A SWIMMING OPEN-WATER NAVIGATION ASSITIVE HEADSET AND RECEIVER

by

Zakk B. Rhodes

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in

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Approved:

<div style="display:flex; gap:4em;">

_____
Jacob Gunther, Ph.D.
Major Professor

_____
Jonathan Phillips, Ph.D.
Committee Member

</div>

_____
Donald Cripps, Ph.D.
Committee Member

UTAH STATE UNIVERSITY
Logan, Utah

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ABSTRACT

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Zakk B. Rhodes, Master of Science

Utah State University, 2019

Major Professor: Jacob Gunther, Ph.D.
Department: Electrical and Computer Engineering

Open water swimming is a common pastime dating back to ancient times. One challenge with open water swimming is navigation. Maintaining proper swimming technique suggests the head be in the water, but doing so makes it difficult to see where one is going. Thus swimmers must bring their head out of the water periodically to sight landmarks. The purpose of this project was to develop a GPS based device designed to assist with open water swimming navigation. A description of the navigational calculations, together with the user interface software and circuit design, is discussed.

(50 pages)

PUBLIC ABSTRACT

A Swimming Open-water Navigation Assitive Headset and Receiver

Zakk B. Rhodes

Open water swimming is a common activity dating back to ancient times. One challenge with open water swimming is navigation because while maintaining proper swimming technique suggests the head be in the water, it is difficult to see where one is going. Thus swimmers must bring their head out of the water periodically to sight landmarks. This work describes a solution to this problem by a design for a GPS device to assist swimmers with navigation. The swimmer can plan their own route, send it to the device, and then be guided by the device. They then will not have to bring their head out of the water to look for landmarks and can save energy for swimming.

ACKNOWLEDGMENTS

CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS

BOM	Bill of Materials
BT	Bluetooth
COTS	Commercial Off-The-Shelf
CSI	Campbell Scientific, Inc.
FINA	Federation Internationale de Natation Amateur
GPIO	General Purpose Input/Output
GPS	Global Positioning System
LiPo	Lithium Polymer
MOSFET	Metal-Oxide-Semiconductor Field-Effect Transistor
NMEA	National Marine Electronics Association
PCB	Printed Circuit Board
PoC	Proof of Concept
QTY	Quantity
RF	Radio Frequency
RMC	Recommended Minimum Specific GPS Data
SONAHR	Swimming Open-water Navigation Assistive Headset and Receiver
SMT	Surface Mount Technology
TH	Through Hole

CHAPTER 1

INTRODUCTION

1.1 Beginnings

The SONAHR system began from a former competitive swimmer making a foray into open water swimming. The Bear Lake Monster swim presented a challenge to be accepted, and during the training for the race several challenges to open water swimming were discovered by the author. The main problems were navigation, disorientation, and fatigue. Traditionally, swimming pools have wide, dark lines on the bottom of the pool to mark the middle of lanes for swimmers making it extremely easy to swim in a straight line. Pools also range from 25 yards to 50 meters in length, making the need to swim straight only over short distances. Open water swimming turns into staring at the bottom of a lake or into the depths of water for extended periods of time, with no guide to direction. A slight imbalance in arm pulls or body positioning can result in changes in direction imperceptible to the swimmer. Without regular head lifting during swimming there can be large changes in direction which, when the swimmer finally does stop to look for landmarks, can lead to some disorientation. With the added challenge of waves in an open water environment, the disorientation can be increased. This challenge is almost impossible to avoid. Advanced swimmers continue to use the head lifting technique for navigation, which causes a slow down in speed and an increase in fatigue.

1.2 Solution

Dating back to pre-historic times, open water swimming is swimming's purist form [1]. For a long time, swimming has remained relatively unchanged. The 20th and 21st centuries have brought incredible technology to the world. This technology can be combined with swimming to allow for a more satisfying swimming experience. From the author's open

water swim experience the idea was born to create a way to combine modern technology with a love of swimming. In order to accomplish the desired effect, several design constraints must be considered, as outlined in the following list.

1. The designed system must be portable and able to be worn by the swimmer. The swimmer cannot carry it in their hand or have to expend to much energy with a bulky system, as that would defeat the purpose for the design to help with fatigue.

2. The system must also be lightweight, weighing less than 8 ounces.

3. The design must be able to help with navigation, thus it must incorporate some direction finding through GPS.

4. The system should have the ability to follow a pre-planned route created by the user.

5. The system must be able to change routes with ease. Using only one track or having a cumbersome way to change it is no good, as the swimmer will be outdoors and away from a computer. As such, the system should incorporate a mobile application so that it can be programmed from a mobile device. These are the most likely to be near the swimmer at the beginning of a swim, and will allow the swimmer to change the route easily.

6. The system should be programmed wirelessly. A cable is cumbersome for the swimmer to carry around, and can be easily lost.

7. The system must notify the user when they leave the pre-defined track by more than 5 degrees. The swimmer needs to be able to know when they are drifting off course.

8. The system must notify the user when they end their swim.

9. In order to be useful for open water swimming, the system must be able to operate for at least 6 hours continuously.

The system devised to meet these requirements became SONAHR. It acts as a navigation assisting device, with side effects of peace of mind and technique help. SONAHR isn't

for the purists, but it is helpful for those making a transition to open water swimming and figuring out how to swim straight in open water, as well as for those who like the added security of knowing something else is keeping track of where they need to go. SONAHR also helps keep a swimmer's form while swimming by allowing them to keep their head in the water and not worry about navigating, just swimming.

1.3   SONAHR Overview

SONAHR is a standalone navigational unit for open water swimming. It takes a user's GPS track input and a current GPS location to guide a swimmer along whatever route they choose to go. It relies on two vibrating motor disks, one on either side of the head, to direct the swimmer on their course. The disks vibrate in patterns to alert the swimmer if they are off course, making progress along their track, or finished with their swim. The accompanying mobile application enables the swimmer to program SONAHR from anywhere, and even load a new route if the current one isn't working out.

CHAPTER 2

BACKGROUND

2.1 Swimming History

Humans have been swimming since pre-historic times. Swimming was taught in ancient Egypt and many people swam in the Nile [1]. The first swimming instructors were in these days, with one nobleman (2160 - 1780 B.C.) recording that his children took swimming lessons with the children of the king [2]. Swimming was a common practice in Greek mythology and culture and is referred to by Homer in his work [3].

Modern swimming competitions began in England in the early 19th century, with the sport being added to the Olympics in 1906. Most competitions were held in pools. Modern open water swimming challenges may have their origin with Lord Byron swimming across the Hellespont, a strait in Turkey now called the Dardanelles. Legendary Greek hero Leander supposedly swam the same four-mile stretch. Captain Matthew Webb, of the British Merchant Navy, became the first person to successfully swim the English channel on August 24, 1875, a distance of more than 21 miles [1].

2.1.1 Swimming and Technology

The earliest swimmers swam unclothed [1]. As society became more advance in the early modern era, swimming became less popular. The first swimwear was bulky and cumbersome, but as technology progressed, swimwear developed as well. In the early 1900s swimwear became more form fitting. In the 1970s Speedo added elastane, commonly known as Spandex, to their suits to create a tighter form fit. Rigorous computer aided design led to the development of more bouyant and streamlined full-body suits using polyurethane in 2008, with 130 world records broken in the newer suits before concerns over the sport's integrity led FINA to ban non-textile suits in 2009 for pool competition [4]. Open water

swimmers continue to use full-body wetsuits in cold water as a way to stay warm. Some organized courses, like the Channel Swimming Association's official English Channel crossing, prohibit wetsuits and other themal or bouyant materials [5].

Swim caps were worn anciently for bathing and made out of silk or taffeta to protect the hair. Caps were made out of rubber in the mid 1800s with a chin strap to hold it in place. In the 1920s stretchable latex swimming caps were produced to replace the chin ties. Silicone swim caps were introduced in the 1970s to provide more hydrodynamic properties and more hair protection. Open water swimmers can use caps to help stay warm, with some swimmers choosing to wear two caps as added insulation.

The first woman to cross the English Channel, Gertrude Ederle, created a waterproof pair of swim goggles by making a paraffin seal on her motorcycle-type goggles in 1926 [6]. The first commercial swimming goggles were introduced in 1968, with goggles first being allowed at the Olympics in 1976. Modern goggles can contain mirrored lenses to protect the eyes while swimming outdoors.

Additional assitive technology has been used for swimming, including the first known swimming fins invented by Benjamin Franklin by strapping planks to his hands and feet [7]. Other training materials can include a snorkel, a pull buoy, kickboard, or other items. A common device for time keeping is a pace clock, used to keep track of the time per lap of a swim in a pool, or the time a distance is covered in open water swimming. Competitive swimmers often use other devices such as heart rate monitors and underwater video recordings to increase performance. Swimming as a sport is increasingly utilizing more technology, especially in the new era of big data. SONAHR aims to build off of these technological devices by adding another useful device for both training and competition.

2.2   Swimming Technique

Early modern swimming was done primarily with the breaststroke, which was considered the fastest stroke until 1800, when the side stroke came into prominence as a racing stroke. A variation of the modern front crawl stroke was discovered to be used by natives in South America and was introduced to the modern world in Australia by Alek Wickham

around 1900 [1]. This stroke was adopted as the fastest stroke and is still used in a variation today. This stroke is the most common open water swimming stroke, with other strokes being used to eat or rest during the swim.

2.2.1 Drag and Fatigue

One basic swimming principle is drag reduction. As a swimmer decreases drag, speed and efficiency increase. The energy required to swim the front crawl stroke increases as the legs sink and decreases as a swimmer maintains a straighter line parallel to the surface of the water. Thus, the more parallel the swimmer's body is to the surface of the water, the easier it is to swim [8]. In open water swimming, as the head is raised out of the water for sighting landmarks and navigation, the torso and feet tend to sink. One study showed that the effect of this torso angle change increases drag on an order of magnitude [9]. This drag increase causes more energy to be expended while swimming to go the same distance. As a swimmer uses more frequent head lifting for navigation, more energy is expended. This is compounded by the fact that farther into a swim a swimmer's stroke efficiency decreases, and thus the energy cost to swim increases [10]. By helping the swimmer eliminate the need for head lifting for navigation, the SONAHR system can be used to decrease drag and energy use in the swimmer, thus increasing swimming efficiency and endurance.

2.3 Navigation

Navigation in open water swimming, even over short distances, can be a challenge. Traditionally in open water swimming, swimmers occasionally bring their head out of the water while swimming to view landmarks and maintain their course. Swimmers often travel significant distance without support and rely on themselves for navigation. In 2010, one swimmer died on an open water course and wasn't found for two hours [11].

Depending on the frequency of the swimmer lifting their head to find their bearing the swimmer can drift off course a significant distance and end up swimming longer than the planned swim. The SONAHR system can be used to mitigate this by alerting the swimmer of the need for a course correction when they start to drift off course, minimizing the need

to swim extra due to navigation errors.

2.3.1 GPS

The SONAHR system incorporates the use of GPS to help the swimmer stay on course. GPS has been used to solve many navigational challenges, but has had limited use for open water sport. This is partially due to the aquatic environment. One challenge is the skin depth of water greatly reducing RF communication at any distance under water. By placing the GPS receiver on the back of the head for a swimmer doing the front crawl, the skin depth problem can be minimized. Another challenge is the rugged design required for any housing of electronics exposed to the water. While not addressing the rugged, waterproof design, this project presents one possible solution to open water swimming navigation by using a GPS device.

CHAPTER 3

Methods

3.1 Theory of Operation

SONAHR is designed to be a standalone unit for open water navigation. It went through three different designs, each building on the last. These are a proof of concept version (section 3.2), version 1.0 (section 3.3), and version 2.0 (section 3.4). The proof of concept design is comprised of several prototype and break-out boards wired together, while version 1.0 and 2.0 are standalone, custom PCBs designed with schematic capture and layout software, and manufactured and assembled into a custom unit.

3.1.1 System Overview

As a navigational unit, SONAHR has a simple overall system design with three main different sub-systems. The system diagram is shown in figure 3.1.
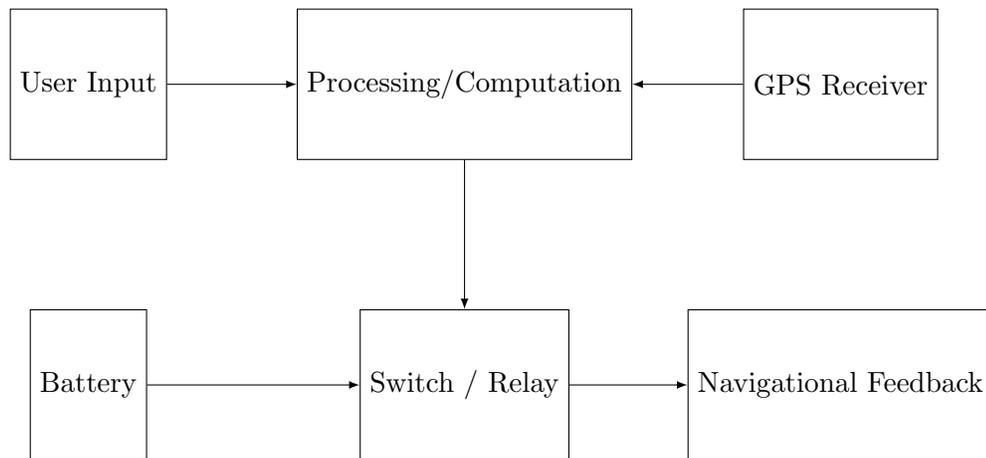

Fig. 3.1: SONAHR System Diagram.

The GPS information from the GPS chip is taken into the processor, where it is compared to the user input. If the user is off course, a command is sent to a relay to activate the haptic feedback on the side of the head directing the swimmer to change course.

SONAHR is a mobile unit, thus it is designed to be operated off of battery power. The addition of a bluetooth device in version 1.0 added the wireless user interface and makes the unit truly mobile and standalone. SONAHR is designed to be incorporated into a waterproof headband or swim cap at a future date.

3.1.2 User Interface

The SONAHR user interface is through a bluetooth chip and Android mobile application. The mobile application was developed for SONAHR 1.0 and 2.0, as the Proof of Concept model does not have wireless capability. The SONAHR mobile application can be used to send .kml GPS tracks, created on a mapping software such as Google Earth, to the SONAHR headset for navigation along the designed route.

The user has the option to choose between different tracks loaded into the app, or load a new file from the mobile device. After selecting the desired track to use, the user sends it to the SONAHR headset by selecting from the currently detected devices broadcasting through bluetooth. Figure 3.2 shows a track loaded in the app ready to transmit.

The SONAHR headset bluetooth device uses a simple program to receive the track from the mobile application, and uses that data for navigation. Figure 3.3 shows the flow chart for the bluetooth signal reception.

The mobile application transmits first the track name and number of points, followed by the each point's index, latitude, and longitude. These points are saved in the track. Once the track is complete, the program can begin the navigation part of the system.

The feedback to the user is done through a vibrating motor disk on either side of the head. Table 3.1 shows the different vibration patterns and their meaning.

In table 3.1 all repeated pulses have a 50% duty cycle. The long pulse is a one second period and the short pulse has a 200 millisecond period. These notifications are provided to the user to direct them on their defined GPS track.

Fig. 3.2: SONAHR mobile application track view

Vibration Pattern	Meaning
Repeating long pulses on one side	Turn away from that side
One long pulse on both sides	Arriving on course after correction. Maintain direction
Short pulse on both sides	Moving to next point in the track
Short pulse on both sides (repeated twice)	GPS fix found
Short pulse on both sides (repeated three times)	GPS fix lost
3 second pulse on both sides	Track complete

Table 3.1: Vibration Feedback Signal Descriptions

Start and Initialize

Advertise

Device Paired

No

Yes

Data Received

Yes

Track Initialized

No

Start Received

No

Yes

Add point

No
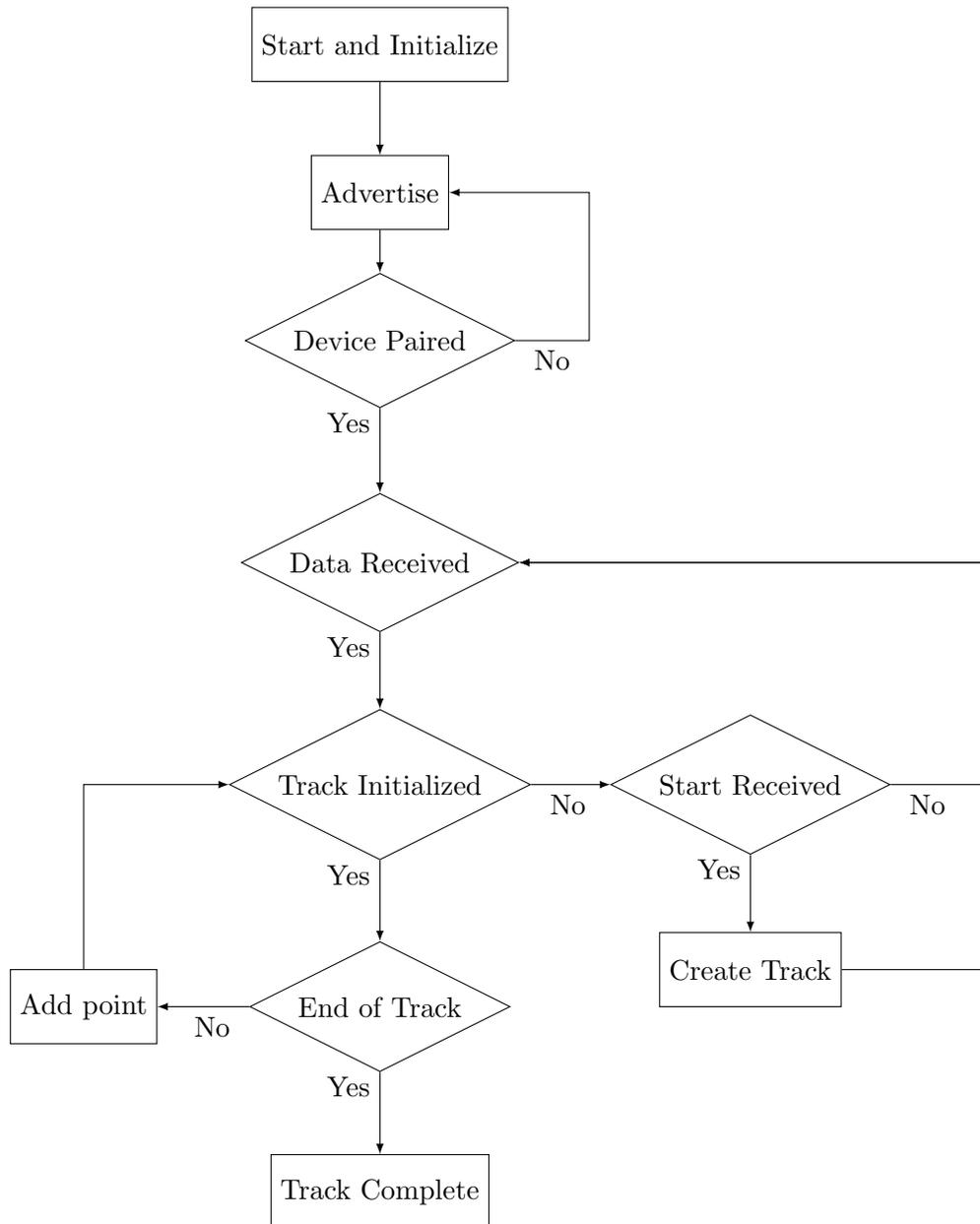
End of Track

Yes

Create Track

Track Complete

Fig. 3.3: Bluetooth Track Reception Flow Chart

3.1.3   Battery Power

The SONAHR system is designed to be used over several hours, to help with navigation. The table 3.2 shows the power considerations used in SONAHR to facilitate an operation time of 6 hours.

Device		3.3V Bus		Battery Bus 4.0V	
Part Number	Description	Current	Power	Current	Power
316040004	Motor Disk			20	80
FGPMMOPA6H	GPS Module	20	66		
Cortex M0	Processor	6.4	21.12		
Cortex M0	Voltage Regulator			0.125	0.5
BC118	BT Module	16	52.8		
Total current				62.525	

Table 3.2: SONAHR 2.0 active components and their power consumption

All currents in table 3.2 are in mA, with power in mW. The current on the main battery bus comes from the motor disks (through the MOSFET circuit) and the quiescent current on the voltage regulator internal to the processor. After voltage regulation to 3.3V by the processor, the main current draws come from the bluetooth module, GPS module, and the processor itself. During normal operation of SONAHR the motor disks will not operate continuously, thus reducing the current draw over time, but the normal current draw was maintained in the trade study in order to allow for some margin in the power system. All these components add up to a total required current of 62.525 mA, which indicates the size of the battery required by multiplying by the number of hours in operation. By using a 500 mAh LiPo battery, 8 hours of continual operation can be attained. This battery was ideally chosen to power SONAHR to balance the need for a lightweight system with the longer operation time needed. Due to product shortages, however, the 500 mAh battery could not be purchased and a 350mAh battery was used for lightweight purposes, with a 1200mAh battery used for initial debugging and testing purposes.

In SONAHR 2.0 a LiPo battery charger was included to allow for directly charging the device, without disconnecting the battery. The battery charger, however, was designed
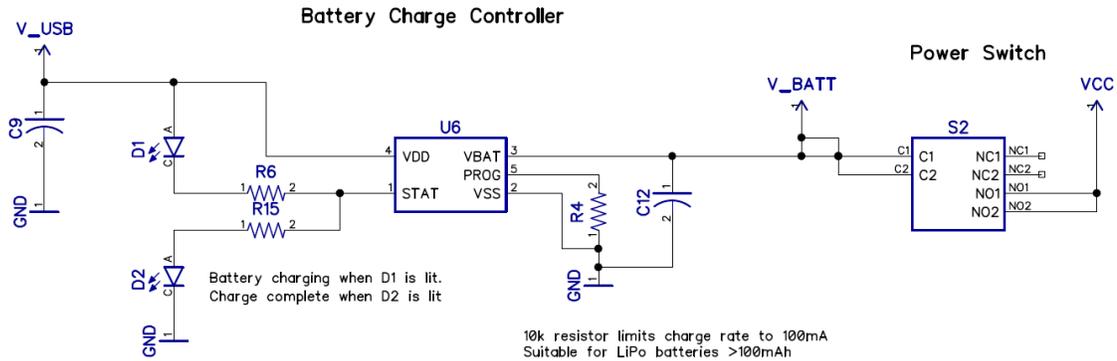
Fig. 3.4: SONAHR 2.0 Battery Charger Schematic

to only be powered when power external to the board is applied, thus disabling the battery charger when not necessary. The change controller (part number MCP73831 from Microchip) used for this design is a small device containing internal preconditioning and termination circuits to disable charging when complete. The termination circuit is set by an external resistor to the 4.2V maximum charge the charge voltage of the battery gets to the completed charge voltage of 4.2V for the LiPo battery cell used. The charge controller was connected through two external LEDs to notify the user of charge completion. The STAT pin on the MCP73831 is a tri-state output, with the output low during preconditioning, constant current, and constant voltage modes. The output switches to a high state when charge is complete and the device moves to standby. If no battery is detected on the VBAT pin, the status changes to High Z.

A power switch is connected between the battery connection and SONAHR's power bus. Disabling power before charging the battery is a must to eliminate the risk of damage to the battery by running it while charging. The external power supplied for battery charging is sufficient to power the charge controller and battery, and will do so with the switch disabling power to the voltage regulator and other circuitry.

3.1.4 Navigation

In theory any commercial GPS chip could be used in the SONAHR system. The GPS

chosen, the FGPMMOPA6H from GlobalTop Technology, has a UART communication interface of NMEA sentences. It was chosen for ease of use and availability in both a breakout board (for the proof of concept) and as a SMT component for SONAHR 1.0 and 2.0. The chip is configured to have the GPS update every 1 second, which is quick enough for most swimming as swimming is a relatively slow travelling form of locomotion. NMEA also has an extensive list of parameters that can be output by the GPS device. For this application, only the recommended minimum specific data (RMC) is requested from the chip. The structure of the RMC sentence is shown in the table below.

$–RMC,hhmmss.ss,A,llll.ll,a,yyyyy.yy,a,x.x,x.x,ddmmyy,x.x,a*hh

$–RMC	Sentence Header defining RMC sentence
hhmmss.ss	Time (UTC)
A	Satus, V = Navigation receiver warning
llll.ll	Latitude
a	N or S
yyyy.yy	Longitude
a	E or W
x.x	Speed over ground, knots
x.x	Track made good, degrees true
ddmmyy	Date
x.x	Magnetic Variation, degrees
a	E or W
hh	Checksum

Table 3.3: RMC NMEA Sentence Structure

These data include GPS fix notifications, speed (in knots), latitude, longitude and course direction. Using only the RMC sentence provides the needed information for navigation in this purpose (latitude, longitude, and direction) while limiting the excess power required in computing longer sentence structures or transmitting additional sentence structures. The 1 Hz update rate is also relatively slow, helping to reduce power consumption by the GPS unit. The GPS unit is configured to automatically send the GPS data, thus allowing the processor to wait for the GPS update and not issue more commands to the GPS chip beyond the required initial setup.

The NMEA sentence is parsed every 1 second and verified with the checksum on each

RMC sentence. If the checksum does not match, the data is discarded and the device waits for the next GPS fix data. After receiving the GPS fix data with a correct checksum, the device moves into navigation and computation. The current reference point input by the user is used as a reference to compare to the GPS data from the chip on SONAHR. The current location data of the user is averaged over the previous 5 seconds to help minimize error due to GPS precision problems. The angle from the current GPS location to the reference point location is described by the equation below.

$$refAngle(degrees) = atan2(\frac{|refLat - currentLat|}{|refLong - currentLong|}) + 180 \qquad (3.1)$$

This equation is a basic slope calculation from the current GPS point to the reference point, and then by taking the arctangent of the slope an angle can be computed. The 180 addition on the end is to make the number a positive number always. By taking the sum of this reference angle with the user's current direction and performing a modulus of 360 degrees, we can get a difference between the two as a positive number between 0 and 360. If the number is less than 180 the user is off course to the right. If the number is between 180 and 360 the user is off course to the left. This navigation system is used because the true navigational direction of the swimmer (with respect to North) does not matter, but merely how their current direction compares to the direction they want to go.

To eliminate the need to notify the swimmer to change course if they are close to the correct direction, the user's off course angle is compared to a pre-determined value. In SONAHR that value is currently hard-coded to 5 degrees based off individual preference, but a future version of the board could have the user set the value. If the swimmer is more than that bearing off in either direction, the navigational feedback system is started. The navigational feedback system consists of two identical circuits comprised of a MOSFET in a pull-up configuration to a connector leading to a vibrating motor disk.

The circuit in figure 3.5 is used to provide feedback to the user, with identical circuits going to a vibrating motor disk on either side of the user's head. The MOSFET is used to save the processor from driving the current required to run the motor disk, which is less
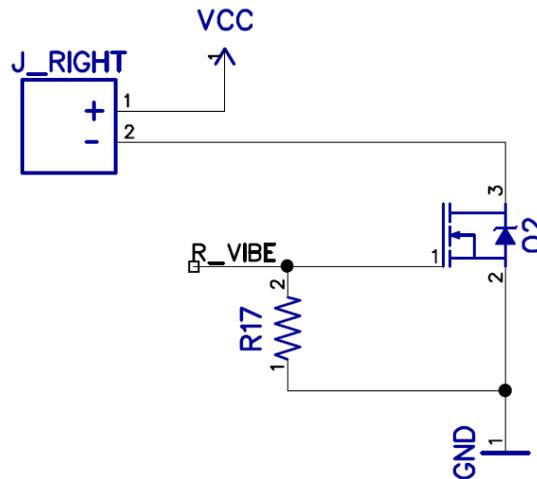
Fig. 3.5: MOSFET pull-up circuit on SONAHR

than 80 mA according to the datasheet, but measured values were closer to 40 mA. The circuit allows the motor disk to be turned on via a GPIO pin (R_VIBE in the schematic) on the processor but have the battery drive the required current from the device. That current is still quite large to be able to accommodate longer use of the device with frequent course correction while limiting size and weight of the battery system, so a pulsed vibration is used to alert the user of being off course. The pulses are given on one side of the head, and the user is to gradually turn away from the pulse. Thus, if the user was off course to the right, the pulse would come on the right side of the head and the user would turn to the left while continuing to swim.

Figure 3.6 shows a simplified flow diagram for the navigational software in SONAHR. Each time the GPS data is received, the distance between the current location and the reference point is calculated using the haversine formula [12]. If the user has not moved from the last point or is not close to the first point of the track (within the tolerance of GPS signals), then the program does nothing, disables course correction, and waits for the next input. If the user is "close" to the next point (currently set to 15 m), the reference point is changed to the next point and a brief pulse is output on both sides of the head to alert the user of the change to the next point. After moving to the next point, the program waits for

Fig. 3.6: SONAHR Navigation Software Flow Chart

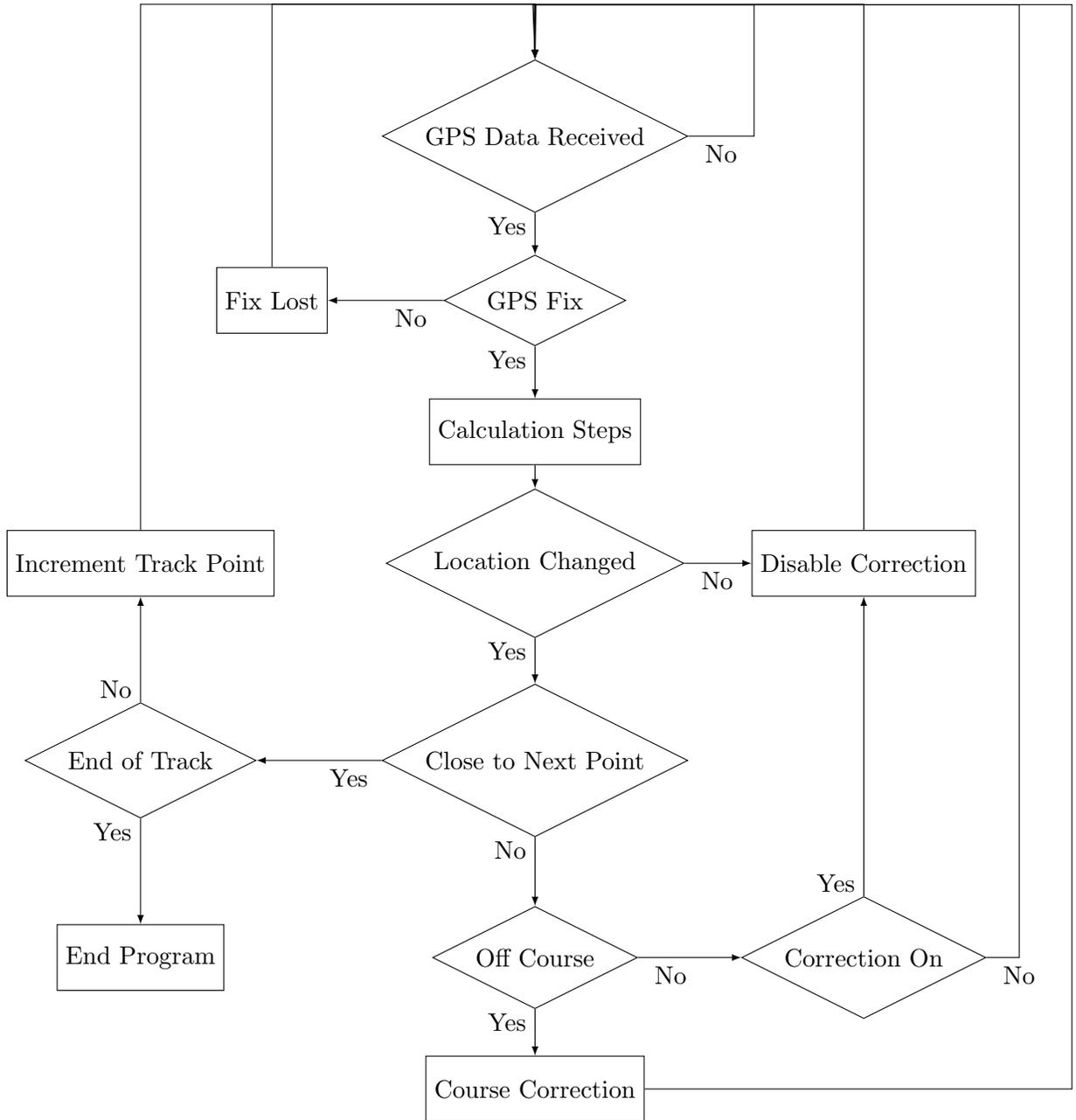more GPS data and then goes through the same navigational process as stated previously, with the reference as the new point. If the current point is the last point, the program terminates with a long pulse of three seconds and enters an infinite loop until reset, either by a power cycle on the device or by pressing the reset button on board itself, clearing the input data and waiting for a new track from the user.

3.2   Proof of Concept

The proof of concept version of SONAHR was developed to show the plausibility of a GPS device for navigation in open water swimming, and was made for the author's senior design project. It was developed using all COTS breakout boards and development kits, primarily purchased through Adafruit. There is no bluetooth capability, and all tracks had to be loaded directly into the device when programming. This unit was helpful for debug and initial testing of the design, as well as code development. The proof of concept design was completed with the Teensy LC Arduino board. A trade study was done to determine the best microcontroller for the job. Table 3.4 show the different design considerations for the decision matrix.

	Familiarity	Physical Size	Speed	Cost	Memory	Total
Weight	**0.4**	**0.9**	**0.1**	**0.3**	**0.6**	
Tiva C	5	1	5	5	5	7.9
Arduino FLORA	2	4	5	3	2	7
Raspberry PI Zero	1	3	5	5	5	8.1
Teensy LC	3	5	5	4	4	9.8

Table 3.4: Decision Matrix for PoC microcontroller

The main consideration in microcontroller is size. Since SONAHR needs to fit on a swimmer's head and be lightweight, there is significant emphasis placed on that part of the decision. Another big consideration is memory. There is no external memory included in the design, and the internal memory of the microcontroller needs to be able to hold the complete GPS track input by the user in addition to the memory required for the code. The other desgin considerations were familiarity with programming the device, speed, and

cost. By combining these weights, the decision was made to go with the Teensy LC for the microcontroller.

The design progressed from there to include a few other breakout boards and COTS components. Table 3.5 shows the bill of materials (BOM) for the proof of concept unit.

Part	Description	QTY
Teensy LC	Arduino Microcontroller	1
316040004	Vibrating Mini Motor Disc	2
1317	Adafruit Waterproof battery pack	1
1059	Adafruit Ultimate GPS breakout module	1
CN048D05	Solid State Relay	2

Table 3.5: Parts list for SONAHR proof of concept

The solid state relays were the original design for the proof of concept unit, being replaced by the MOSFET due to size and weight constraints in later versions. The proof of concept model was wired by hand and sewed onto an elastic headband for demonstration at the senior design night. The greatest challenge was the flexibility of the headband and the rigidity of the wires. Figure 3.7 shows the completed design of the SONAHR proof of concept.
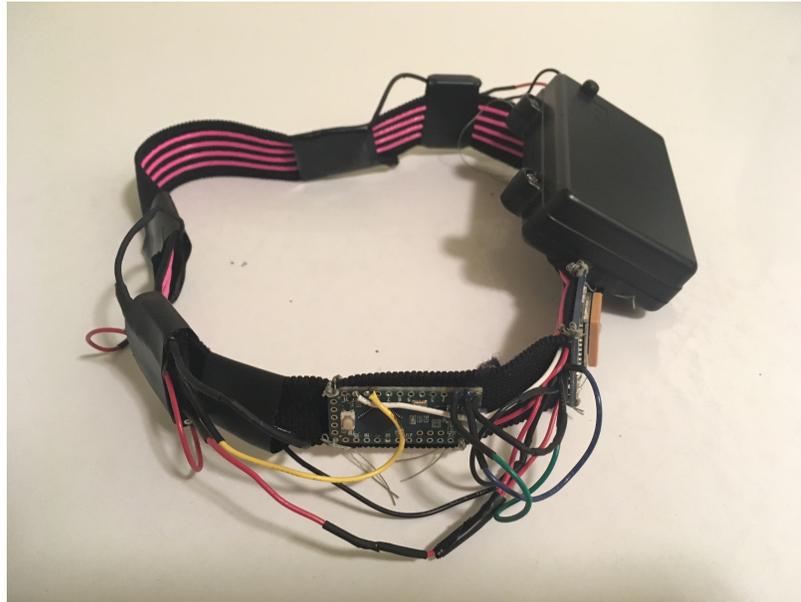
Fig. 3.7: SONAHR Proof of Concept complete

3.3 SONAHR 1.0

The Sant Fellowship money was used to develop the first true version of SONAHR. This design leveraged the proof of concept design, and took the steps to create a smaller, lighter weight board. The main point of this design was to get everything integrated into one unit, while also adding bluetooth functionality. A mobile application was also developed, with the help of a friend. This allowed the SONAHR unit to become truly a standalone unit, and didn't need to rely on direct programming from the computer anymore.

The schematic design for SONAHR 1.0 was done in Eagle, while using many of the breakout board schematics to help with the design. An Arduino pre-programmed bootloader was purchased to facilitate this design, with a Cortex-M0, the same microcontroller as on the Teensy LC, as the main processor on the device. The MOSFET circuit was designed for SONAHR 1.0 to replace the bulky solid state relay circuit. In addition, an external voltage regulator was added, as there was some uncertainty as to whether or not the internal voltage regulator on the processor could handle the current load from the various devices. Table A.1 in the appendix shows the complete list of parts on SONAHR 1.0.
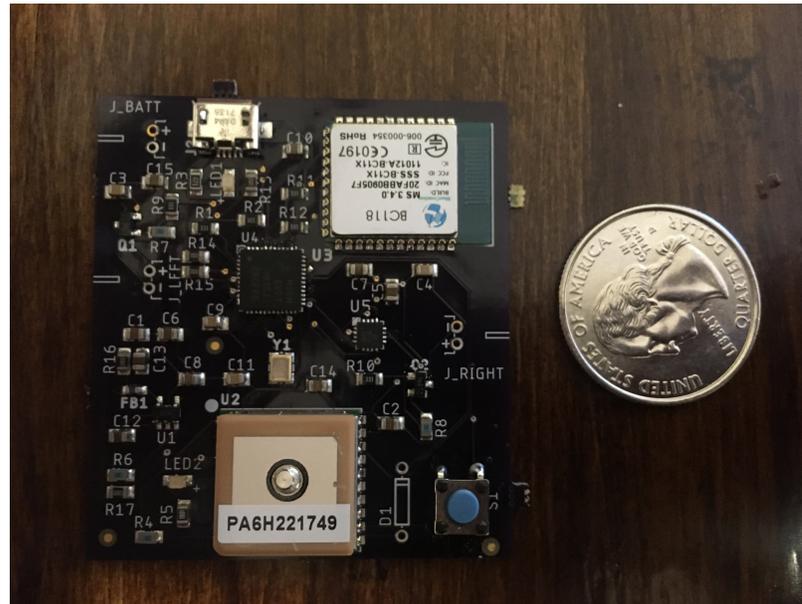
Fig. 3.8: SONAHR 1.0 assembled minus connectors, vibrating disks and battery

SONAHR 1.0 was completely assembled in March 2018, with verification and performance testing completed shortly thereafter. Figure 3.8 shows a mostly assembled version of the board.

The battery update was perhaps the most significant change on this board. Going from a very bulky and heavy AA battery pack to a small, Li-Po battery allowed SONAHR to become feasible as a mobile unit. One challenge with the battery design, however, was that there was no way to power off the device, besides unplugging the battery. That feature was overlooked. In a commercial design there would need to be a battery replacement ability or the ability to charge the battery. As a Li-Po battery was used in the design, another revision of the board was necessary to update the design with more features. Figure 3.9 shows the completed unit, including the battery and motor disks attached.

3.4   Sonahr 2.0

SONAHR 2.0 built off of version 1.0 by miniaturizing the device. Instead of 0805 SMT components, 0402 components were used for the majority of the passive components. Both sides of the board were used for this design, and the external voltage regulator was removed
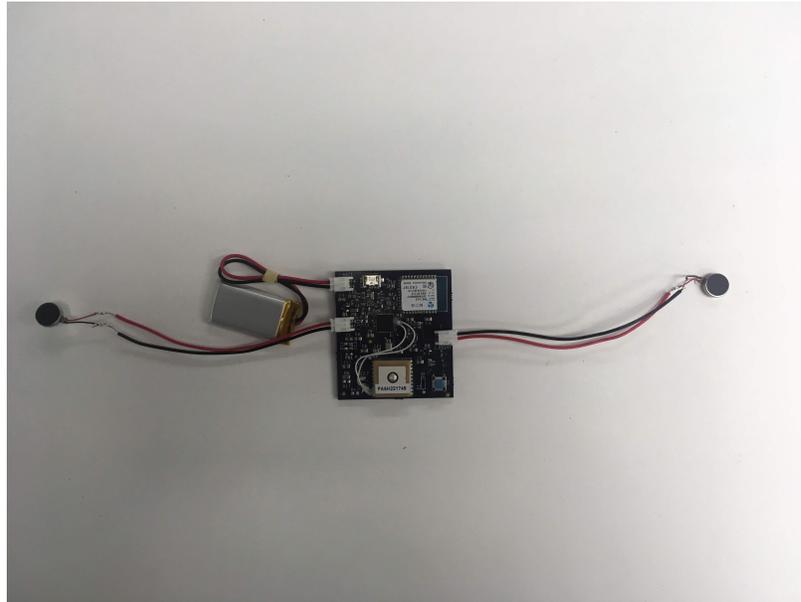
Fig. 3.9: SONAHR 1.0 with battery and vibrating motor disks - ready for navigation

after testing showed that it was not needed on version 1.0. The major design change from version 1.0 to version 2.0 was to change the design to add battery charging, as described in section 3.1.3. This allowed SONAHR to become even more of a standalone design and progress further into potentially becoming a commercial design. One design flaw was that the part ordered for the power switch does not have the capability of latching. This was an oversight by the author and could be remedied in future work. Due to the board already being fabricated, the decision was made to proceed with the design as it was and to use tape to hold down the power switch in the off position when necessary for battery charging.

Another design feature added was a reset button, to allow the user to reset the system without powering off. This allowed a design even closer to a commercial product. Figure 3.10 shows the completed board after assembly. This board was completed in January 2019 with debug and testing completed shortly afterwards. Table A.2 shows the complete bill of materials for SONAHR 2.0.

There were significant changes from the Proof of Concept design to the final design of SONAHR 2.0. These range from the much smaller Li-Po battery

Fig. 3.10: SONAHR 2.0 after board assembly

Fig. 3.11: A comparison of size between PoC unit, SONAHR 1.0 and 2.0

CHAPTER 4

Results

Testing electronics that are designed to be worn by a swimmer in the water without having a waterproof design is a challenge. To be able to test the design in the water would limit the ability to provide a quick prototype and tes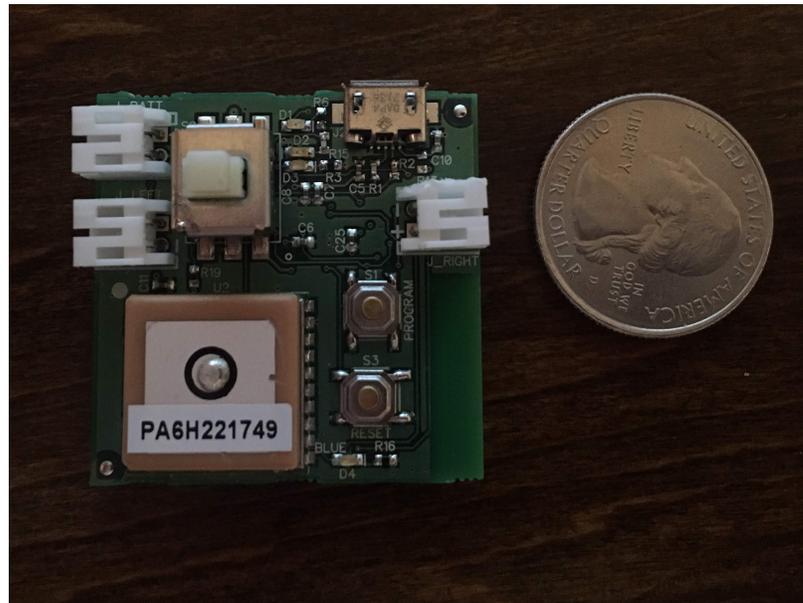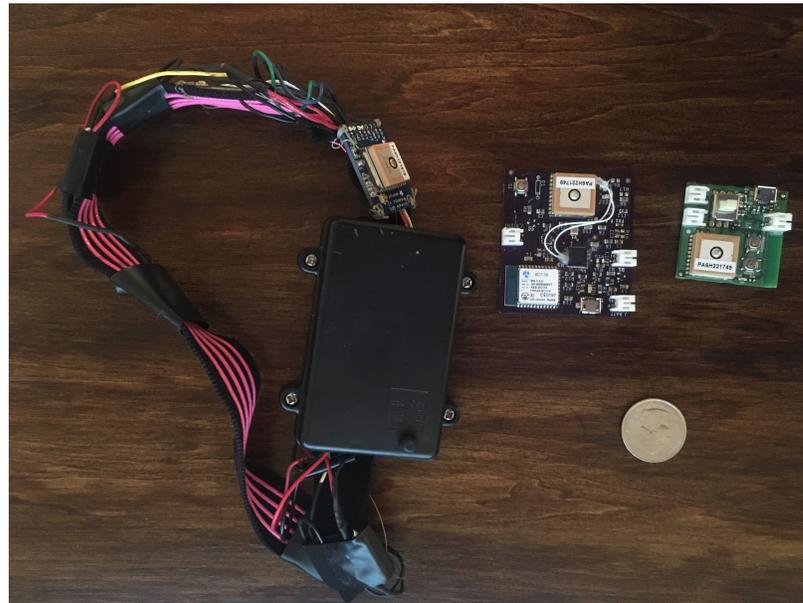t results, and would require a rigorous housing design, which is beyond the scope of Electrical Engineering. Thus, in order to provide adequate test data, the tests were conducted on dry land. The fastest humans in the water can travel at around 2 meters per second [13]. This speed translates to a brisk walking pace of around 4.5 miles per hour. As this speed is unlikely to be maintained over a long distance swim, a casual walking pace of around 2 miles per hour was deemed adequate for testing SONAHR. This speed allows for testing in a typical environment that a SONAHR user would be likely to experience.

Research bias is also a concern in the testing results, as the author has the most experience with the system and is therefore able to manipulate the system to perform in a favorable way. This was minimized by using testers who had no prior knowledge of the system and/or routes being used by the device. Some learning was required before testers could use SONAHR, but once they became accustomed to the vibration patterns the system was fairly easy to understand.

The testing configuration for SONAHR was with a USB cable connecting SONAHR to a laptop, as the normal operational mode for SONAHR does not report any data back to the mobile deive. A serial monitor (like PUTTY) on the laptop was used to monitor debugging information coming back from SONAHR to get the current location of the user, the on course variable (left, right, on course), and many other variable values each time the GPS location was transmitted to the processor. This data was then used to create plots in MATLAB to compare the user's pre-defined route with the route that they went. The results from these tests are summarized in sections 4.1 and 4.2.

4.1   Block testing

A common testing environment for SONAHR are routes around city blocks. These tests were easy to perform because city blocks or other routes are readily available around the area. The results of a test around the block in a Providence, UT neighborhood can be shown in figure 4.1. The course was chosen for convenience and shows the block test with the proof of concept version.

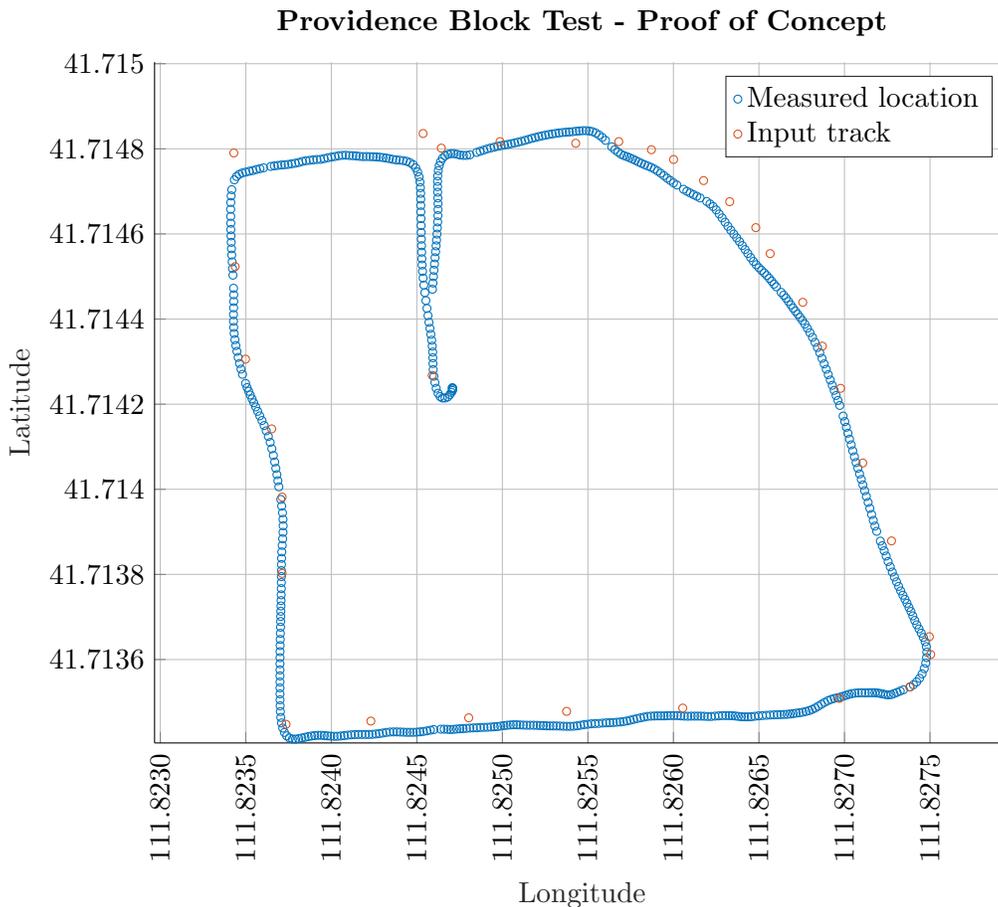Fig. 4.1: City block test in Providence,UT - Actual position versus input track

Another example of a block test - this one with the SONAHR 2.0 version, around a block in the River Heights, UT neighborhood - is shown in figure 4.2. In this test, designed to take advantage of a baseball field for a little open space testing as well, the user was on

Fig. 4.2: Block test in River Heights, UT - actual route vs input track

course 25.01% of the time, off to the right 23.6% of the time, and to the left 43.01% of the time. The rest of the points (8.38%) were the user arriving on course. This is indicative of how many times the user went off course. The great amount of time off course was in large part due to obstacles being in the way. The large proportion of time being off to the left is due to the course having The GPS accuracy was such that the points could sometimes be off the sidewalk or road and on the other side of a fence, thus making it impossible to be on the correct path. The user had to travel around the obstacles before they could return to the course. In addition to these problems, the open space route test for part of this track (seen in the upper portion of the plot) was done in such a way as to create some zig-zag type pattern for the user to have to correct course frequently. This also contributed to the greater number of off-course readings.

4.2   Open space test

A more indicative test of SONAHR's ability to direct a swimmer is an open space test. In this test, a larger, open space was selected (such as a field), to direct the user on a track. This more open space is much more indicative of a lake or ocean in which a swimmer would most likely be training or competing. The designed route was a half-mile square track, similar to some competitive open-water swimming tracks used for triathlons or other events, with the corners of the track marked by buoys. In order to more fully simulate swimming, the user did the track with their head down, looking at the ground, and not at landmarks to ascertain direction.

On the track shown in figure 4.3, the user was on course more. The total on-course percentage was 59.17%, with 10.28% to the left and 23.10% to the right. The remainder of the time (7.45%) was spend arriving on course, which gives a good measure of how many times the user was off course. The greater number of points off to the right is indicative of all of the route turns being to the left. Thus every time the track turns the user is off course to the right until they correct. This test is a better example of open water swimming, and SONAHR performed according to specifications and requirements in directing the user along the course.
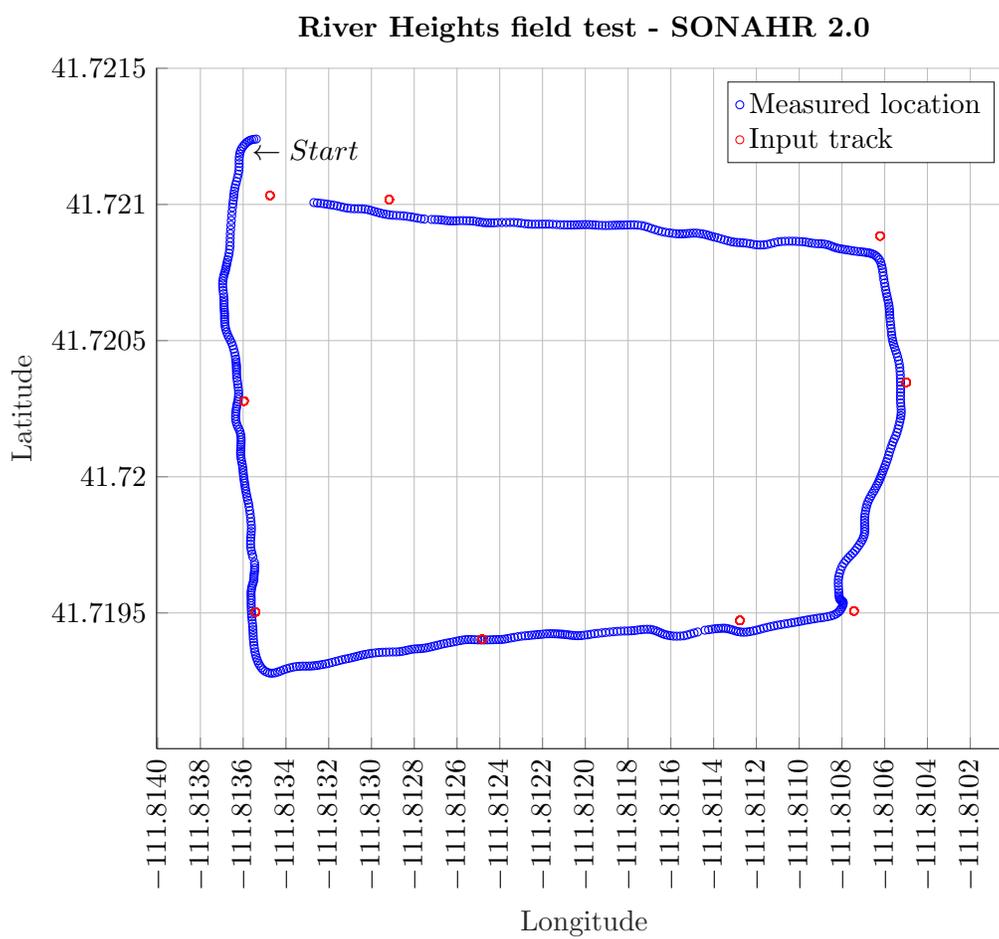
Fig. 4.3: Half mile square field test in River Heights, UT - actual route vs input track

CHAPTER 5

Conclusion and Future Work

In this report, one solution to an open-water swimming navigation problem is described. Open-water swimming navigation is currently done by repeatedly lifting the head to sight landmarks, leading to increased drag and fatigue on the the swimmer. To solve this issue, it was desired to have a system that would be lightweight and portable and assist the swimmer to navigate a pre-planned track. The user had to be able to change the track and there had to be success in directing the swimmer on that course.

SONAHR was designed to partially fill these needs. SONAHR is a standalone device that takes a user-defined GPS track transmitted over bluetooth from a mobile application. Data from an on-board GPS chip is compared to that track to direct the user along a given course. The swimmer is notified of direction changes by two vibrating motor disks, designed to be placed on both temples of the swimmer.

SONAHR is a good first attempt at trying to solve the open water swimming navigation problem. Several changes could be made to improve the system, however. First, SONAHR is not in a waterproof or water resistant packaging. In order to be used for its intended purpose, a rugged, lightweight mechanical design for a housing for SONAHR needs to be completed. Once that step is accomplished the goal of seeing open water swimmers using SONAHR could become a reality.

Second, SONAHR works as a rudimentary GPS navigational system, but a more intuitive feedback system would be more beneficial. This could include an earbud system with verbal cues instead of the vibrating motor disks on the head. In addition to the updated feedback system, a more comprehensive user interface on the front end would also help. Integrating Google Maps into the SONAHR mobile app would help to make SONAHR easier to use and more marketable to a broader range of people.

Third, SONAHR could add other capability, such as real-time communication with the

mobile device for trainers to track swimmers. Other options include adding temperature sensors and keeping track of distance and/or speed swum. Other data could be taken as well and either be fed back immediately to the mobile device, or stored onboard before syncing with the mobile device after the swim is complete. By adding these changes, SONAHR could also be used for navigation in other environments, not just open water. The current design could function as a navigational device in other areas, as shown by the testing on land to verify feasibility in the water. Hiking or backpacking are great examples of where SONAHR could be useful.
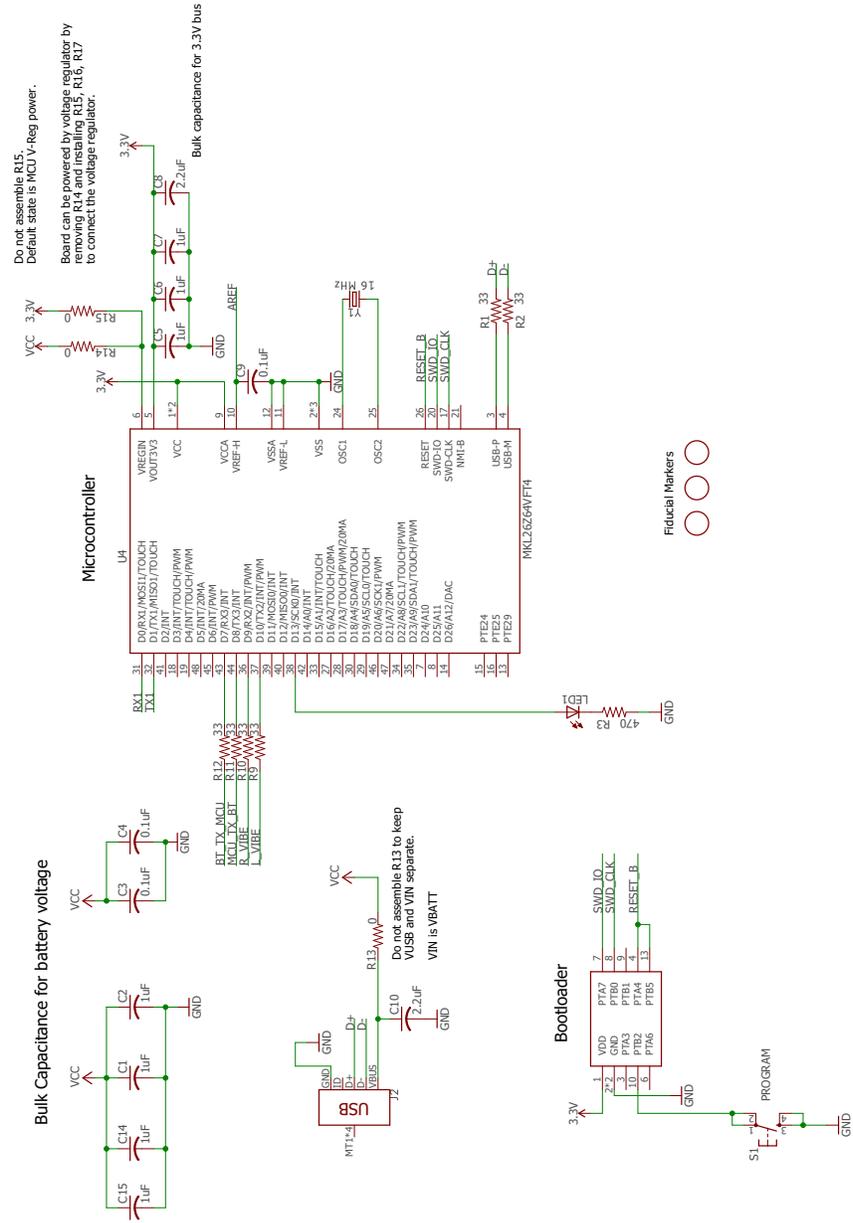
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APPENDICES

APPENDIX A

Reference Diagrams

A.1 SONAHR 1.0

Do not assemble R15.
Default state is MCU V-Reg power.

Board can be powered by voltage regulator by removing R14 and installing R15, R16, R17 to connect the voltage regulator.

Bulk capacitance for 3.3V bus

3.3V

C8 2.2uF

C7 1uF

C6 1uF

VCC 3.3V

R15 0

R14 0

C5 1uF

3.3V

AREF

GND

C9 0.1uF

16 MHz
Y1

R1 33 D+
R2 33 D-

Microcontroller

U4

VREGIN
VOUT3V3
VCC
VCCA
VREF-H
VSSA
VREF-L
VSS
OSC1
OSC2
RESET
SWD-IO
SWD-CLK
NMI-B
USB-P
USB-M

D0/RX1/MOSI1/TOUCH
D1/TX1/MISO1/TOUCH
D2/INT
D3/INT/TOUCH/PWM
D4/INT/TOUCH/PWM
D5/INT/PWM
D6/INT/PWM
D7/RX3/INT
D8/TX3/INT
D9/RX2/INT/PWM
D10/TX2/INT/PWM
D11/MOSI0/INT
D12/MISO0/INT
D13/SCK0/INT
D14/A0/INT
D15/A1/INT/TOUCH
D16/A2/TOUCH/20MA
D17/A3/TOUCH/PWM/20MA
D18/A4/SDA0/TOUCH
D19/A5/SCL0/TOUCH
D20/A6/SCK0/PWM
D21/A7/20MA
D22/A8/SCL1/TOUCH/PWM
D23/A9/SDA1/TOUCH/PWM
D24/A10
D25/A11
D26/A12/DAC
PTE24
PTE25
PTE29

MKL26Z64VFT4

RESET_B
SWD_IO
SWD_CLK

RX1
TX1

R12 33
R11 33
R10 33
R9 33

BT_TX_MCU
MCU_TX_BT
R_VIBE
L_VIBE

LED1

470 R3

GND

Fiducial Markers

Bulk Capacitance for battery voltage

C4 0.1uF
C3 0.1uF

GND

VCC

C2 1uF
C1 1uF
C14 1uF
C15 1uF

VCC

GND

VCC

Do not assemble R13 to keep VUSB and VIN separate.

VIN is VBATT

R13 0

C10 2.2uF

GND

USB

J2

GND
ID
D+
D-
VBUS

MT1*4

D+
D-

Bootloader

VDD
GND
PTA3
PTB2
PTA6

PTA7
PTB0
PTB1
PTA4
PTB5

SWD_IO
SWD_CLK

RESET_B

3.3V

GND

PROGRAM

S1

GND

Bluetooth

GPS Unit

Voltage Regulator

Do not assemble R16 and R17.
Default state is MCU V-Reg power.

Using TLV700DCT, Pin 4 is a No Connect

QTY	Part Number	Description	Ref. Designator
1	FGPMMOPA6H	IC, GPS Receiver Chip - NMEA	U2
3	S2B-PH-K-S(LF)(SN)	Connector, 2-Pin JST-PH	J_BATT, J_RIGHT, J_LEFT
2	CSI: 21090	SMT LED 0805 RED	LED1, LED2
1	1981568-1	USB Type Micro-B Connector	J2
5	CSI: 13637	Resistor, SMT 0 Ohm 0805	R13, R14, R15, R16, R17
4	CSI: 33238	Capacitor, SMT 0.1uF 0805	C3, C4, C9, C11
4	CSI: 20825	Resistor, SMT 10k Ohm 0805	R4, R6, R7, R8
2	C0805C106K8PACTU	Capacitor, SMT 10uF 0805	C12, C13
1	FA-238 16.000MB-K3	16MHz crystal	Y1
1	CSI: 10116	Resistor, SMT 1k Ohm 0805	R5
7	C0805C105K4RACTU	Capacitor, SMT 1uF 0805	C1, C2, C5, C6, C7, C14, C15
2	C0805C225Z4VACTU	Capacitor, SMT 2.2uF 0805	C8, C10
2	BSS138KCT-ND	MOSFET N-Channel	Q1,Q2
1	TLV70033DDCT	IC, Voltage Regulator 3.3V, 150mA	U1
1	CSI: 29908	Ferrite bead	FB1
6	CSI: 17487	Resistor, SMT 33 Ohm 0805	R1, R2, R9, R10, R11, R12
1	CSI: 20832	Resistor, SMT 470 Ohm 0805	R3
1	BC118-1103394	IC, SMT Bluetooth Module	U3
1	MKL26Z64VFT4	IC, ARM Cortex M0+ Processor	U4
1	IC_MKL02Z32_QFN16	IC, Arduino Pre-programmed Boot-loader	U5
1	CKN9112CT-ND	Momentary Switch, SMT	S1

Table A.1: BOM for SONAHR 1.0

A.2   SONAHR 2.0
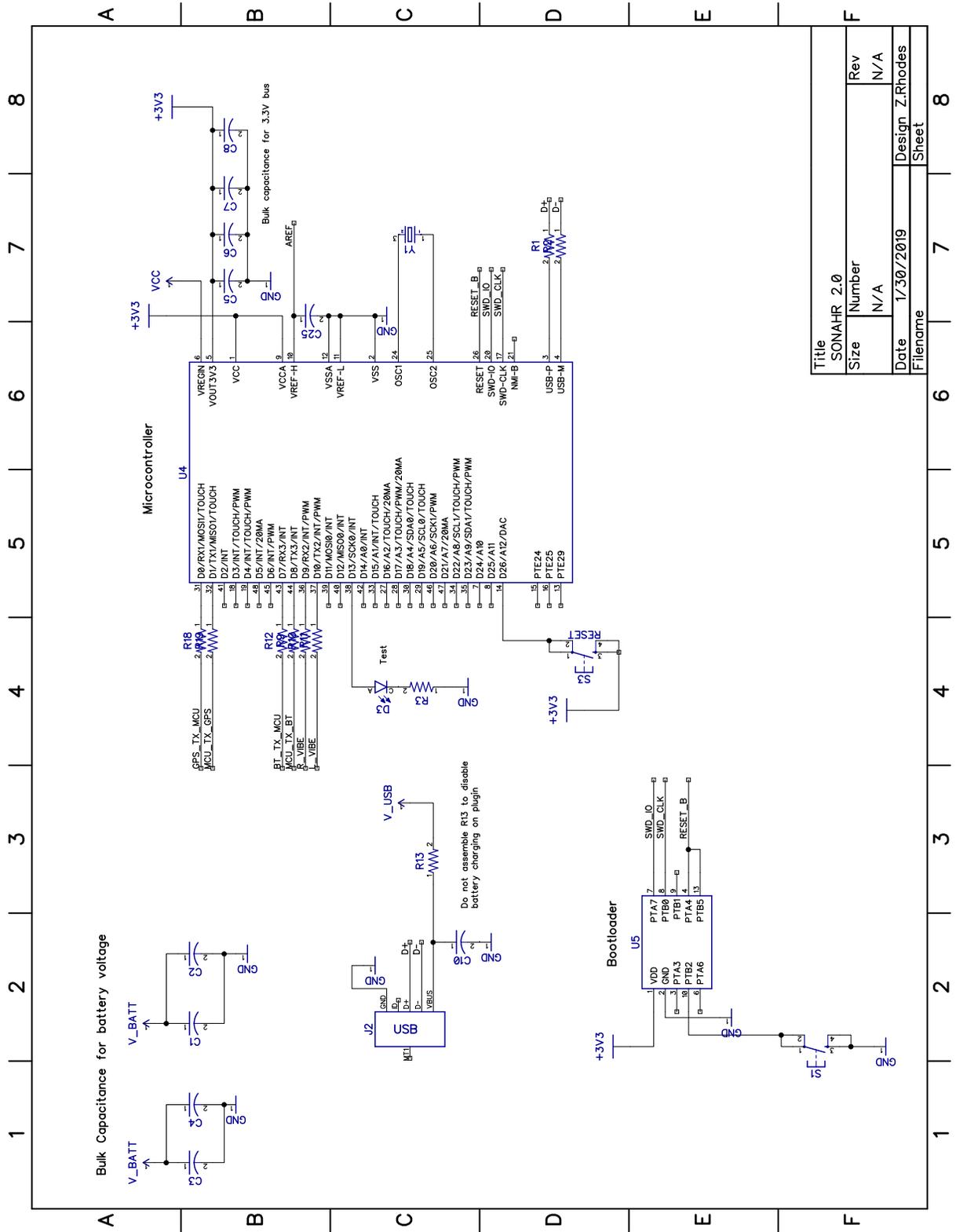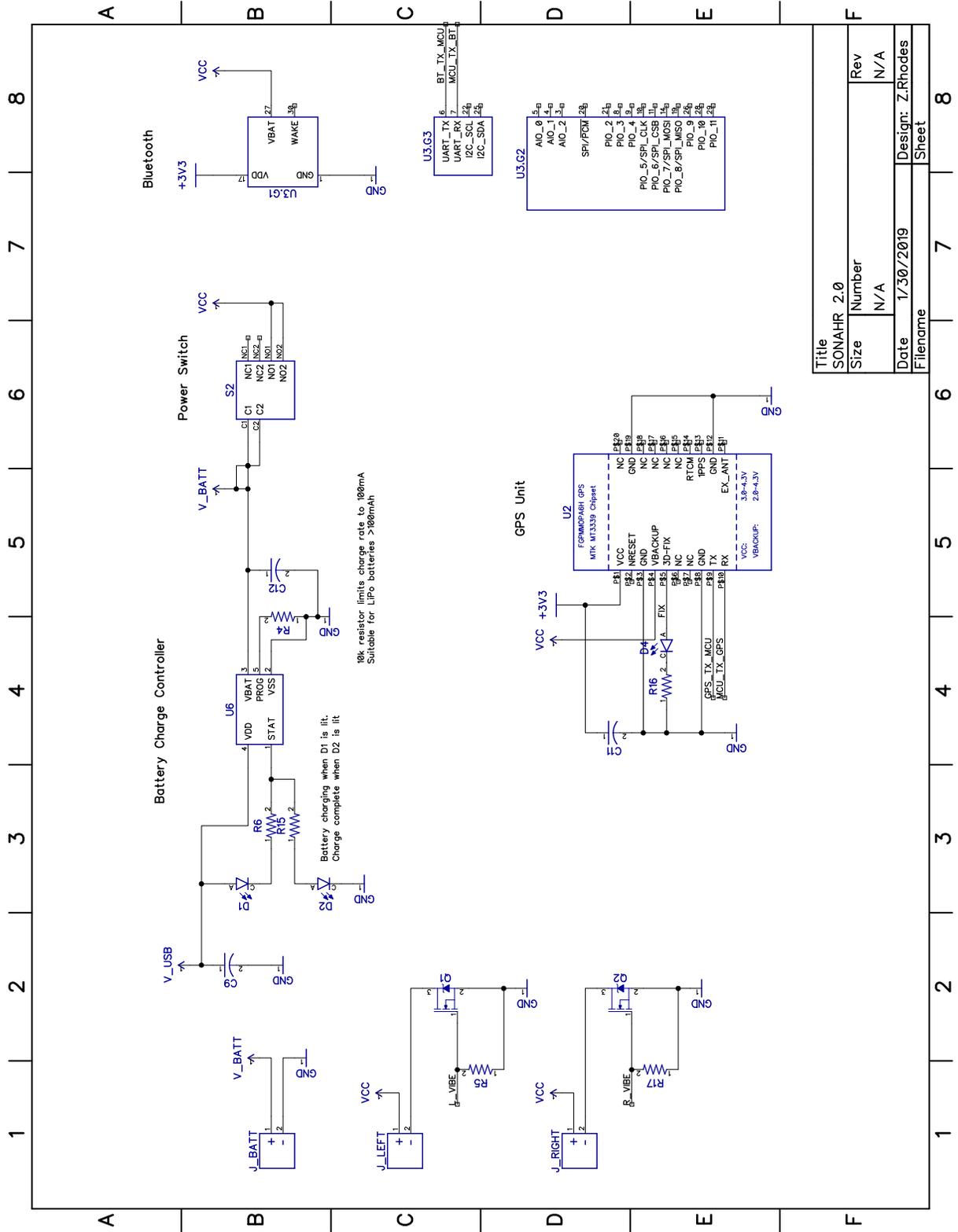
Microcontroller

Bulk Capacitance for battery voltage

Bulk capacitance for 3.3V bus

Do not assemble R13 to disable battery charging on plugin

Bootloader

38

QTY	Part Number	Description	Ref. Designator
5	C0402KRX5R5BB105	Capacitor, SMT 1uF 0402	C1, C2, C5, C6, C7
4	CSI: 27407	Capacitor, SMT 0.1uF 0402	C3, C4, C11, C15
2	GRM155R60J225ME15D	Capacitor, SMT 2.2uF 0402	C8, C10
2	CSI: 31498	Capacitor, SMT 10uF 0603	C9, C12
1	CSI: 27656	LED, Red 0603	D1
1	CSI: 27655	LED, Green 0603	D2
2	CSI: 31963	LED, Blue 0603	D3,D4
1	A97800CT-ND	Micro USB Connector	J2
3	S2B-PH-K-S(LF)(SN)	Connector, 2-Pin JST-PH	J_BATT, J_RIGHT, J_LEFT
2	BSS138KCT-ND	MOSFET N-Channel	Q1,Q2
8	CSI: 29918	Resistor, SMT 33 Ohm 0402	R1, R2, R9, R10, R11, R12, R18, R19
4	CSI: 28498	Resistor, SMT 470 Ohm 0402	R3, R6, R15, R16
3	CSI: 8798	Resistor, SMT 10k Ohm 0603	R4, R5, R17
1	CSI: 31898	Resistor, SMT 0 Ohm 0402	R13
2	B3F-1000	Switch, SMT tactile	S1,S3
1	ESB33536	Switch, SMT Push-Button DPDT	S2
1	FPGMMOPA6H	IC, GPS Receiver Chip - NMEA	U2
1	BC118-1103394	IC, SMT Bluetooth Module	U3
1	MKL26Z64VFT4	IC, ARM Cortex M0+ Processor	U4
1	IC_MKL02Z32_QFN16	IC, Arduino Pre-programmed Boot-loader	U5
1	MCP73831T-2DCI/OT	IC, Li-Ion cell charge controller	U6
1	SER4046CT-ND	IC, 16 MHz oscillator 3.2x2.5mm	Y1

Table A.2: BOM for SONAHR 2.0