Baby Buoy: Surface Pool Alarm

Fernando Bilbao, Harold Grafe, and Neysha Irizarry-Cardoza

Department of Electrical Engineering and Computer Science, University of Central Florida, Orlando, Florida, 32816-2450

***Abstract* — The objective of this project is to construct a pool alarm that will assist families with protecting their kids from drowning in a pool. This device uses a PIR sensor to capture motion above the surface of the water. An accelerometer that will capture the motion of the water's surface and an underwater camera that will capture feedback once a motion sensor is triggered. All information will be transferred via WiFi to a mobile application so the user may keep an eye on the pool even when they step away from the pool area. The overall device is lightweight, portable and user-friendly, ideal for any family in need of more supervision around the pool area.**

***Index Terms* — WiFi, motion sensors, accelerometer, mobile application, camera, solar power, battery.**

I. INTRODUCTION

In the sunshine state of Florida, it is always summertime. Having approximately 392,048 swimming pools throughout the state; scattered between civilian homes and community clubhouses, Florida holds second place in the nation with the most amount of swimming pools. Nevertheless, Florida takes the lead in the nation for the number of child fatalities due to drowning. According to the USA Swimming Foundation, in 2017, there was a total of 51 children that passed away due to drowning in pools or spas. This was a 20% increase from the figures that were analyzed in the previous year, 2016. Based on the profiles recorded by the USA Swimming Foundation, 80% of those fatalities involved children between the ages of 1-4, and 20% being kids 15 and younger.

Our goal with this project is to construct a pool alarm with sensors to alert any parents with children that come in contact with the pool. The main objective of this project is to reduce the number of child fatalities that occurs every year in the sunshine state of Florida.

Our device includes features such as a sounding alarm to alert individuals that there may be trouble in the swimming pool. Also, a mobile application that would be connected through WiFi to inform parents if they happen to be far from the reach of the sounding alarm. The mobile application also contains information such as logs from when the motion was detected, user information and a picture gallery. Our pool alarm is equipped with a water surface sensor. We have implemented solar power capabilities to further maintain and sustain battery life.

We have also implemented a two-step verification method by using above ground motion detection and surface water motion detection. The 2-step verification allows us to reduce the rate at which false alarms occur. False alarms can be caused by gusts of wind, pets, or any other miscellaneous objects that might disturb the surface of the water or the perimeter of the pool.

There is an underwater camera for visual verification to the user. The camera takes an image and sends it to the user via the mobile application. The user will also be alerted through a push notification when the alarm is triggered. These features are crucial to perfect as it would send an alert to parents. The system is meant to be portable and lightweight to conveniently travel with it and use it at a pool away from your home.

II. SPECIFICATIONS

The Baby Buoy was designed to be cost competitive with additional features. Similar devices only offer 1-step verification and no visual representation of what's in the pool. The Baby Buoy features 2-step verification and an image of what's underneath the pool when triggered. The system adheres to the following list of requirements:

Primary Requirements

1. The system shall have a maximum power consumption of ≤ 5W.
2. The system shall have an IP58 rating.
3. The system shall cost ≤ $250.
4. The system shall have an electronics housing no larger than 23*10*7 in. (L*W*H)
5. The system shall have a wireless communication range of ≤ 115ft.
6. The system shall have 2-step verification.

Secondary Requirements

1. The system shall have a mobile application to control the system.
2. The system shall sound an alarm with triggered.
3. The system shall capture an image and send it to the user via a mobile application

4. The system shall function under a temperature range of 0°C to 60°C.
5. The system shall have 16 hours of battery life between charging.
6. The system shall have solar power capabilities to sustain battery life.
7. The system shall weigh less than 10 lbs.

III. SYSTEM OVERVIEW

To display the overall system concept, a block diagram is provided below. The following diagram offers a high-level overview of the Baby Buoy, and how each component interfaces with one another.

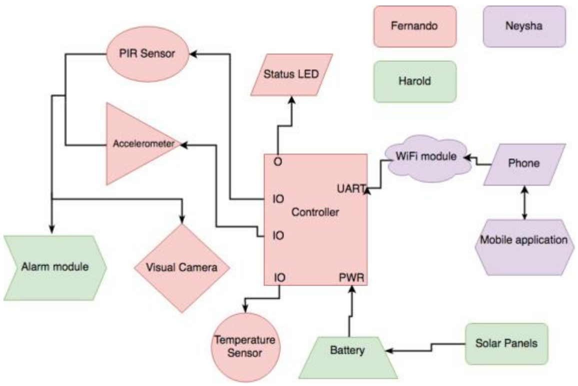

Figure 1: Overall Block Diagram

As illustrated in Figure 1, the WiFi module interfaces with all hardware components of the system. The ESP32 comes with a built-in processor that is capable of all I/O data being transmitted within the device. The PIR sensor and the accelerometer monitor any motion that is around the pool's edge or on the surface of the water. This will give our device two-step verification before sounding the alarm. Once any data is received, the ESP32 will directly send out the information to Firebase in the backend, and the mobile application will interpret any relevant information to the user on the frontend. The Baby Buoy is powered by a lithium battery but given its outdoor nature of the device, there are solar panels installed for maintaining charge through the day.

IV. SYSTEM COMPONENTS

A. Microcontroller

The microcontroller of choice for this project was the ESP32-WROOM-32U. The ESP32 operates at 3.3V and is capable of connecting to wireless signals at the 2.4GHz frequency. We found that this frequency is commonly found in most households, as opposed to the 5GHz frequency, which typically requires more expensive routers. The ESP32 will connect to the home WiFi and control the PIR sensor for motion detection, the accelerometer for fall detection, the camera for image capture, and the temperature sensor for logging the temperature of the water.

When the PIR sensor detects motion, and the accelerometer detects a fall, a signal will be sent to Firebase and an alarm will sound. Once the signal is sent to Firebase, the user will get a push notification to their phone through the mobile application. If an alarm is triggered, then the user will also get an image of the object that has fallen into the water. The image will first be stored onto an external server, and then utilized by the mobile application for visual verification to the user.

B. Motion Sensors

The HC-SR501 is a PIR (Passive Infrared) motion sensor that operates at 3.3V, features adjustable sensitivities, a 110° FOV (Field-Of-View), and motion detection ranges of 3m to 7m. Since the average length of a home pool is 4.5m to 6m, we found that this motion detection sensor was sufficient enough to detect motion below and above those ranges. It utilizes a pyroelectric sensor to detect levels of infrared radiation and a Fresnel lens that condenses light to provide a larger range of IR to the pyroelectric sensor. The PIR sensor will output LOW when no motion is detected, and HIGH when motion is detected to the ESP32. The PIR sensor communicates with the ESP32 via a output signal pin.

C. Accelerometer

The MMA8451 accelerometer is a 3-axis accelerometer, with a g-force range of 2g to 8g. For the Baby Buoy, no more than 4g will be used for detecting if a person has fallen into the water. The accelerometer detects the waves of when a person has fallen into the water. The magnitude of the acceleration for the x, y, and z-axis were utilized in computing an appropriate threshold.

Although the z-axis is the most prominent axis for detecting a fall, the magnitude of the x, y, and z-axis acceleration were utilized for determining an appropriate g-force calculation. A manual threshold (or sensitivity) was set, where if the threshold is greater than the calculated g-force, then the user will be notified. If the threshold is less than the calculated g-force, then the Baby Buoy will continue polling the pool until both the PIR sensor and accelerometer are triggered. The accelerometer communicates with the ESP32 via I2C (Inter-Integrated Circuit). I2C allows multiple digital integrated circuits to communicate with 1 or more master chips.

D. Camera

The Baby Buoy utilizes the popular ArduCAM OV2640 for capturing images underneath the surface of the pool. The ArduCAM features a 2MP camera that has several image processing capabilities in the included library. Color saturation, hue control, exposure control and more are programmable through its interface. This camera is low powered, cost competitive and extremely effective in capturing images as opposed to other cameras that aren't capable of communicating with the ESP32, are more expensive, or are TTL Serial cameras.

The ArduCAM will be trigerred by the ESP32 when the system detects motion and a fall. The ArduCAM will take a picture of the person underneath the water and store it into an external server. The mobile application will communicate with the external server to pull the image and show it to the user via a picture gallery in the application. The user can either delete or keep the image. The image resolution can be changed in the code, but for the Baby Buoy system, a 320*240 resolution was used. The image resolution is adequate for distinguishing between a human or an object.

The image should minimize any false alarms for the user, since it allows them to see what is underneath the surface of the water, as opposed to other pool alarms that have no image capabilities.

E. Temperature Sensor

The TMP36 temperature sensor was chosen for this task. It is already calibrated directly to degrees Celsius with an accuracy of ±2℃. It has a low quiescent current of 50µA and a wide temperature range from -40℃ to 125℃. The temperature sensor will be used to notify the user of the temperature of the water using °F. For the overall environment that the system will be in, a temperature range of 0℃ to 60℃

F. Audible Alarm

The Baby Buoy features a piezo buzzer to create an audible alarm for the user. The piezo buzzer will be located in the solar panel housing unit and be triggered when the PIR sensor detects motion and the accelerometer detects a fall. The alarm will sound for 60 seconds, but can be

G. Voltage Regulators

The Baby Buoy requires a 5V power supply for the PIR, temperature sensor, and accelerometer, as well as a 3.3V power supply for the ESP32 and Camera. Assuming a lithium-ion battery is used with a nominal voltage of 3.7V, then the design needed both a boost converter to reach 5V and a buck converter for 3.3V. The maximum current load of the system was calculated to select voltage regulators capable of delivering it, Table 1 shows the maximum current for each component.

Table 1: System Maximum Current Consumption

Component	**Max Current Draw (mA)**
PIR	65
Camera	110
MCU	80
Temp. Sensor	0.05
Buzzer	30
Accelerometer	0.165
Total	**285.21**

Using this data, the switching boost converter TPS613222A was selected to output Vout = 5V and Iout = 500mA. The increased output current was chosen to have a generous safety margin in case of current spikes. It has a range of input voltages from 0.9V to 5.5V. Also, a switching regulator was chosen because it is more efficient than a linear regulator. For the buck converter, an AZ1117E-3.3 linear regulator was chosen to provide Vout = 3.3V. The maximum output current of this regulator is 1 A which is more than enough and has a low dropout voltage of 1.1V. The linear regulator was chosen to minimize electrical noise to the MCU.

H. Battery

Either a lithium ion or lithium polymer battery would have been ideal for this project due to their high energy density, no memory effect, and low self-discharge rate. A lithium polymer battery was selected because of space limitations in the waterproof electronics housing. The battery capacity was calculated under normal operation with the camera and buzzer turned off, which resulted in current consumption of 145.21mA. Assuming the device runs on battery alone for 16 hours a day, the capacity needed would be 2323.36mAh for one day. As a safety precaution, a 5000mAh battery capable of powering the device for two days was chosen in case environmental conditions prevent charging one of the days.

I. Battery Charger

Lithium polymer batteries have a specialized charging procedure that needs to be managed by hardware. The BQ21040DBVR battery charger IC was chosen. It provides an adjustable charging current up to 800mA which is necessary to fully charge the 5000mAh in less than 8 hours of sunlight. The charger has a maximum input current rating of 1.25A and a wide variety of input voltages up to 30V. This IC is also capable of charging the battery while powering the system in parallel which is ideal to preserve battery power during the day.

J. Solar Panels

The solar panels need to be compact to fit in the solar housing and provide enough current to reach the maximum output current of the battery charger of 800mA. Two solar cells that output 6V and 600mA were placed in parallel to provide maximum current to the charger of 1.2A. The larger potential current output was selected in case non-ideal solar conditions result in less current.

V. HARDWARE DESIGN

The Baby Buoy consists of two main waterproof housings. The Solar housing is made of clear acrylic to let sunlight in, rubber legs to prevent slipping on wet surfaces by the pool, and an aluminum rod that suspends the electronics housing over the pool. It contains the two solar cells and a buzzer to create an audible alarm during emergencies. The audible alarm will be initialized by the ESP32. Figure 2 depicts this housing in more detail.

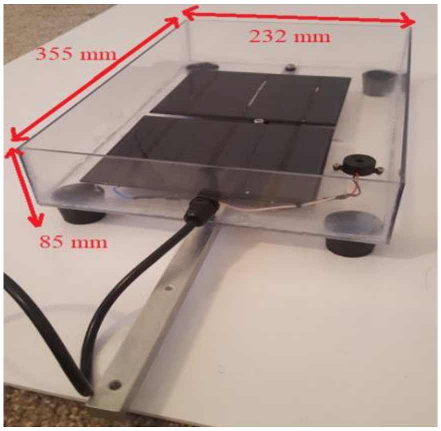

Figure 2: Solar Housing

The electronics housing is made of aluminum that has been anodized to prevent corrosion. It is open at the top and bottom for ease of access during troubleshooting. Two caps cover these openings when it is ready to go in the pool, neoprene gaskets between the housing and caps prevent water leakage. The housing has two windows, one above and one below the water. The window above the water is for the PIR sensor to detect motion on or around the pool. The underwater window is for the camera to take a picture once the sensors trigger an alarm.

There is a power switch at the back of the housing to preserve battery power when the device is not in use. The top cap has an opening for the external wires from the solar housing, it also has an indicator LED and external antenna to connect to the internet wirelessly. An external antenna is necessary since the aluminum body of the housing acts as a faraday cage preventing any signals from going in or out. The bottom cap contains the temperature sensor to measure the temperature of the pool. Figure 3 shows the electronics housing with its dimensions.

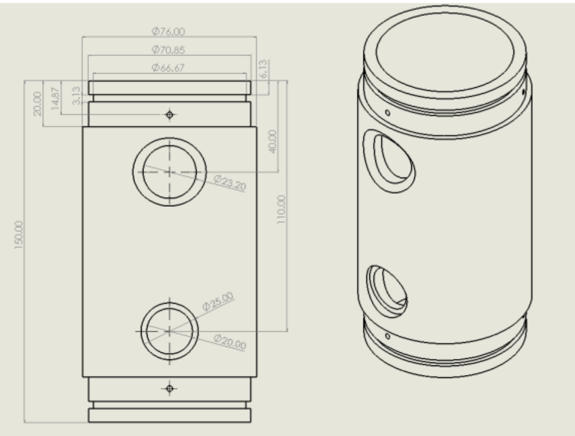

Figure 3: Electronics Housing

A wire also comes out of the side of this housing with a small waterproof box containing the accelerometer, which detects ripples on the surface of the water when a person or an object falls into the pool. The complete design of the Baby Buoy is shown in Figure 4.

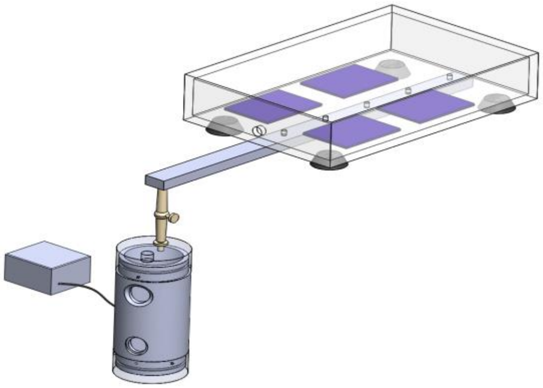

Figure 4: Baby Buoy Design

The power design of the Baby Buoy is shown in Figure 5. The solar panels and optional USB charger feed into the battery charger IC, they include diodes for reverse current protection. The USB is only used to charge the battery while the PCB is being troubleshot since there is no access to it once the housing is closed. The battery charger connects to the battery and also to the 5V boost converter which outputs 500mA for the system.

The 5V supply powers the PIR, temperature sensor, accelerometer, and also connects to the linear buck converter to step down the voltage to 3.3V. The buck converter is connected in series with the boost converter instead of in parallel because of its dropout voltage of 1.1V, the difference from the battery voltage of 3.7V to 3.3V is not enough for it to work. The 3.3V supply then powers the ESP32 and the camera.

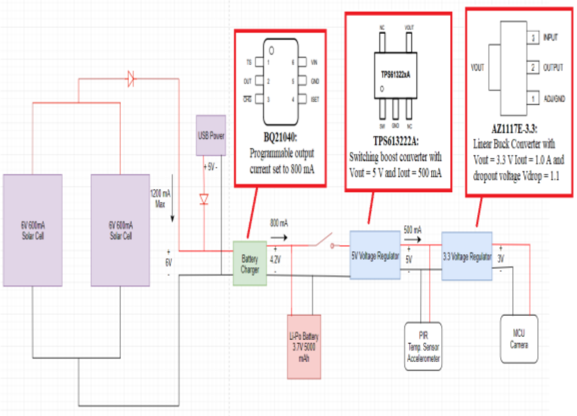

Figure 5: Power Design

The schematic for the PCB is shown in Figure 6. In addition to the main components listed already, there are two buttons used for programming purposes, one for reset and the other for flash. There are headers for all the sensors as well as for serial communication to program the board. Finally, there are two N-channel MOSFET switches used to turn on and off components whose current consumption exceeds what the microcontroller pins can provide (40mA).

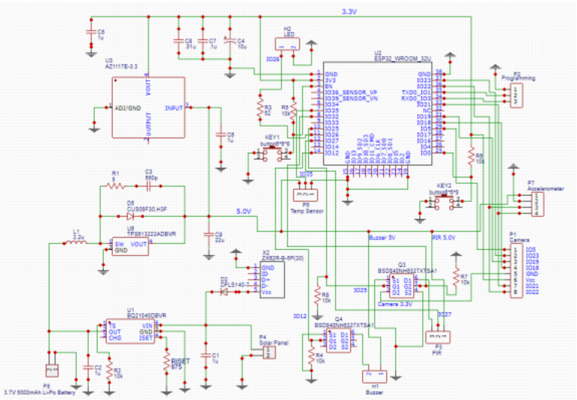

Figure 6: PCB Schematic

The PCB has two copper layers with a ground plane on each layer. The board dimensions are 63.5mm by 44.45mm, with 4mm mounting holes in the corners. All the power components are concentrated on one side of the board along the pins for the battery, solar cells, and USB. The trace width for the main power lines are 20 mil while the signal traces are 10 mil. All the sensor inputs and outputs are on the opposite side of the board along with the MOSFET's. The ESP32 sits at the center of the board. All components are surface mounts except for the buttons and sensor pins. Figure 7 shows the layout of the board.

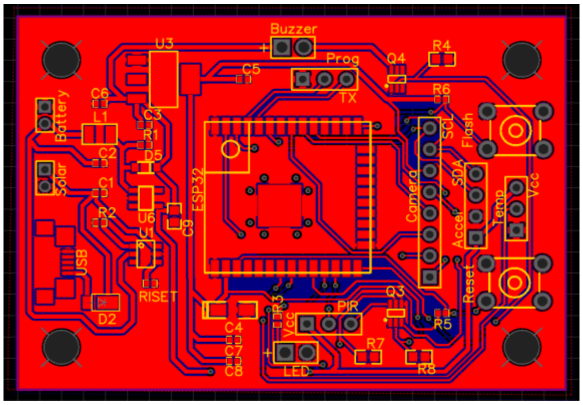

Figure 7: PCB Design

The PCB, battery, and camera are mounted to a 3D printed base made of PLA that slides into the electronics housing to keep all the components and battery organized. It is made so that friction will keep it in place once it is pushed into the housing.

VI. SOFTWARE DESIGN

The basic interface of the mobile application can be illustrated in Figure 8**.** The class diagram establishes the classes and operations in a basic structure, in efforts to illustrate the relationship amongst objects.

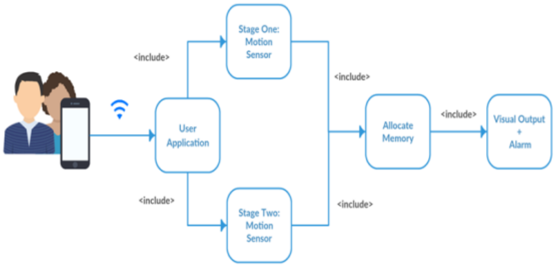

Figure 8: Software Class Diagram

Based on the illustration above, the user has a friendly interface to operate and manage the device from the use of a mobile application. The application itself will have the abilities to manage the general user settings and the capability of monitoring the motion sensor outputs through logs and viewing images from the onboard camera of the Baby Buoy if triggered.

In the software that will be encrypted within the ESP32 module, data is received through the digital inputs. From the collection of information retrieved from the motion sensors, the device will send it off through WiFi. The mobile application will collect the digital outputs based on date and time, and store them in a log for the user's records. After drawing up a conclusion, based on the database sensor information, the ESP32 will decide to stay dormant or to set off the alarm and send out a push notification to the mobile application.

This is a very basic high-level class diagram, in the following sections we will go more in detail on what actual class and function will be store in each the class that will be created in efforts to master the mobile application and its software development.

A. Software Class Diagram

The image below illustrates the high-level design of the Baby Buoy mobile application. This class diagram goes into descriptive detail of the individual headers and probable structures that would play a role within each class. This design will integrate ease of functionality between the user and the device visuals.

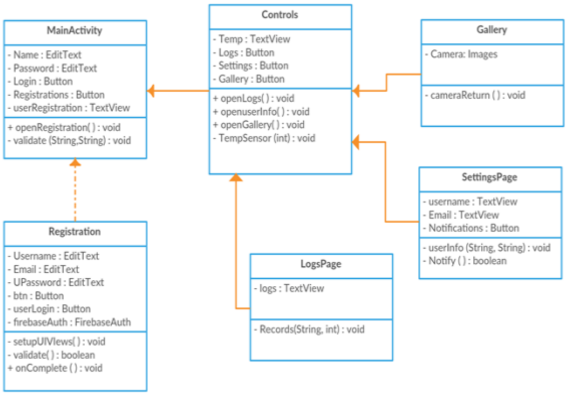

Figure 9: High-Level Software Class Diagram

In the high-level class diagram that is illustrated above, there will be a MainActivity that will essentially be the home page for the user to login and logout of their personal account. This class consists of the basic email and password encryption along with ClickListeners. This allows new users to create an account, and existing users to reset their password if forgotten. These are all string inputs that are cross examined and stored in Google Firebase Database.

The Registration class is constructed for new users. This is where anyone may create an account with their individual Baby Buoy pool alarm. The class consists of three string variables; a name, email, and password. Once registered the user will receive an email to verify their account. Only when the user verifies their account via email will they be able to access the controls of their Baby Buoy device, otherwise they will not be able to sign in from the main page.

Once the user is registered and has completed verifying their device via email, they will log in and have access to their control. In the Controls class, an individual will have three buttons to direct them throughout the mobile application. The three buttons will be the logs, the gallery, and the user settings. Along with instant navigation throughout the device application, the user will have a reading of the water temperature at an easy glance.

The LogsPage class consists of a RecyclerView widget that collects all the information from Google

Firebase Database that is related to the date and time a sensor is triggers and updates in real time in a list format. The user settings are managed in the SettingsPage class. All the information in this class is retrieved from the database and can be altered from two integrated buttons that give the user the ability to change their password and name the mobile application. Integrated within the Gallery class is a CardView widget that allows the user to look through the images collected from the underwater camera, once triggered, in an easy manner.

B. User Interface (UI)

The user interface of a mobile application is crucial to creating a mutual relationship between the device and the user. Having the ability to read any directional text and to see any pictorial images crisp and clear, gives the user a clarity of how to best maneuver throughout the app without assistance. The application for this project will be very user-friendly. With sharp images and visual text, so that the user does not place strain in their eyes.

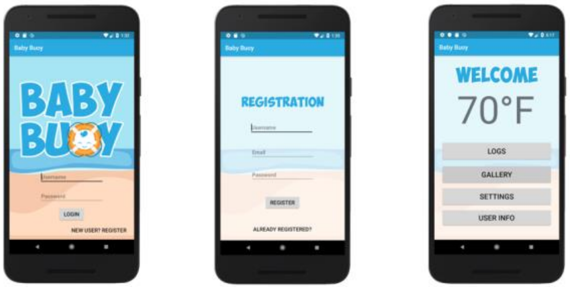

Figure 10: User Interface

The figure above illustrates some key features that are implemented in the mobile application. At first glance, a user may notice prototype is minimalistic, as a minimalist design is seen to attract better user mobility as well as clarity.

The mobile application for this device will only be implemented for android users. The programming language for Android Studios is Java which is a more universal language that has derived much of its syntax from C and C++; two languages that the team is more familiar with. Having the ability to submit an application into the Google Play Store for evaluation and having it evaluated within 24 hours is a great advantage. This has allowed for more time to fix and/or update the app, so that it may be published properly on the Google Play Store.

Having this device be compatible with the iOS platform has been a stretch goal for the team, but given the time constraint and hardware/ software issues that have come up throughout the journey, has made the goal less likely to be implemented for the time being.

VII. CONCLUSION

Throughout the development of this project, our team's goals and motivations were a leading factor in constructing a device that can bring assistance to families in need of extra supervision around the pool area. Our team has taken extra measures to ensure that the children’s safety is our top priority.

In addition, our requirements and specifications that were discussed in our design process helped bring the project to life. The Baby Buoy is made up of a multitude of different components and modules. This includes technologies such as wireless communication, solar power capabilities, motion and fall detection, and a user interface via a mobile application.

The system’s primary requirements were met throughout the projects life cycle by various phases of testing. The system is rated for IP58 due to its durable waterproof electronics housing, the cost of creating the system is far below $250, the electronics housing size was created and measured to meet the size requirement. The datasheet of all the components verify that even through each components maximum power consumption, the system consumes $\leq$ 5W, while also maintaining a WiFi range of $\leq$ 115ft . The 2-step verification requirement was met with the PIR sensor and accelerometer.

The system’s secondary requirements were additional features that the team felt was needed in order to make it much more competitive to other pool alarms. No pool alarms offer solar power capabilities, or image capturing of the water underneath the surface of the pool, or 16 hours of battery life between charging.

Since the project was self-funded, the team had a concern with the overall cost of the system. Although the development of the system had to be done within a specific budget, our team was determined in creating a low-cost device to not only be a reasonable purchase to the average family, but to also be competitive with similar devices in the market.

VIII. BIOGRAPHIES

Fernando Bilbao

Fernando Bilbao is a Computer Engineering student, with a minor in Information Technology. He is interested in hardware development and embedded programming. Fernando currently interns at Lockheed Martin part-time, and intends to work there full-time as a Systems Engineer after graduation. He also intends to further his education by pursuing a Master's Degree in Systems Engineering.

Harold Grafe

Harold Grafe is a Mechanical Engineer pursuing an Electrical Engineering bachelor's and master's degrees. He currently works at Levil Technology Corp. as quality control and lead machine assembly technician. His main area of interest is nanotechnology and he hopes to find a job in that field in the future.

Neysha Irizarry-Cardoza

Neysha Irizarry-Cardoza is currently a Computer Engineering senior at the University of Central Florida. Her interests include embedded programming and software programming. After graduating, she plans on obtaining an engineering job and furthering her education by pursuing a Master's Degree in Systems Engineering.

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