be found to not be possible for this application.

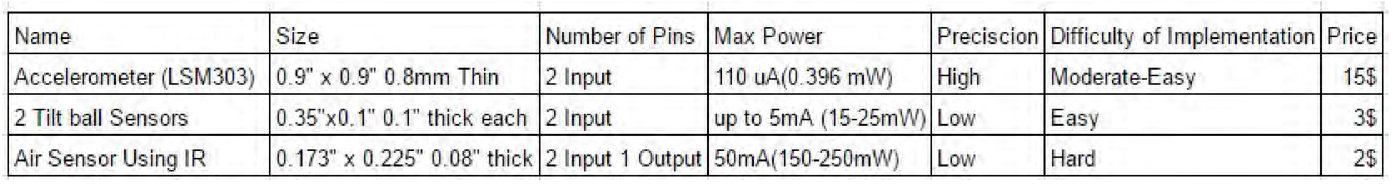
The last two proposed microcontrollers were the IOIO-OTG and the Adafruit Metro Mini. Each had the same output voltage, similar power outputs, and similar processing rates. In the end the Metro Mini was chosen due to it running Arduino. This microcontroller also is considerably cheaper than the IOIO-OTG at 15$ compared to 40$, leaving it under the projected price point. A picture of the chosen microcontroller can be seen below in Figure 7.[18]

Figure 7: Chosen Microcontroller for Prototype- Adafruit Metro Mini

4.2 Orientation Sensor

Next, the orientation sensor was chosen. Since this sensor is the most important in terms of precision, it was chosen before the other sensors. The decision matrix for the orientation sensor can be seen in Table 4 below.

Table 4: Decision Matrix for Orientation Sensor



Name	Size	Number of Pins	Max Power	Preciscion	Difficulty of Implementation	Price
Accelerometer (LSM303)	0.9" x 0.9" 0.8mm Thin	2 Input	110 uA(0.396 mW)	High	Moderate-Easy	15$
2 Tilt ball Sensors	0.35"x0.1" 0.1" thick each	2 Input	up to 5mA (15-25mW)	Low	Easy	3$
Air Sensor Using IR	0.173" x 0.225" 0.08" thick	2 Input 1 Output	50mA(150-250mW)	Low	Hard	2$

To measure orientation three methods were considered, an accelerometer[19], two tilt ball sensors[20], and an IR sensor[21]. Both the accelerometer and the tilt ball sensors use the assumption that gravity will be constant inside the dive goggles to accurately show which way is down. Then, knowing which way is down, the LED displays the opposite direction of that to show which way is up. The air method uses fluid dynamics to determine which way is up using an air bubble in a tube of water. Ideally the air bubble will always float in the upwards direction, away from gravity. By keeping track of the air bubble, direction can be measured.

After comparing all these methods, as seen in Table 4 above, only the accelerometer has a high level of precision. Due to this, the accelerometer was chosen to measure orientation. A picture of the chosen orientation sensor can be seen below in Figure 8.[19]

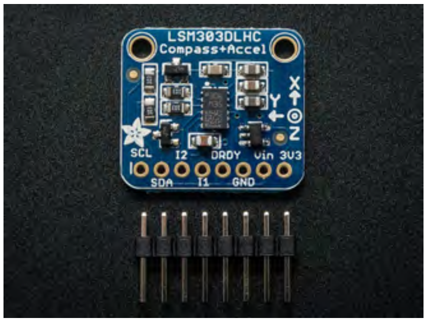


Figure 8: Chosen Orientation Sensor for Prototype- Accelerometer LSM303

4.3 Vertical Acceleration Sensor

The next sensor chosen was the vertical acceleration sensor. Ideally a depth sensor would be chosen to measure depth, and then the change in depth would be used to measure vertical acceleration. Due to the vacuum-like environment of the dive goggles, the depth sensor would not be possible for this use due to the ideal gas law, seen in Equation 1 below.

$$PV = nRT \tag{1}$$

Due to the hard plastic material of the dive mask, volume, V, is constant. There is also no way for air to escape or enter the dive mask, ideally, so the amount of gas in the dive goggles, n, is also constant. The temperature in the mask, T, might change due to the outside water temperatures, but the amount the temperature changes is determined by more factors than just depth. Lastly R is a constant, resulting in pressure, P, to be solely determined by temperature in the dive mask.

Luckily the orientation sensor chosen is an accelerometer. This type of sensor is a valid way of measuring acceleration. For this prototype, size is one of the biggest design constraints, combining two sensors into one is ideal. Therefore the accelerometer was chosen to be both the orientation sensor and the vertical acceleration sensor.

4.4 Oxygen Sensor

Similar to how the depth sensor was chosen, the oxygen sensor was chosen in a similar manner. Due to the device being rather self contained in the dive goggles, it is difficult to interact with the oxygen tank. As a result, to measure oxygen remaining, the internal clock in the microcontroller is used as a timer. The user then is responsible to input how long they think they will be diving.

Alternatively the diver can include the volume of the oxygen tank, V, the current pressure in the tank, Pc, the max pressure in the tank, Pm, and their projected oxygen rate, L, for a more accurate amount of dive time remaining, T. This relation can be seen in equation 2 below. [22]

$$(V/Pm) * Pc/L = T \tag{2}$$

4.5 Display

Even though the display was chosen to be LED’s there are many types of LED’s to pick from. Because there are three values that need to be displayed, multicolored LED’s were chosen. Assuming there are 4 LED’s, on the top, bottom, left, and right sides of the device, orientation can be displayed through whether an LED was on or off. Time remaining can be displayed through color, with green meaning the diver has plenty of oxygen, and red meaning the diver is running out. Lastly if the diver is accelerating too quickly, the LED can blink, blinking faster if the user is diving much faster than they should be.

There are many different types of shapes of multicolored LED’s. Due to the size constraints, a round LED[23], a rectangular LED[24], and a surface mounted LED[25] were chosen to be considered in a decision matrix. This matrix can be seen below in Table 5.

Table 5: Decision Matrix for LED

Name	Colors	Size	Price	Power	Number of Pins
Typical Round LED	RGB	5mm D 8mm	3$ for 5	20mA(up to 100mW)	3
Rectangular	RGB	2.5mmx5mm	6$ for 10	25mA(up to 125mW)	3
Surface Mounted	RGB	2mm x 2mm	6$ for 10	100mW to 500 mW	3

As can be seen above, all the LED’s selected were very similar except for size. Even though the surface mounted LED’s were the smallest, the rectangular LED’s were chosen due to ease of assembly, meaning it is suspected that the surface mounted LED’s would be too difficult to attach to the dive mask. The chosen LED’s can be seen in Figure 9 below.[24]

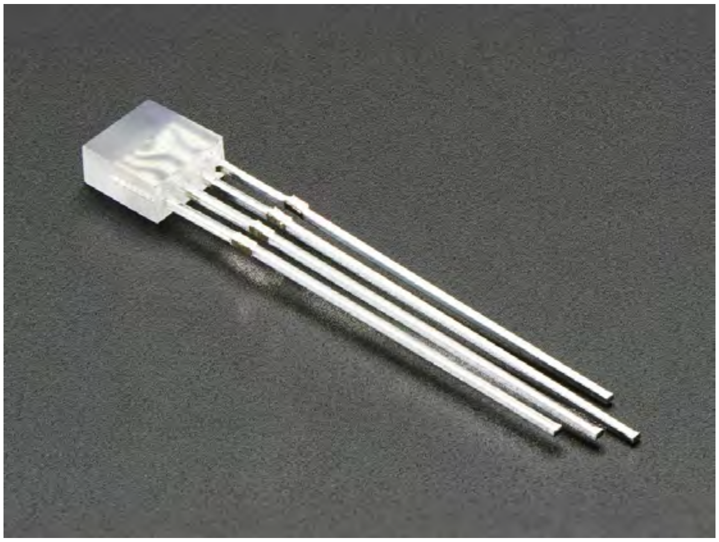


Figure 9: Chosen Display- Rectangular Multicolored LED

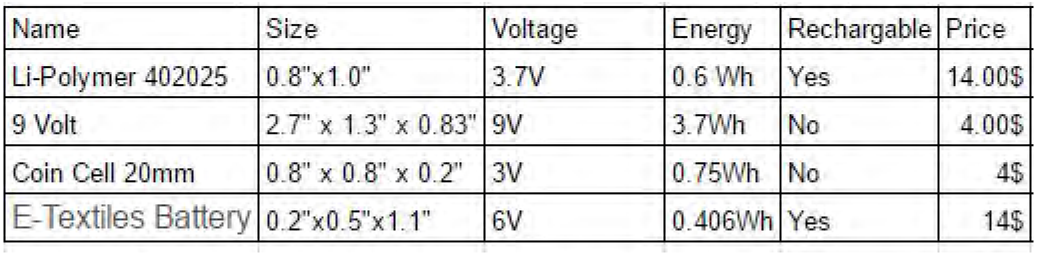
4.6 Power Supply

Lastly a power supply was selected. The total energy required for each use was calculated using equation 3 below, where E represents energy, P represents power, and T represents time.

$$E=P*T \qquad (3)$$

From the constraints, time was chosen to be 1 hour. Power was then found by adding up the power needed for the microcontroller, the accelerometer, and 2 LED’s using the power values in Tables 3, 4, and 5 respectively. From this calculation it was found that about 1Wh was needed from the power supply. Using these values, 4 batteries were chosen, a 9 volt[26], recommended by the microcontroller supplier[18], an Li-polymer battery 402025[27], a E-textiles battery[28,29], and a 20mm coin cell battery[30]. From these values a decision matrix was created, which can be seen in Table 6 below.

Table 6: Decision Matrix for Power Supply



Name	Size	Voltage	Energy	Rechargable	Price
Li-Polymer 402025	0.8"x1.0"	3.7V	0.6 Wh	Yes	14.00$
9 Volt	2.7" x 1.3" x 0.83"	9V	3.7Wh	No	4.00$
Coin Cell 20mm	0.8" x 0.8" x 0.2"	3V	0.75Wh	No	4$
E-Textiles Battery	0.2"x0.5"x1.1"	6V	0.406Wh	Yes	14$

Despite it being convenient to have a rechargeable battery, these types of batteries are seen to be dangerous by the public. Since the prototype is designed to work around diver's eyes, the rechargeable batteries were not chosen. Despite being recommended by the supplier, the 9 volt battery was found to be way too big to use in this application. This leaves the coin cell batteries remaining. The microcontroller needs at least 6V to run. As a result of this, and the minimal energy requirements, 3 coin cell batteries were chosen to work in series. Due to the combined depth and orientation sensor, there is enough room to store these batteries. The chosen battery can be seen in Figure 10 below.[30]

Figure 10: Chosen Power Supply-20mm Coin Cell Battery

5. Preliminary Proposed Design

Now that the initial components have been chosen, as seen in the above section, an updated block diagram is created, as can be seen in Figure 11 below.

Figure 11: Preliminary Design Block Diagram

From Figure 11 it can be seen that all sensor readings are taken from the Accelerometer. Initially more than one sensor was proposed, but because of size constraints the less sensors used, the better the projected outcome. As a result, combining all measurements needed into one sensor is ideal. For the measurements needed, orientation and vertical acceleration, this was seen to be possible by using an accelerometer. Similarly it was found that oxygen could be measured by the microcontroller if it was treated as a timer. This timer will function doubles as a method of keeping track of the time remaining for the power supply as well. An updated functional decomposition for the preliminary design can be found below in Table 7.

Table 7: Preliminary Design Functional Decomposition

Function	Device	Display Method
Senses Orientation	Accelerometer	LED-On/Off
Senses Vertical Acceleration	Accelerometer	LED-Blinking
Senses Time/Oxygen	Microcontroller	LED-color
Processes Information	Microcontroller	
Displays Information	RGB LED’s	
Power Supply	3 20mm Coin Cell	LED-color

For time specifically a user interface needs to be designed for the user to input their projected time of the dive, through a time value or values mentioned in Equation 2 above in the design alternative section. At this point in the design the software components have yet to be considered outside of the language of the code, Arduino. The language was only chosen due to the microcontroller supporting it. As a result the specifics for the code, including this user interface, will be finalized as the prototype is being assembled.

The initial physical assembly of the prototype can be seen in Figure 12 below. Represented in this device are the three main components, the microcontroller, accelerometer, and LED's. The microcontroller and accelerometer are calculated to be the biggest components in the device. Due to this they are both placed respectively in the corner of the dive goggles, in an area with the dimensions 1”x2”.

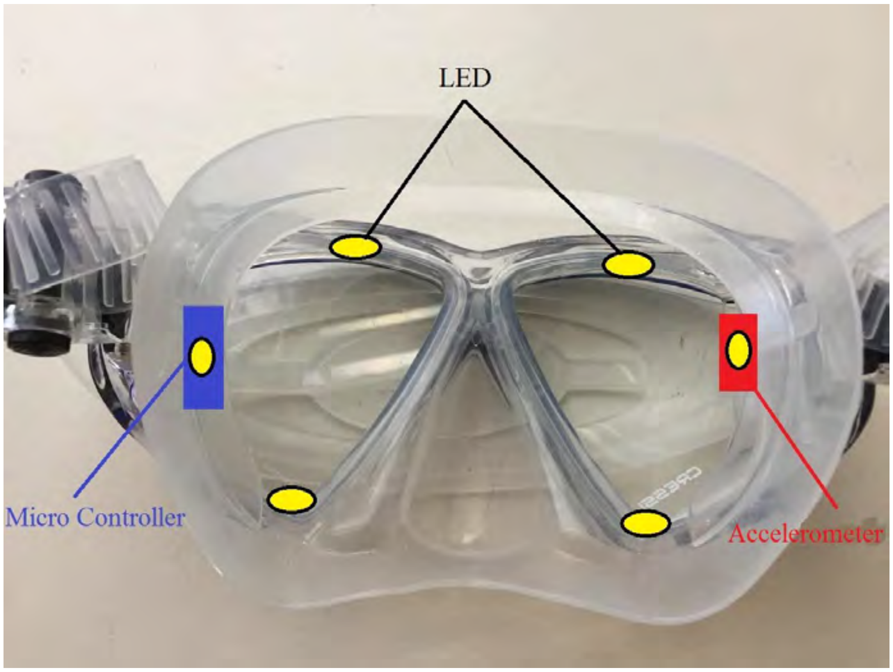


Figure 12: Preliminary Proposed Design

The Display has been updated from 4 RGB LED's to 6 RGB LED's around the device. This was changed due to the amount of sensors decreasing. As mentioned in the design alternative section, the microcontroller chosen, the Adafruit Metro Mini, has 14 output pins and 6 input pins. The accelerometer is using 2 Input pins. This means there are 14 output pins and 4 input pins remaining. The input pins can also be converted to output pins if need be. This leaves 18 output pins. Since each LED needs 3 output pins, this allows for 6 LED's to be present in the device. This allows for a more precise display of orientation, the focus of the device.

Not shown in Figure 12 are any wires connecting the devices, as well as the power supply. The three coin cell batteries used as a power supply are thought to be small enough to fit in any side area remaining. Even if there is little room, the batteries are thin enough, at 0.2”, to overlap the accelerometer without creating problems. The wiring for the device is designed to run around the inner rim of the dive goggles. From measuring the thickness of the goggles, there is a 0.2” track for any wires to fit in.

Lastly a method of adhesion has been proposed, but not finalized. Due to the placement of components, a method of adhesion like an epoxy might be dangerous to be close to the eyes alone. At the same time, any method of adhesion that could allow for any components to fall off is more dangerous, as the dive goggles can not be removed while diving. Because of these reasons both an epoxy, and a layer of tape will be used. An epoxy should be strong enough to hold all the components in place, while the layer of tape acts as a secondary method to hold the components in place, as well as a method to insulate any epoxy fumes.

It should be noted that the power supply uses non-rechargeable batteries which should be replaced after each dive. This means that it needs to be possible for the batteries to become removeable. As a result, the method of adhesion will be changed for the power supply to focus on coin cell battery holders, as opposed to the coin cell batteries themselves. These battery holders chosen do not add much to the size of the batteries, and can be seen in Figure 13 below.[31]

Figure 13: 20mm Coin Cell Battery Holders

Now that all the components are chosen, a parts list is created. The parts list can be seen in Table 8 below. The initial upper limit for the price of the device was set at 75.00$. This was thought to be the maximum amount the price can be to not be too expensive to work along with another device, the dive computers. As seen in Table 8, the total cost of the preliminary design is 46.50$, with a recurring cost of 4.00$ for batteries. This falls below the 75.00 price point, even after five dives.

Table 8: Parts List of Preliminary Design

Part	# of Units	Total Unit Price
Adafruit Metro Mini	1	12.50$
Accelerometer LSM303	1	15.00$
Rectangular RGB LED’s	10	6.00$
20mm Coin Cell Batteries	3	4.00$
20mm Battery Holders	3	9.00$
Total Price	1	46.50$

6. Final Design and Implementation

Due to a variety of factors there were several changes between the preliminary design and the final design. The display method, the power supply, and an adhesion method were all changed. Similarly the method of calculating orientation and time were updated, and the method for calculating acceleration was scrapped. The final implemented circuit can be seen below in Figure 14.

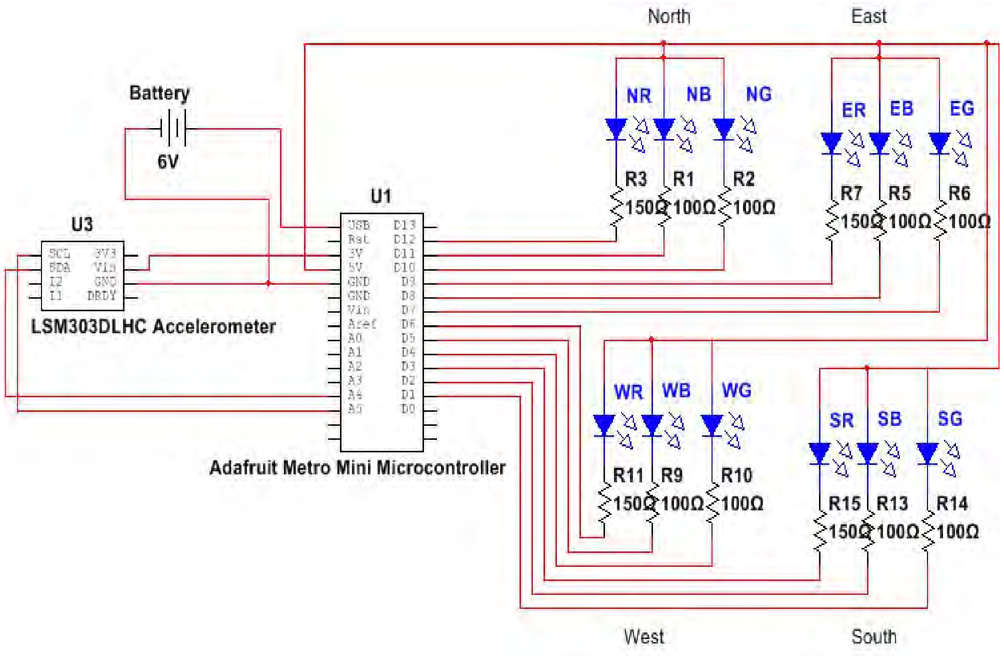


Figure 14: Final Implemented Circuit

6.1 Display Method

Originally the display method consisted of 4-6 multicolored LED's placed around the device. Multicolored LED's were chosen as they could display three different values using separate functions. Orientation could be displayed by whether the LED was on, acceleration would be displayed by having the LED blink, and time remaining would be displayed through the color of the LED.

While this generally remained the same in the final design, some small changes were made. First only 4 LED's were chosen. The benefits of having an extra 2 LED's were a higher precision in orientation. This was later replaced by having the LED's change in brightness based on a more precise measurement of orientation discussed later in the subsection 6.4. Since the LED's now varied in brightness, this would make the extra 2 LED's make the display method more complex and confusing. Similarly, as seen in Figure 14 above, there were only so many digital output pins remaining on the microcontroller. While there were some analog pins remaining, there were not enough to fully add on two more LED's which each require three pins.

Lastly resistors were added on each of the three colored LED’s for the four multicolored LED’s. These resistors limited the current flowing into the LED’s. To calculate the resistance for each of the different colored LED’s equation 4, based on Ohms law, found below was used:

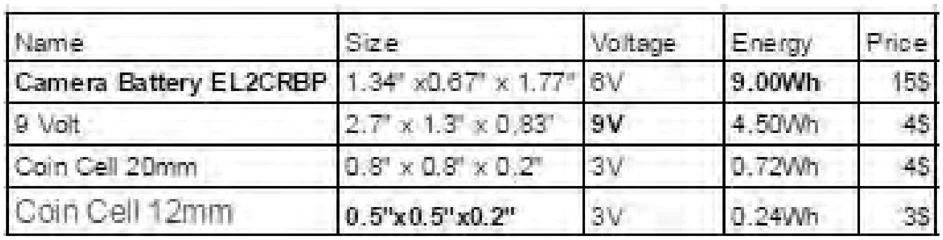
$$R = \frac{(V - V\,LED)}{I} \tag{4}$$

In the above equation, V represents the source voltage, which in this case is 5V, V_{LED} is the forward voltage for each of the LED’s, and I is the required current. The forward voltage for each LED’s depends on the color of each of the LED’s. The red LED has a forward voltage of 2.0V, while the blue and green LED’s both have a forward voltage of 3.2V. The current used in all three cases was 20mA. After inputting these values, the resistor for the red LED was found to be 150Ω, and the blue and green LED’s were found to be 90Ω. The resistor values for the blue and green LED’s were then increased to be 100Ω to limit the current slightly more. The forward voltages and recommended current values were all found using the LED datasheet provided by the manufacturer.[32]

6.2 Power Supply

Initially the power supply chosen was a series of three 20mm coin cell batteries. After testing this power supply, the device only lasted at most 30 minutes, which is considerably less than what is required from the device. At this point the energy needed from a power supply was recalculated using equation 4 above. The power used by all the components was found to be 900mW from the microcontroller, 120mW from the LED’s, and 0.3mW from the accelerometer. Assuming a time of one hour, this results in the device using 1.02Wh. Using this value as a benchmark, the rechargeable battery packs were replaced with 6V camera batteries and a decision matrix was remade. This can be seen in Table 9 below.

Table 9: Remade Decision Matrix for Power Supply



Name	Size	Voltage	Energy	Price
Camera Battery EL2CRBP	1.34" x0.67" x 1.77"	6V	**9.00Wh**	15$
9 Volt	2.7" x 1.3" x 0.83"	**9V**	4.50Wh	4$
Coin Cell 20mm	0.8" x 0.8" x 0.2"	3V	0.72Wh	4$
Coin Cell 12mm	**0.5"x0.5"x0.2"**	3V	0.24Wh	3$

While the newly added camera battery was much bigger than the others, the energy supplied by the battery was much greater than the other options. After measuring the dive mask, an area of 1.5”x2.0” was available if the battery was placed on top of either the microcontroller or the accelerometer. The problem with the power supply is its thickness at 0.67”, making it slightly peek out of the corner of the dive mask. This was seen as a necessary tradeoff as the device should now last several hour and a half long dives. After testing this power supply, the device was capable of lasting eight and a half hours. The battery chosen can be seen in Figure 15 below.

Figure 15:Final Chosen Power Supply-6V Camera Battery EL2CRB

6.3 Adhesion Method

Initially an adhesion method was not chosen in the preliminary design. Similarly to how all the other components of the device were chosen, a decision matrix was created to compare several methods of adhesion. This can be seen in Table 10 below.

Table 10:Decision Matrix for Adhesion Methods

Name	Method	Strength	Harmful to eyes	Price	Waterproof
3M DP-270 BLACK	Potting	Strong	Yes	18$	Yes
Electrical Tape	Tape	Weak	**No**	**2$**	As long as it stays on
Dow Corning Silicone Sealent	**Potting**	**Strong**	**No**	26.30$	**Yes**
Superglue Tape	Tape	Weak	**No**	8$	As long as it stays on
Loctite Silicone Adhesive	Epoxy	Strong	Semi	24$	Yes

When picking an adhesion method there were three main factors. First whatever method used needed to be safe when near the eyes. As the device is meant to be used while diving, any substance present in the device needed to not cause any eye strain be it through any chemical reaction or otherwise.

Next the device needed to be firmly in place. Since the material of the dive mask where all the components needed to be was silicone, any adhesion method needed to be able to fully stick to silicone. The best material to stick to silicone, is a silicone based adhesive so a majority of the methods chosen, were silicone based.

Lastly, the device needed to be fully waterproof. Several different methods were considered in adhesion methods, but only a potting method would fully make the device waterproof. A potting method would fully encase all the components in silicone, making it impossible to access the components, but also make it impossible for water to enter the device. After comparing several methods seen in Table 10 above, the Dow Corning Silicone sealant was chosen. This sealant can be seen below in Figure 16.

Figure 16: Adhesion Method Chosen-Dow Corning Silicone Sealant

6.4 Orientation Method

While the method of detecting orientation was determined in the preliminary design, the actual method was not. After deciding on only using four LED's, linking the orientation with the display was determined. It was decided that each LED would represent one of the four cardinal directions, north, south, east, and west, and that the display will represent a 2d plane for the X and Y directions. This means that the device would be working on a 2D plane parallel to the user, where the user's up, down, left and right, correspond to the north, south, west, and east LED's. To display the Z direction, if the user is facing directly at or away from the surface of the water, meaning the x-y plane of the LED's is perpendicular to the direction of the surface, all four LED's are either on, if facing towards the surface, or off, if facing away.

Mathematically the device determines the direction based on the readings from the accelerometer. The accelerometer consists of three separate accelerometers, for the x direction, the y direction, and the z direction. Assuming that the acceleration of gravity is larger than any other source of acceleration by a large amount at 9.8 m/s^2, the three accelerometers each detect a portion of this value. Since the display runs on a 2d plane of LED's corresponding to the x and y direction, two methods of detecting orientation are used.

The first method is used for the z direction. When the device detects that the user is either facing directly at or against the surface, meaning when the surface is found to be mainly in the z direction, all LED's are either on or off. Since this overrides the x and y display, the device needs to be completely sure that the user is facing so that the mask is perpendicular to the surface. As a result, the device uses solely the magnitude of the Z direction accelerometer to determine this. If the Z direction accelerometer detects an acceleration magnitude of at least 8 m/s^2, the device determines that the user is facing towards or away from the surface. A value of 8 m/s^2 is chosen as it is roughly 80% of the acceleration of gravity. This is high enough to be much higher than the x and y acceleration components of gravity. While going in this direction the diver is usually solely going in the z direction for ascension or descension. This makes it less important for the diver to know their relative x and y components as long as they know which way the surface is.

For the x and y components of orientation, the display method allows for a more analog display. Due to the method of determining the z direction being based solely on magnitude, it is assumed that if the z direction is not detected, the user is not going in the z direction. This simplifies the remaining directions to only two accelerometers, one in the x direction, and one in the y, with four LED's to display direction. To determine the orientation of the device on this 2d plane, an angle between the two magnitudes acquired from the x and y accelerometers is used. This angle is the inversetan relation between the x and y acceleration magnitudes. This angle is then used to relate the x and y acceleration values. An angle of 90° suggests that the device detects the surface to be in the x direction, while an angle of 0° suggests that the device detects the surface to be in the y direction. Depending on whether the acceleration values measured are positive or negative, an accurate direction of where the surface is on the x y plane can be found. In order to display a value between the cardinal directions, the LED's vary in brightness depending on the angle. This can be seen in Figure 17 below.

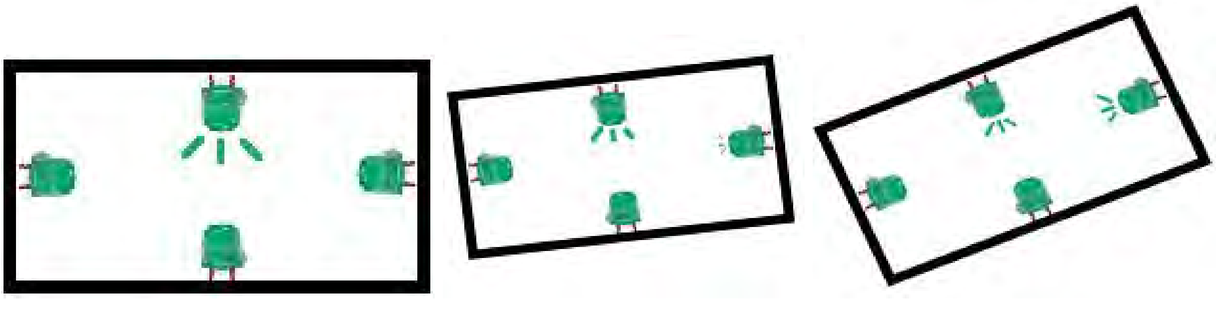


Figure 17: Example of X-Y Orientation LED Display at 90°, 70°, and 45°

The brightness of the LED's in Figure 17 above is depicted by the lengths of the green lines coming out of the LED's. In the first case, when the device is at a 90°, the north LED is fully as bright as it can be. In the middle image, at 70°, the north LED begins to dim, while the eastern LED begins to illuminate at. In the last image the device is at 45°, meaning the surface is equally in the north and east directions. This means that the brightness of the north and east LED's are the same. The actual calculation of the brightness used in the code, found in the appendix at the end of the report, allows for 15° where only one LED is on. This means if the angle between the x and y magnitudes is between -15° and 15° only the north or south LED is on. Similarly if the angle is between 75° and 105°, where only the east or west LED is on. This is depicted for the y and x direction LED's in Figure 18 below.

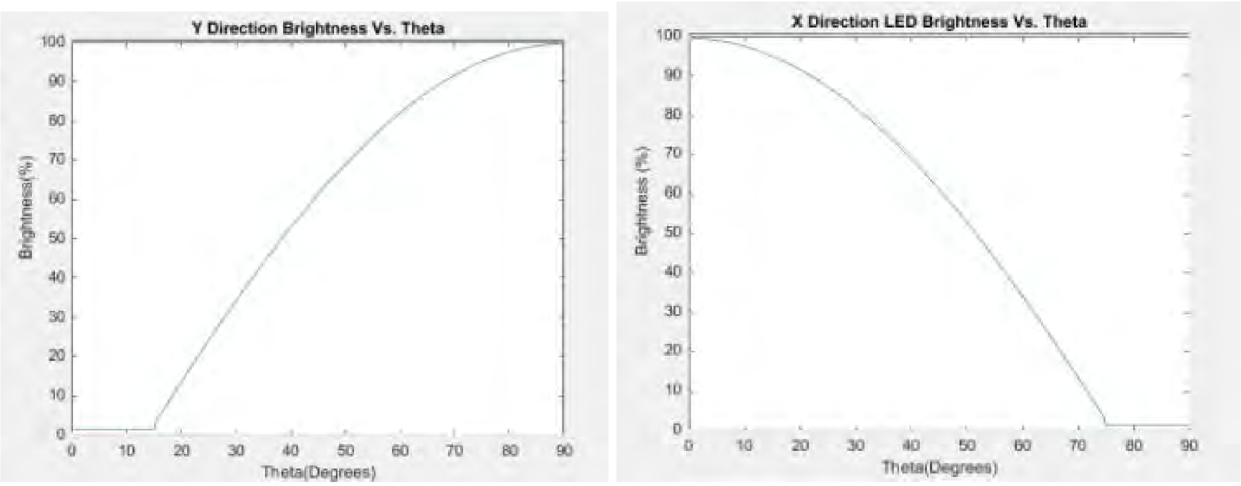


Figure 18:Brightness of the Y and X direction LED's Based on Angle

6.5 Time Method

While the method for determining time was always based on the internal clock of the microcontroller, the method has been refined. Time was used to determine the amount of oxygen remaining for the diver. By having a general understanding of the length of the dive in relation to the amount of oxygen left, by just keeping track of the time of the dive, an estimate on the oxygen remaining can be found. In this case, the device is set for one hour dives.

The color of the LED's then represent the amount of time remaining. For the first thirty minutes of the dive, whatever LED is on, based on the orientation reading discussed in subsection 6.3 above, will be green. The next fifteen minutes will have the LED be yellow, a combination of the red and green

LED's. Once the timer reaches 45 minutes, the LED's will be red and begin to blink for 6 seconds. This repeats every five minutes. Since the device is supposed to work in tandem with the device, the blinking is supposed to warn the user and have them manually check either their dive watch or the oxygen tank itself for a more accurate idea of the oxygen remaining.

6.6 Acceleration Method

The preliminary design of the device had the accelerometer measure both orientation, and acceleration. The initial idea was that the device would warn the user if they are accelerating too quickly. This implies that there is a constant acceleration number that can be used as a cutoff acceleration. In reality the maximum acceleration heavily depends on the depth the user is at, and how long the user has been at the depth. This can be seen in Figure 19 below.

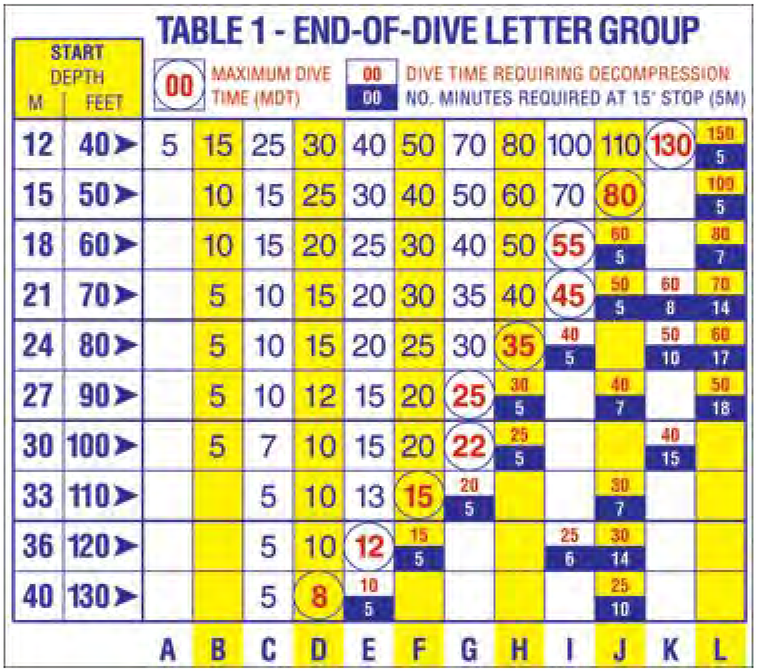


TABLE 1 - END-OF-DIVE LETTER GROUP

00 MAXIMUM DIVE TIME (MDT)

00 / 00 DIVE TIME REQUIRING DECOMPRESSION / NO. MINUTES REQUIRED AT 15' STOP (5M)

START DEPTH M	FEET												
12	40➤	5	15	25	30	40	50	70	80	100	110	130	150 5
15	50➤		10	15	25	30	40	50	60	70	80		100 5
18	60➤		10	15	20	25	30	40	50	55	60 5		80 7
21	70➤		5	10	15	20	30	35	40	45	50 5	60 8	70 14
24	80➤		5	10	15	20	25	30	35	40 5		50 10	60 17
27	90➤		5	10	12	15	20	25	30 5		40 7		50 18
30	100➤		5	7	10	15	20	22	25 5			40 15	
33	110➤			5	10	13	15	20 5			30 7		
36	120➤			5	10	12	15 5			25 6	30 14		
40	130➤			5	8	10 5					25 10		
		A	B	C	D	E	F	G	H	I	J	K	L

Figure 19: Dive Table[33]

From the dive table, the left hand column depicts the depth the user is at. The red number in the circle is the maximum amount of time in minutes the diver should be at that depth. The number on the far right in blue is the amount of time the diver should stop and the number above is the amount of time the diver needs to be at the certain dive level before they need to worry about decompression sickness. The other numbers in the middle are the minimum minutes spent traveling between the depths.

The amount of minutes in each of the cases thus heavily depends on depth. Since the device does not have a depth sensor, an accurate amount of time between depths is difficult to acquire, and can only be found using the accelerometer by constantly keeping track of the vertical acceleration and extrapolating a depth from those values. The amount of time between zones at minimum is 5 minutes between 3m. This would result in a minimum change of 0.6 m/min. Since the precision of the accelerometer is 0.01 m/s^2, accurately taking the derivative of the acceleration to acquire a velocity near that minimum change would be impossible as the minimum acceleration detected would result in a velocity higher than the minimum needed dangerous velocity over the full five minutes. As a result the current method can not thoroughly warn the user if they are accelerating too quickly and was not implemented into the device.

7. Performance Estimates and Results

This section will discuss the overall performance of the device based on whether or not the device fit within the design specifications mentioned in Table 1 above, depth, time, size, visibility, price, weight, and precision for the preliminary design and final design. Then the final designs performance will be determined based on how well the device achieved its three functions of measuring orientation, acceleration, and time. Any testing will be discussed followed by any improvements needed.

7.1 Preliminary Design

The main differences between the preliminary design and the final design are the power supply changes and the display changes. The preliminary design initially used 3 20mm coin cell batteries as a power supply and 6 RGB LED’s as a display while the final design uses a 6V camera battery and 4 LED’s.

For the requirement of time, this means that the preliminary design used significantly more energy, on a much smaller power supply. As a result the device failed to reach its minimum 1 hour time limit, only reaching a maximum of 30 minutes. As for size and visibility, all components did fit inside the dive goggles, and only mildly inhibited visibility as a permanent adhesion method was not yet determined.

For a price point, the device was 45$, which is under the 75$ limit. As for weight, since the adhesive method was not fully applied, the weight of the device is not final, but it can be assumed to be well under the 50g limit as the microcontroller weighs 3g, the accelerometer weighs 1.5g, each LED weighs 0.3g, and the coin cell batteries each weighs 4g. This results in a total weight of 18g well under the 50g limit. Lastly, depth was not tested so no conclusion can be said for this requirement.

7.2 Final Design

Due to a change in power supply, the time requirement, which was not fulfilled in the preliminary design, was fully achieved in the final design at over eight hours of battery life. This did have a trade off, as the camera battery used was much larger than the coin cell batteries in the preliminary design. The new batteries dimensions are 1.77”x1.34”x0.67”. While the battery did fit in the corner of the device, the 0.67” thickness did hamper visibility slightly. Even with the wide battery, all the components did manage to fit in the dive mask.

As for price, the price of the new battery is equivalent to the price of the three coin cell batteries and battery holders resulting in a final price point of around 45$. Including the adhesion method, the price point then becomes 71.2$ which is still under the 75$ limit. As for weight, the camera battery is much heavier at 44g. Not including the adhesion, this brings the weight of the device to just below 50g. With the adhesive method the device falls between the 100g and 50g weight limits. It is with great regret that this device never was fully tested underwater and no conclusion on the depth requirement could be made.

As for the functional requirements, the final device was required to measure orientation, acceleration, and oxygen remaining through time. For orientation, the device can provide an analog display if the user is not facing directly at the surface or away from the surface and can provide a digital display if they are facing towards or away from the surface. Considering the device is limited to only 4 LED's, the precision of the orientation reading is exactly what was wanted. The accuracy of the reading is discussed in the following section which discusses the testing methods used.

As for acceleration, the device could not provide an accurate warning due to the reasons discussed in subsection 6.5 above. It was found that the acceleration limits needed were heavily dependent on depth, something the device could not measure. Similarly, the minimum acceleration needed to cause decompression sickness was found to be too small for the accelerometer chosen to perceive.

The measurement of oxygen remaining was always designed to be vague as it was dependent on time. For the device to display oxygen remaining, the device needed to accurately display time remaining. In this case, the device is always set for a one hour dive. This in it of itself is a limitation, and a more customizable time interface is definitely a useful feature for the future of this device. Currently the device depicts time using three colors of LED, green for the first half of the dive, yellow for the third quarter of the dive, and red for the last quarter of the dive. Also during the last quarter of the dive the device blinks for six seconds, every five minutes to alert the user they are running out of time in a second manner. Since the device clearly has a method of alerting the user when they are running out of time, the device successfully displays a vague amount of oxygen remaining to the user.

7.3 Testing

The device was tested in two methods. The power supply and the method of displaying time were both tested in a similar manner, the device was left on for a long period of time. The amount of time the battery lasted was then recorded with all four LED's on. Similarly, the color of the LED was kept track of over the course of the testing. If the LED was any color other than green for the first thirty minutes, yellow for the next 15, and red for the last 15 minutes the code was altered.

The second method of testing involved testing the orientation sensor. In this method of testing the accelerometer was placed on a protractor on a flat surface, first horizontal, and then vertical. The accelerometer was then rotated 5°**.** Every 5° the accelerometer readings from all three accelerometers were taken as well as the angle of the device. By comparing the accelerometer values with the ideal values based on the angle and the acceleration of gravity, the x-y angle and the angle between the x axis and z axis, called the angle of elevation, were tested. These data sets were then put into a line of best fit and compared with the ideal angle values. The x-y angle analysis can be seen in Figure 20 below.

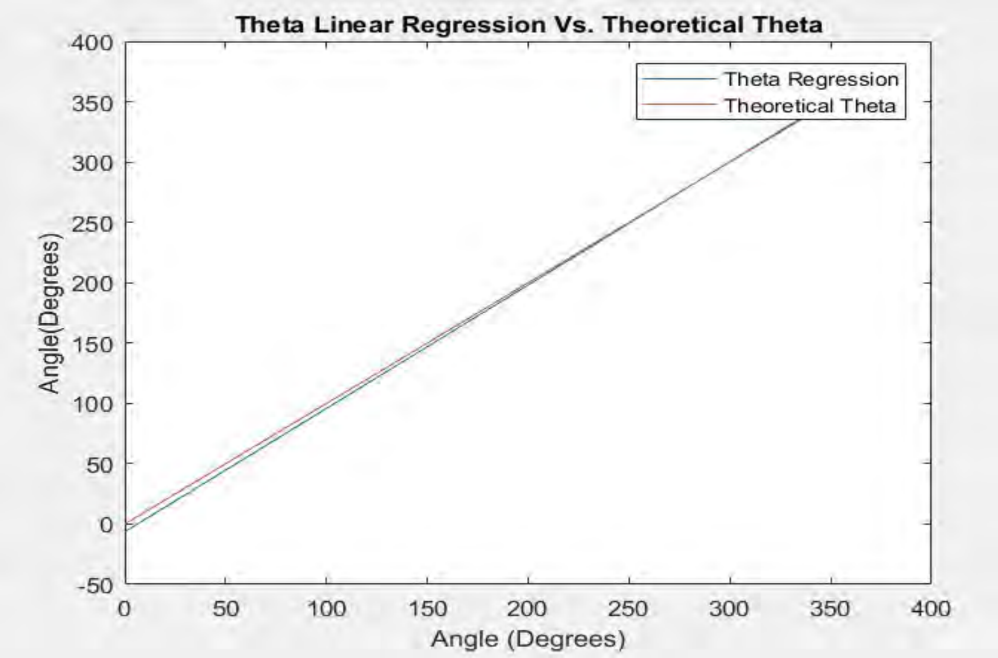


Figure 20: x-y Angle Analysis Using Linear Regression y = 1.0226x -6.4

Looking at Figure 20 above, the blue line represents the actual data, while the red line is the theoretical. This angle is used in determining the relation between the x and y acceleration magnitudes and is important in determining the brightness of the LED's. The closer the red and blue lines are the better. The standard deviation of the x-y angle is found to be 2.3° meaning there is a 2.3° margin of error in the x-y value. This value was acquired by averaging three trials. The data can be seen in the appendix below. The same process was done for the angle of elevation between the x and z axis seen in Figure 21 below.

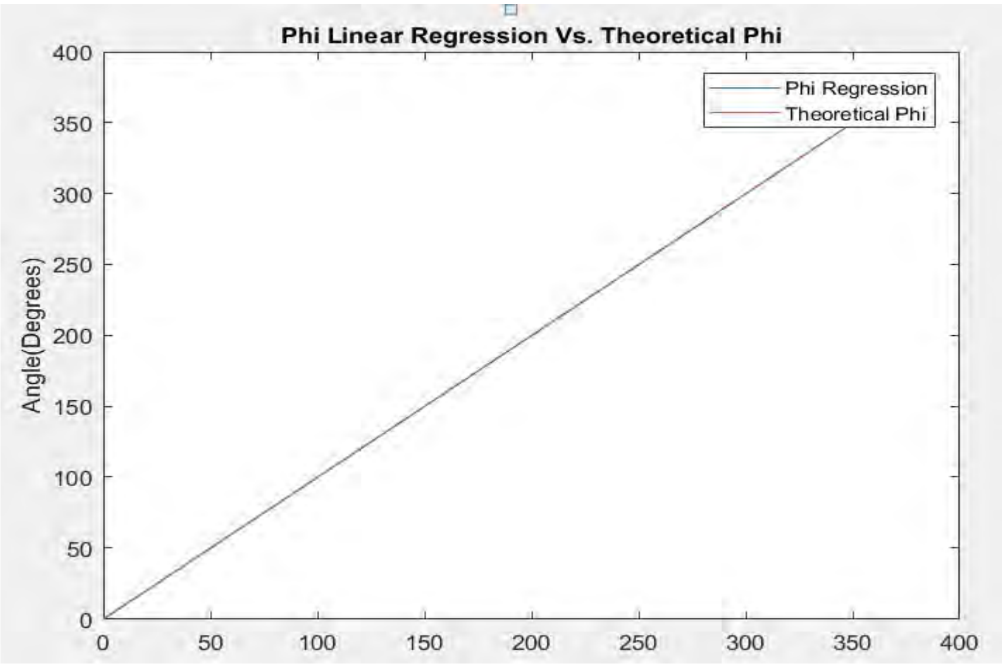


Figure 21: x-z Angle Analysis Using Linear Regression y=1.0002x -0.431

While the angle of elevation was not used, the data for this angle was even more accurate than the x-y angle. It is difficult to see that there are two lines in Figure 21, a testament to how accurate the reading is. The standard deviation for this angle is found to be 0.2° meaning there is only a 0.2° difference on average between the angle of elevation measured and the actual angle of elevation.

7.4 Improvements

Besides the improvements of underwater testing, there are some additional features that would greatly improve the design. First, as mentioned in section 7.2, the time display is set to be for one hour dives. The device should be usable for any length of dive. Since the device is locked in due to the adhesion method, a wireless add on to the device that would make it programable would be a valuable addition to the device.

Since the device can be programmed on land before the dive, any issued involving wireless signals communicating underwater can be avoided.

Next, and perhaps a bigger issue, the device currently is inaccessible and has a non-rechargeable battery. This means the device is only good for eight hours of diving before it is functionally useless. A power supply that can be charged through the silicone sealant, through induction, would greatly increase the lifespan of the device. By making the device rechargeable, the price point of the device would become more reasonable allowing for a much more marketable device.

Lastly the addition of a depth sensor as well as a more precise accelerometer would be needed to add the functionality of warning the user if they are accelerating too quickly. While this was a feature proposed in the initial design, adding the programmable time and rechargeable battery would be much more beneficial additions to the device.

8. Project Schedule

At the end of march of 2017 a 20 week project schedule was created. This schedule was created halfway through the schedule at week 10 and can be seen in Table 11 below.

Table 11: Preliminary Project Schedule

Week	What Was Planned
Weeks 1-4 (January 2017)	Choose an idea
Weeks 5-8 (February 2017)	Finalize Preliminary Design
Weeks 9-10 (March 2017)	Order Preliminary Design Equipment Create Preliminary Design Presentation Create Preliminary Design Report
Weeks 11-12 (March 27th -April 7th)	Create a prototype
Weeks 13-14 (April 8th - April 21st)	Assemble onto Dive Mask
Weeks 15-16 (April 22nd - May 1st)	Underwater Testing
Weeks 17-18 (May 2nd - May 13th)	Create User Interface to Input Time
Weeks 19-20 (May 14th - June 1st)	Create Final Design Presentation Create Final Design Report

In hindsight this schedule was both optimistic and incomplete, providing no time for any testing before a prototype was created. Similarly, this schedule did not provide any time for any changes in the design in case the preliminary design failed in any way. As a result of this, the actual project schedule, which can be seen in Table 12 below, is fairly different. Since the preliminary project schedule was created in week 10, weeks 1-10 were accurate and were not put in Table 12, as the information would be the same as in Table 11.

Table 12: Actual Project Schedule

Week	What Was Planned
Weeks 1-10	See Table 11
Week 11 (March 27th-April 2nd)	Initial Accelerometer-Microcontroller Readings
Week 12(April 2nd - April 9th)	Initial Orientation Implementation
Weeks 13 (April 10th - April 16th)	Adhesion Decision Matrix Time Remaining Implementation
Week 14 (April 17th - April 23rd)	Orientation Sensor Testing
Weeks 15 (April 24rth - April 30th)	Orientation Sensor Analysis Power Supply Test
Weeks 16-17 (May 1st - May 14th)	Orientation Sensor Analysis Power Supply Decision Matrix Display Testing Create Initial Prototype
Week 18 (May 15th - May 22nd)	Create Final Design Presentation Time Remaining Implementation
Week 19 (May 23rd - May 29th)	Nothing-Sick
Week 20 (May 30th - June 5th)	Create Final Design Report

As can be seen in Table 12, the initial prototype was only created during week 17, while the initial project schedule had it created in week 12. That was due to a variety of reasons. First it took several weeks to become comfortable enough with linking the accelerometer with the microcontroller and understanding the data produced. Once that was done, several weeks of testing the orientation sensor, initially not planned in the first project schedule were done. This provided valuable information in creating a more precise orientation display that was not originally envisioned at the time of the creation of the preliminary project schedule.

After the orientation sensor testing, the power supply was tested. This slowed down the project the most, as the power supply in the preliminary design was found to not be a valid option. After the new power supply was chosen, it was only until week 19 when all the components of the project were together. It was also at this time that work on the project was put on hold due to sickness for a full week. Around these weeks, presentations and final reports were needed, which required a significant amount of time to create. While the final project timeline accomplished much less than the original preliminary project timeline, the extra testing done was a very necessary component in creating a successful design.

9. Cost Analysis

While no budget was ever fully established, a soft goal of 75$ for a design was set as a design requirement. This did not include the price of the dive goggles. A total cost analysis for all the components ordered in this project can be seen in Table 13 below.

Table 13:Cost Analysis of All Components Bought

Component	Number Ordered	Unit Price	Total Price
Metro Mini Microcontroller	2	12.50$	25$
LSM303 Microcontroller	1	14.95$	14.95$
Cressi Dive Mask	1	24.99$	24.99$
Rectangular RGB LED	10	0.595$	5.95$
20mm Coin Cell Batteries	10	0.578$	5.78$
20mm Coin Cell Battery Holders	3	2.95$	8.85$
6V Camera Battery EL2CRBP	3	15$	45$
Silicone Sealant	1	26.30$	26.30$
Total Price			156.82$

It should be noted that no formal SRG budget request was submitted. Most of the cost of the components was subsidised by the ECE department. Only the dive mask, accelerometer, and one of the two microcontrollers purchased were not bought by the ECE department. While the total price spent during the entire project was 156.82$, the price per prototype, consisting of a microcontroller, dive mask, accelerometer, 4 LED’s, and a 6v battery is only 69.82$. This price should be increased dependent on the amount of silicone sealant used. The amount purchased should be enough for several electronic dive masks.

10. User Manual

Assuming the device is already put assembled and the current Arduino code, found in the appendix below, is already loaded onto the device, the operation of the device can be seen below. It should be noted that there is a small push button on the completed device used to turn the device on and off. This button is not mentioned in above, and is an addition to the finished design.

1. Inspect the device for any openings in the sealant. If there appears to be any cracks in the silicone sealant or openings for water to contact any of the components, the device is faulty and should not be used.
2. Assuming the device is waterproof, the device should be ready for use. Press the small push button on the left side of the device, under the silicone sealant. The device should turn on, shown by at least one LED turning on.
3. Once the dive mask is turned on, place the device on the diver's head, just like any dive mask.
4. To ensure that the device is working correctly, notice which LED’s are on. The LED that is on should be in the direction of either the surface if under water, or the sky if on land. When facing forward, the top LED should be on and green. When looking straight up, all four LED’s should be on. When turned more than 15° clockwise or counterclockwise, both the top LED and either the left or right LED’s should be on, all green.

5. As soon as the device is turned on, it is assumed that a one hour dive has begun. To reset the dive, push the button located on the left hand side of the device twice to turn the device off and on again.
6. Once the device has been tested, it can be used for a full dive. After 30 minutes, all of the LED’s that should be on, should be yellow. Similarly at 45 minutes, all of the LED’s on should be red. At the 45 minute mark, whatever LED is on should blink for six seconds. This should occur at every 5 minute interval passed the 45 minute mark and is used as a warning that the one hour allotted time is coming to an end.
7. If the device blinks when the LED’s are green or yellow, or for longer than six seconds when red, the device’s power supply is running low. This should occur after eight hours of the device being on. At this time the device should not be used.
8. If at any point the silicone sealant begins to crack, any connections appear to be loose, or the power supply shows signs of running low, dispose of the device. Due to the potting method of waterproofing and adhesion the device, accessing any of the components is difficult and should not be done.

11. Discussion, Conclusions, and Recommendations

11.1 Discussion

The purpose of this device was to provide additional information either not found on a current dive watch or computer or information that could be useful to be constantly displayed inside a dive mask. This was in order to mitigate the top five risks of diving, dangerous marine life, pulmonary embolism, nitrogen narcosis, asphyxiation, and faulty equipment. Specifically the device is set to combat nitrogen narcosis,disorientation, with a constant display of which way the surface is, pulmonary embolism by warning the user if they are accelerating too quickly, and asphyxiation by providing a constant display of time remaining in a dive. The device also helps against faulty equipment by providing another source of information.

For the final design, the device successfully displays the user’s orientation, combatting against nitrogen narcosis, and warns the user of the time remaining in their dive, combatting against asphyxiation. This extra amount of information thus also helps against the risk of faulty equipment. The only two risks the device do not mitigate is pulmonary embolism, as the current design could not provide a reasonable method of detecting if the diver is accelerating too quickly, and dangerous marine life.

11.2 Conclusion

The current finished product was never fully assembled and tested under water so no complete conclusion can be made about the effectiveness of the device. On land the device does successfully provide a clear and precise display of orientation as well as providing a general understanding of the time remaining in a one hour dive. While it is important for the device to be able to work on land, the risks of diving are not a concern outside of the water. While there is little reason to believe that this device will not work underwater, without testing it is impossible to know for sure. As for the other design requirements, the device did manage to fit into a dive mask, proving that it is possible to fit the necessary equipment to create an electronic dive mask inside of the dive mask itself. While visibility was slightly impacted, with a slightly bigger dive mask, the visibility problem be mitigated.

11.3 Recommendations

The major problem in the creation of the device was time. As can be seen in the project schedule section above, the proposed project schedule and the actual project schedule differed greatly. This was mainly due to no time being allotted for rigorous testing of the device. At the same time, this testing was proven necessary as it allowed for a much more accurate display of orientation, the key feature of the device, as well as shed light on the problems with the proposed power supply. It also did not help that the last couple of weeks available in the project were taken up by sickness and reports.

Given more time, a fully completed waterproof prototype of the device could be created and a clear conclusion on whether the device works in its desired environment could be determined. Other than more time for testing, more time should have been put into researching the causes of pulmonary embolism for divers. With further research it could have been found that the vertical acceleration limits are much more complicated than initially thought, and perhaps an additional sensor could have been added to the preliminary design. It was determined that a depth sensor would not be possible to add into the device due to the pressure inside the dive mask, so perhaps it is too difficult to detect acceleration using only sensors inside the dive mask. Depth and acceleration are two features found in most dive watches and computers, making this feature less important compared to the orientation feature not covered by the current dive equipment.

11.4 Future work

Aside from what was mentioned in the recommendation section, there are two necessary add ons for a device like this to be much more beneficial as a piece of diving equipment. First, not all dives are one hour long. A method or programming how long the specific dive will be can be seen as a necessity. In order to program a specific time, the device locked away in a silicon shell needs to be accessible somehow. This can be done using a wireless receiver on the device. The device can then be accessed through the adhesion method, possibly through a phone app, and the time can then be customized. Similarly this could allow for other smaller features to be added, like LED color if the user is color blind, or the frequency of the warnings when the user is running out of time.

Besides improving on the time remaining function of the device, improving on the devices power supply is important. Currently the device is disposable, only meant to be used for four to six dives. Once the power supply runs out, it can not be replaced due to the adhesion method. This can be solved by using a rechargeable battery that charges through contact. By charging the battery through induction, the device can be used for much more than six dives. While the wireless addon and the different power supply would increase the price of the device, the added functionality and reusability would make it much more cost effective, as opposed to the current disposable device.

11.5 Lessons Learned

As can be seen in the recommendation subsection, the biggest lesson learned is that a project like this takes time. Not only does it take time to physically work on the device, but it takes time to order new components. This time could have been saved with proper planning, ultimately saving a couple weeks of time. Besides proper planning, proper testing is equally as important. There is no way to fully foresee any complications between the preliminary design and the final design without fully testing all aspects of the preliminary design. As a result it is impossible to state with confidence that the device will work fully underwater as it has not been tested underwater.

Besides time, it is important to set proper design specifications and requirements before working on the design. While the device did meet almost all requirements stated, besides vertical acceleration and underwater testing, there are still some glaring flaws in the design. Mainly the power supply greatly limits the functionality of the device. While the device does work for the specified hour and a half, a device like this that only works for a small amount of dives is effectively inadequate as a marketable safety device. By setting stronger design requirements the overall quality of the device could be greatly improved. Overall the experience is rewarding, even with the complications.

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Appendix

A.Orientation Testing

X-Y angle testing. Device held vertically rotating counter clockwise

Angle(degrees)	X(m/s^2)	Y(m/s^2)	Z(m/s^2)
0	-10.32	0.08	-0.82
5	-10.36	0.55	-0.82
10	-10.24	1.06	0.78
15	-10.28	1.69	0.82
20	-10.08	2.43	0.82
25	-9.85	3.22	0.9
30	-9.53	4.12	0.75
35	-8.87	5.33	0.67
40	-8.67	5.81	0.78
45	-7.81	6.75	0.67
50	-7.65	7.02	0.71
55	-7.26	7.49	0.51
60	-6.47	8.08	0.75
65	-5.45	8.75	0.55
70	-4.59	9.34	0.51
75	-3.73	9.61	0.55
80	-3.02	9.85	0.51
85	-2.04	10.04	0.47
90	-0.63	10.2	0.59
95	1.49	10	0.39
100	1.92	10.04	0.43
105	2.43	9.96	-0.39
110	3.18	9.69	0.31
115	3.69	9.45	0.35
120	4	9.34	0.55
125	4.86	9.02	0.2

130	5.26	8.67	0.31
135	6.59	7.61	0.2
140	7.1	7.14	0.39
145	7.77	6.39	0.04
150	8.47	5.53	0.04
155	8.79	4.82	0.8
160	9.26	3.69	0.2
165	9.77	3.1	0.35
170	9.61	2.59	0.08
175	9.73	2.16	-0.12
180	9.53	-0.08	0.31
185	9.69	-2.24	0.04
190	9.53	-2.47	0.04
195	9.49	-2.9	-0.04
200	9.3	-3.41	-0.04
205	8.98	-4.28	0
210	8.63	-4.79	-0.04
215	8.32	-5.65	0.2
220	7.88	-5.88	-0.04
225	7.45	-6.32	0.16
230	7.06	-6.98	0.12
235	6.28	-7.57	-0.47
240	5.65	-8	-0.43
245	5.06	-8.39	-0.35
250	4.43	-8.9	-0.31
255	3.73	-9.22	-0.12
260	2.82	-9.45	0
265	1.57	-9.77	0.27
270	0.04	-10.08	0.39
275	-2.12	-9.85	0.47
280	-2.51	-9.69	0.47
285	-2.98	-9.57	0.51
290	-3.45	-9.49	0.51
295	-4.24	-9.14	0.59

300	-5.22	-8.63	0.59
305	-6	-8.16	0.47
310	-6.55	-7.61	0.55
315	-7.22	-7.14	0.71
320	-7.85	-6.43	0.67
325	-8.47	-5.57	0.67
330	-8.83	-5.06	0.67
335	-9.41	-3.92	0.75
340	-9.85	-2.9	0.67
345	-10.08	-1.88	0.75
350	-10.2	-0.98	0.67
355	-10.28	-0.43	0.65
360	-10.28	0.59	0.75

Angle of elevation testing between x and z axis. Device held horizontally and rotated counter clockwise

Angle(degrees)	X(m/s^2)	Z(m/s^2)	Y(m/s^2)
0	-10.32	0.08	-0.77
5	-10.24	0.56	-0.81
10	-10.32	1.01	0.74
15	-9.85	1.81	0.77
20	-9.65	2.26	0.81
25	-8.98	2.93	0.84
30	-8.71	3.96	0.73
35	-8.65	5.53	0.63
40	-8.14	5.98	0.80
45	-7.76	6.51	0.63
50	-7.24	6.71	0.78
55	-6.68	6.79	0.54
60	-5.98	7.32	0.72
65	-4.95	8.34	0.60
70	-4.61	8.98	0.49
75	-3.95	9.06	0.59
80	-3.00	9.14	0.51
85	-1.97	9.65	0.51

90	-0.66	10.24	0.59
95	1.58	9.98	0.40
100	1.89	9.60	0.45
105	2.37	9.29	-0.38
110	3.48	9.04	0.29
115	3.57	9.02	0.32
120	3.90	8.76	0.53
125	4.99	8.32	0.21
130	5.11	7.86	0.33
135	7.01	6.97	0.20
140	7.19	6.39	0.38
145	8.14	5.79	0.04
150	8.46	5.80	0.04
155	8.83	4.85	0.88
160	9.01	3.98	0.21
165	9.33	2.93	0.33
170	9.88	2.36	0.07
175	10.16	1.67	-0.11
180	9.32	-0.07	0.30
185	9.16	-2.29	0.04
190	9.03	-2.45	0.04
195	8.98	-2.77	-0.04
200	8.86	-3.61	-0.04
205	8.72	-4.66	0.00
210	8.03	-4.70	-0.04
215	7.70	-5.16	0.21
220	7.70	-5.64	-0.04
225	6.75	-6.04	0.16
230	6.43	-6.44	0.12
235	5.74	-7.14	-0.50
240	5.17	-7.64	-0.42
245	4.98	-8.13	-0.33
250	4.62	-8.25	-0.33
255	3.81	-8.48	-0.12

260	2.93	-8.51	0.00
265	1.62	-9.45	0.30
270	0.04	-9.89	0.38
275	-1.97	-10.02	0.50
280	-2.67	-9.69	0.51
285	-3.12	-9.57	0.52
290	-3.36	-9.52	0.53
295	-3.85	-9.21	0.62
300	-5.20	-8.66	0.62
305	-6.05	-8.14	0.43
310	-6.68	-7.72	0.58
315	-7.00	-7.14	0.76
320	-8.21	-6.67	0.66
325	-8.31	-5.21	0.70
330	-9.40	-4.40	0.64
335	-9.68	-3.71	0.68
340	-9.81	-2.90	0.62
345	-9.89	-1.73	0.80
350	-10.11	-1.01	0.63
355	-10.13	-0.43	0.70
360	-10.25	0.61	0.80

B.Final Implemented Code

```
#include <Wire.h>
#include <Adafruit_Sensor.h>
#include <Adafruit_LSM303_U.h>


Adafruit_LSM303_Accel_Unified accel = Adafruit_LSM303_Accel_Unified(54321);
Adafruit_LSM303_Mag_Unified mag = Adafruit_LSM303_Mag_Unified(12345);
int Phi;/* Assign an integer to represent the angle between the X and Y plane */
int Time;/* Assign an integer to represent time*/
float AccelX;/* This represents acceleration values for X Y and Z */
float AccelY;
float AccelZ;
char Direction;/* Used to represent whether the user is looking in the Z direction or not*/
char X;/* Used to determine if the device is in the positive or the negative x/y directions */
char Y;
int redEast = 2;/* Assign all the LED's with their respective pins*/
int greenEast = 3;
int blueEast = 1;
int redNorth = 12;
int greenNorth = 11;
int blueNorth = 10;
int redWest = 8;
int greenWest = 5;
int blueWest = 4;
int redSouth = 9;
int greenSouth = 6;
int blueSouth = 7;

long lastDisplayTime;

void setup(void)
{
  Serial.begin(9600);
  Serial.println("LSM303 Calibration"); Serial.println("");

  /* Initialise the accelerometer */
  /* This came with the sample code, used to determine if there is a wiring error */
  if (!accel.begin())
  {
    /* There was a problem detecting the ADXL345 ... check your connections */
    Serial.println("Ooops, no LSM303 detected ... Check your wiring!");
    while (1);
  }
  /* Initialise the magnetometer */
```

```
  if (!mag.begin())
  {
    /* There was a problem detecting the LSM303 ... check your connections */
    Serial.println("Ooops, no LSM303 detected ... Check your wiring!");
    while (1);
  }
  lastDisplayTime = millis();
}

void loop(void)
{
  /* Get a new sensor event */
  sensors_event_t accelEvent;
/* sets up the accelerometer to read acceleration values*/
  accel.getEvent(&accelEvent);
Time = ++Time;/* Increases the Time variable ever millisecond*/
  AccelY = accelEvent.acceleration.x;
  AccelZ = accelEvent.acceleration.y;
  AccelX = accelEvent.acceleration.z;
  /* Sets an acceleration reading to a variable*/
  /* Due to the orientation of the sensor not being the same as during testing, the Y direction on the device
corresponds to the X direction accelerometer */
  /* Z on the device is Y on the accelerometer and X on the device is z on the accelerometer */
  Phi = round( atan2 (AccelX, AccelY));
/* Creates the angle between the X and Y axis using the inverse tan function*/
  if (AccelZ > 8) Direction = 'z';
  /* Determines if the device is going in the Z direction by checking if the magnitude is greater than 8 m/s^2 */
  else if (AccelZ < - 8) Direction = 'c';
  else Direction = 'n';
  if (AccelX > 0) X = 'y';
  else X = 'n';
  if (AccelY > 0) Y = 'y';
  else Y = 'n';

  if ((millis() - lastDisplayTime) > 1000)  // display once/second
  { Serial.println();
    Serial.print("Accel X: "); Serial.print(AccelX); Serial.println();
    Serial.print("Accel Y: "); Serial.print(AccelY); Serial.println();
    Serial.print("Accel Z: "); Serial.print(AccelZ); Serial.println();
    Serial.print("Direction "); Serial.print(Direction); Serial.println();
    lastDisplayTime = millis();
  }
  /* Displays the accelerometer readings*/
```

```
 /* Creates a blink effect at 45 minutes, 50 minutes, and 55 minutes */
 if (Time == 2700000)
  analogWrite(2, 255), analogWrite(8, 255), analogWrite(9, 255), analogWrite(12, 255) analogWrite(3, 255),
analogWrite(5, 255), analogWrite(6, 255), analogWrite(11, 255);
  else  if (Time == 2701000)
  analogWrite(2, 255), analogWrite(8, 255), analogWrite(9, 255), analogWrite(12, 255) analogWrite(3, 255),
analogWrite(5, 255), analogWrite(6, 255), analogWrite(11, 255);
   else  if (Time == 2702000)
  analogWrite(2, 255), analogWrite(8, 255), analogWrite(9, 255), analogWrite(12, 255) analogWrite(3, 255),
analogWrite(5, 255), analogWrite(6, 255), analogWrite(11, 255);
   else  if (Time == 2703000)
  analogWrite(2, 255), analogWrite(8, 255), analogWrite(9, 255), analogWrite(12, 255) analogWrite(3, 255),
analogWrite(5, 255), analogWrite(6, 255), analogWrite(11, 255);
   else  if (Time == 2704000)
  analogWrite(2, 255), analogWrite(8, 255), analogWrite(9, 255), analogWrite(12, 255) analogWrite(3, 255),
analogWrite(5, 255), analogWrite(6, 255), analogWrite(11, 255);
   else  if (Time == 2705000)
  analogWrite(2, 255), analogWrite(8, 255), analogWrite(9, 255), analogWrite(12, 255) analogWrite(3, 255),
analogWrite(5, 255), analogWrite(6, 255), analogWrite(11, 255);
  else if (Time == 3000000)
  analogWrite(2, 255), analogWrite(8, 255), analogWrite(9, 255), analogWrite(12, 255) analogWrite(3, 255),
analogWrite(5, 255), analogWrite(6, 255), analogWrite(11, 255);
  else  if (Time == 3001000)
  analogWrite(2, 255), analogWrite(8, 255), analogWrite(9, 255), analogWrite(12, 255) analogWrite(3, 255),
analogWrite(5, 255), analogWrite(6, 255), analogWrite(11, 255);
   else  if (Time == 3002000)
  analogWrite(2, 255), analogWrite(8, 255), analogWrite(9, 255), analogWrite(12, 255) analogWrite(3, 255),
analogWrite(5, 255), analogWrite(6, 255), analogWrite(11, 255);
   else  if (Time == 3003000)
  analogWrite(2, 255), analogWrite(8, 255), analogWrite(9, 255), analogWrite(12, 255) analogWrite(3, 255),
analogWrite(5, 255), analogWrite(6, 255), analogWrite(11, 255);
   else  if (Time == 3004000)
  analogWrite(2, 255), analogWrite(8, 255), analogWrite(9, 255), analogWrite(12, 255) analogWrite(3, 255),
analogWrite(5, 255), analogWrite(6, 255), analogWrite(11, 255);
   else  if (Time == 3005000)
  analogWrite(2, 255), analogWrite(8, 255), analogWrite(9, 255), analogWrite(12, 255) analogWrite(3, 255),
analogWrite(5, 255), analogWrite(6, 255), analogWrite(11, 255);
    else if (Time == 3300000)
  analogWrite(2, 255), analogWrite(8, 255), analogWrite(9, 255), analogWrite(12, 255) analogWrite(3, 255),
analogWrite(5, 255), analogWrite(6, 255), analogWrite(11, 255);
  else  if (Time == 3301000)
  analogWrite(2, 255), analogWrite(8, 255), analogWrite(9, 255), analogWrite(12, 255) analogWrite(3, 255),
analogWrite(5, 255), analogWrite(6, 255), analogWrite(11, 255);
   else  if (Time == 3302000)
```

```
    analogWrite(2, 255), analogWrite(8, 255), analogWrite(9, 255), analogWrite(12, 255) analogWrite(3, 255),
analogWrite(5, 255), analogWrite(6, 255), analogWrite(11, 255);
      else  if (Time == 3303000)
    analogWrite(2, 255), analogWrite(8, 255), analogWrite(9, 255), analogWrite(12, 255) analogWrite(3, 255),
analogWrite(5, 255), analogWrite(6, 255), analogWrite(11, 255);
      else  if (Time == 3304000)
    analogWrite(2, 255), analogWrite(8, 255), analogWrite(9, 255), analogWrite(12, 255) analogWrite(3, 255),
analogWrite(5, 255), analogWrite(6, 255), analogWrite(11, 255);
      else  if (Time == 3305000)
    analogWrite(2, 255), analogWrite(8, 255), analogWrite(9, 255), analogWrite(12, 255) analogWrite(3, 255),
analogWrite(5, 255), analogWrite(6, 255), analogWrite(11, 255);

    /* If time is less than 30 minutes, the green LED's are on, determined by whether or not the device recieved
a Z acceleration greater than 8m/s^2 and dependent on phi */
  else if (Time < 1800000)
  {
  if (Direction == 'z')
    analogWrite(3, 254), analogWrite(5, 254), analogWrite(6, 254), analogWrite(11, 254);
  if (Direction == 'c')
    analogWrite(3, 255), analogWrite(5, 255), analogWrite(6, 255), analogWrite(11, 255);
    if (AccelX > 8) analogWrite(3, 240), analogWrite(5, 255), analogWrite(6, 255), analogWrite(11, 255);
    else if (AccelX < -8) analogWrite(3, 255), analogWrite(5, 240), analogWrite(6, 255), analogWrite(11, 255);
    else if (AccelY > 8)    analogWrite(3, 255), analogWrite(5, 255), analogWrite(6, 255), analogWrite(11,
240);
    else if (AccelY < -8)   analogWrite(3, 255), analogWrite(5, 255), analogWrite(6, 240), analogWrite(11,
255);
    /* By using using the information found above of whether or not the device is in the positive or negative x
and y directions, the corresponding N S E or W LED is on at a brightness determined by phi */
   else if (Direction == 'n') if (X == 'y') if (Y == 'y') analogWrite(3, (260 - 20 * cos(Phi))), analogWrite(11,
(260 - 20 * sin(Phi))), analogWrite(5,255), analogWrite(6,255);
    else if (Direction == 'n') if (X == 'y') if (Y == 'n') analogWrite(3, (260 + 20 * cos(Phi))), analogWrite(6,
(260 + 20 * sin(Phi))),analogWrite(5,255), analogWrite(11,255);
    else if (Direction == 'n') if (X == 'n') if (Y == 'y') analogWrite(5, (260 + 20 * cos(Phi))), analogWrite(11,
(260 + 20 * sin(Phi))),analogWrite(3,255), analogWrite(6,255);
    else if (Direction == 'n') if (X == 'n') if (Y == 'n') analogWrite(5, (260 - 20 * cos(Phi))), analogWrite(6, (260
- 20 * sin(Phi))),analogWrite(3,255), analogWrite(11,255);
  }
  /* Between 30 and 45 minutes, all the LED's are yellow */
    else if (Time >1800000)
  {
     if (Direction == 'c')
    analogWrite(2, 254), analogWrite(8, 254), analogWrite(9, 254), analogWrite(12, 254) analogWrite(3, 254),
analogWrite(5, 254), analogWrite(6, 254), analogWrite(11, 254);
  if (Direction == 'z')
```

```
   analogWrite(2, 255), analogWrite(8, 255), analogWrite(9, 255), analogWrite(12, 255)    analogWrite(3,
255), analogWrite(5, 255), analogWrite(6, 255), analogWrite(11, 255);
   if (AccelX > 8) analogWrite(3, 240), analogWrite(5, 255), analogWrite(6, 255), analogWrite(11, 255)
analogWrite(2, 240), analogWrite(8, 255), analogWrite(9, 255), analogWrite(12, 255);
   else if (AccelX < -8) analogWrite(3, 255), analogWrite(5, 240), analogWrite(6, 255), analogWrite(11,
255)analogWrite(2, 255), analogWrite(8, 240), analogWrite(9, 255), analogWrite(12, 255);
   else if (AccelY > 8)     analogWrite(3, 255), analogWrite(5, 255), analogWrite(6, 255), analogWrite(11,
240) analogWrite(2, 255), analogWrite(8, 255), analogWrite(9, 255), analogWrite(12, 240);
   else if (AccelY < -8)     analogWrite(3, 255), analogWrite(5, 255), analogWrite(6, 240), analogWrite(11,
255)analogWrite(2, 255), analogWrite(8, 255), analogWrite(9, 240), analogWrite(12, 255);
  else if (Direction == 'n') if (X == 'y') if (Y == 'y')  analogWrite(3, (260 - 20 * cos(Phi))), analogWrite(11,
(260 - 20 * sin(Phi))), analogWrite(5,255), analogWrite(6,255)analogWrite(2, (260 - 20 * cos(Phi))),
analogWrite(12, (260 - 20 * sin(Phi))), analogWrite(8,255), analogWrite(9,255);
   else if (Direction == 'n') if (X == 'y') if (Y == 'n') analogWrite(3, (260 + 20 * cos(Phi))), analogWrite(6,
(260 + 20 * sin(Phi))),analogWrite(5,255), analogWrite(11,255) analogWrite(2, (260 + 20 * cos(Phi))),
analogWrite(9, (260 + 20 * sin(Phi))),analogWrite(8,255), analogWrite(12,255);
   else if (Direction == 'n') if (X == 'n') if (Y == 'y') analogWrite(5, (260 + 20 * cos(Phi))), analogWrite(11,
(260 + 20 * sin(Phi))),analogWrite(3,255), analogWrite(6,255) analogWrite(8, (260 + 20 * cos(Phi))),
analogWrite(12, (260 + 20 * sin(Phi))),analogWrite(2,255), analogWrite(9,255);
   else if (Direction == 'n') if (X == 'n') if (Y == 'n')  analogWrite(5, (260 - 20 * cos(Phi))), analogWrite(6,
(260 - 20 * sin(Phi))),analogWrite(3,255), analogWrite(11,255) analogWrite(8, (260 - 20 * cos(Phi))),
analogWrite(9, (260 - 20 * sin(Phi))),analogWrite(2,255), analogWrite(12,255);
  }
   }
   /* After 45 minutes the LED's are red */
  else if (Time > 2700000)
  {
    if (Direction == 'c')
   analogWrite(2, 254), analogWrite(8, 254), analogWrite(9, 254), analogWrite(12, 254);
  if (Direction == 'z')
   analogWrite(2, 255), analogWrite(8, 255), analogWrite(9, 255), analogWrite(12, 255);
   if (AccelX > 8) analogWrite(2, 240), analogWrite(8, 255), analogWrite(9, 255), analogWrite(12, 255);
   else if (AccelX < -8) analogWrite(2, 255), analogWrite(8, 240), analogWrite(9, 255), analogWrite(12, 255);
   else if (AccelY > 8)    analogWrite(2, 255), analogWrite(8, 255), analogWrite(9, 255), analogWrite(12,
240);
   else if (AccelY < -8)   analogWrite(2, 255), analogWrite(8, 255), analogWrite(9, 240), analogWrite(12,
255);
  else if (Direction == 'n') if (X == 'y') if (Y == 'y') analogWrite(2, (260 - 20 * cos(Phi))), analogWrite(12,
(260 - 20 * sin(Phi))), analogWrite(8,255), analogWrite(9,255);
   else if (Direction == 'n') if (X == 'y') if (Y == 'n') analogWrite(2, (260 + 20 * cos(Phi))), analogWrite(9,
(260 + 20 * sin(Phi))),analogWrite(8,255), analogWrite(12,255);
   else if (Direction == 'n') if (X == 'n') if (Y == 'y') analogWrite(8, (260 + 20 * cos(Phi))), analogWrite(12,
(260 + 20 * sin(Phi))),analogWrite(2,255), analogWrite(9,255);
   else if (Direction == 'n') if (X == 'n') if (Y == 'n') analogWrite(8, (260 - 20 * cos(Phi))), analogWrite(9, (260
- 20 * sin(Phi))),analogWrite(2,255), analogWrite(12,255);
```

```
}
  }
```