November 9th, 2015

Dr. Andrew Rawicz
School of Engineering Science
Simon Fraser University
Burnaby, BC, V5A 1S6

LocalSonic

Re: ENSC 440W - Design Specifications for Local Guidance System

Dear Dr. Rawicz,

The attached document is from LocalSonic entailing the design specifications for the Local Guidance System (LGS). We are designing and implementing a local positioning system that will assist the visually impaired by informing the user where they are in relation to the closest nodes in the system. Our project consists of ultrasonic beacons and a user device, the NavU. Using time of flight, distance can be measured between the two devices and the user's location can be found. This system will serve as an elementary guidance system to give users audio feedback on their physical location and may be improved on outside of this project course.

The purpose of our design specifications document is to outline the design details and justifications to achieve the functional requirements entailed in a previous document "*Functional Specification – Local Guidance System (LGS)"* [1]. These design specifications mainly focus on the proof-of-concept model due to time and page restrictions. In addition, the test plan documentation has been included in the design specification to be used as a guide when verifying the model functionality.

LocalSonic consists of five talented engineering students: Andrew Chan, Justin Crosby, Yihao Zhang, Shuo Yang, and Han Shen. If you have any concerns, or questions about our design specifications, please feel free to contact Andrew Chan 604-671-1028 or by email at acc37@sfu.ca.

Sincerely,

Andrew Chan
Chief Executive Officer
LocalSonic

Enclosure: *Design Specifications for Local Guidance System*

Design Specification
Local Guidance System (LGS)

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Issued Date: Nov. 9, 2015

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Executive Summary

This design specifications document covers the details of the design and development of the individual components that make up the proof-of-concept model for the LGS. The goal of this document is to provide a detailed description towards the justifications of our design choices.

The proof-of-concept model of the LGS contains of two major components – the NavU and the beacon. This document will be divided into sections that describe the hardware and firmware development of these individual components and the technical details that satisfy the functional requirements labeled I or II in the previous document “Functional Specification – Local Guidance System (LGS)” [1].

The last section of this design specifications document covers a set of test cases that will evaluate the functionality of the proof-of-concept model. The test plan consists of two parts: individual component testing and integrated system testing. Details towards the testing procedures will be discussed in their respective parts.

Although the target of the development cycle was to be four months, as noted in the document Functional Specification – Local Guidance System (LGS), the deadline may not be met due to unforeseen issues such as large delays in delivery and faulty delivered components [1]. Therefore, it is possible that the development phase may be extended.

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Glossary

Aumix	Sound application included with the Raspberry Pi's Raspbian operating system
C	General-purpose programming language
CAD	The Canadian dollar
Cartesian coordinate	Refers to a system that identifies points with a pair of numerical coordinates
dB	Decibels - used to measure volume, sensitivity, or general gain in a circuit
ID	Identification value
kHz	A metric used that represents one thousand Hertz
LGS	Local Guidance System
NavU	Wearable user device for the LGS
LGS User	A person operating the NavU with the following characteristics:

- Is capable of maneuvering in a public indoor environment
- Has healthy hearing capabilities
- Is not accompanied by animals
- May be visually impaired

Ping	A radio message that elicits a response to the source of the message
RPi	Raspberry Pi, the microcontroller that is used throughout this project
RSS-GEN	Industry Canada Standards for General Requirements for Compliance of Radio Apparatus
RSS-102	Industry Canada Standards for Radio Frequency (RF) Exposure Compliance of Radiocommunication Apparatus (All Frequency Bands)
Ultrasound	Sound waves having a frequency above 25kHz
V	Voltage
wiringPi	A library of code used to interface Raspberry Pi's input/output pins

1. Introduction

LocalSonic's Local Guidance System (LGS) is a turn-by-turn navigation system for indoor use to aid the visually impaired. Pressing a button on the user device (NavU), a component of the LGS, will make the NavU emit a combination of radio and ultrasonic waves. These ultrasonic waves will be received by nearby beacons with ultrasonic sensors, which will relay the LGS user's distance from the beacon to the NavU. The NavU will then inform the LGS user of their physical position in relation to the closest landmarks inside the building via audio. The design details for each component of the proof-of-concept model of the LGS will be described in this design specifications document.

1. Scope

The technical design details of the proof-of-concept LGS to meet the functional requirements specified in the document *Functional Specification – Local Guidance System (LGS)* are described in this design document [1]. These design specifications will fully cover the requirements of the proof-of-concept model and may partially cover the requirements of future evolutions of the LGS. Since the focus of the design is to accommodate the proof-of-concept system, only design considerations that meet the functional requirements labeled **I or II** of the document *Functional Specification – Local Guidance System (LGS)* will be discussed [1]. Test plans to evaluate the model functionality will be discussed in section 6.

2. Intended Audience

This design specifications document is intended for use by all members of LocalSonic and any party desiring to recreate the LGS. This document will be referred to throughout the development of the LGS and will be used to measure progress and accuracy of desired results. Any testing required of the LGS will also refer to this document to assess proper functionality. Any party desiring to assess compliance of standards may refer to this document.

2. System Specifications

2.1. System Overview

LocalSonic's Local Guidance System consists of two main components, the NavU and the beacon(s) that handle user input and provide feedback as shown in Figure 1.

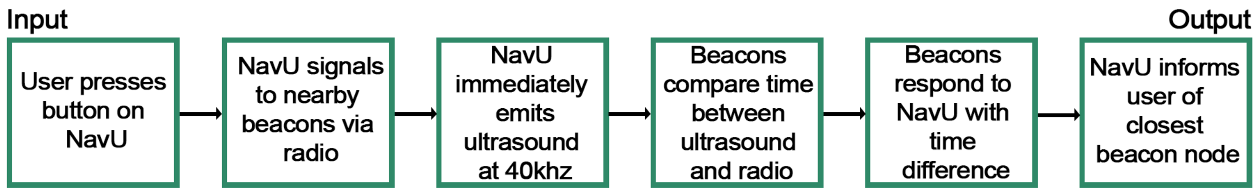

Figure 1: System Response Diagram

The Local Guidance System is a local positioning system that, at the press of a button, informs users of the closest landmarks via audio. It uses a combination of radio and ultrasound to triangulate the user. The LGS is designed to work inside public and multi-level buildings such as libraries and schools. However, the LGS is not designed to work out of the box. Each building is different and therefore the number of beacons and beacon placement has to be recorded and stored in the NavU for accurate triangulation of the user.

The LGS requires adequate line-of-sight between the NavU and beacons to function accurately. To guarantee line-of-sight from the user, the NavU has to be worn in a way such that the emitters can emit ultrasound without obstruction from the user's body. Beacon nodes will be spaced out and placed over main landmarks such as doors in a way that will have little obstruction and line-of-sight to the user can be established.

The NavU consists of 5 emitters, a radio transceiver, a microcontroller, and a battery pack. Of the 5 emitters, there are 4 on the horizontal plane and 1 on the vertical plane for a near complete hemispheric coverage as seen in Figure 2. The radio transceiver must operate on a frequency that is not commercially licensed and must not interfere with other radio devices in its environment.

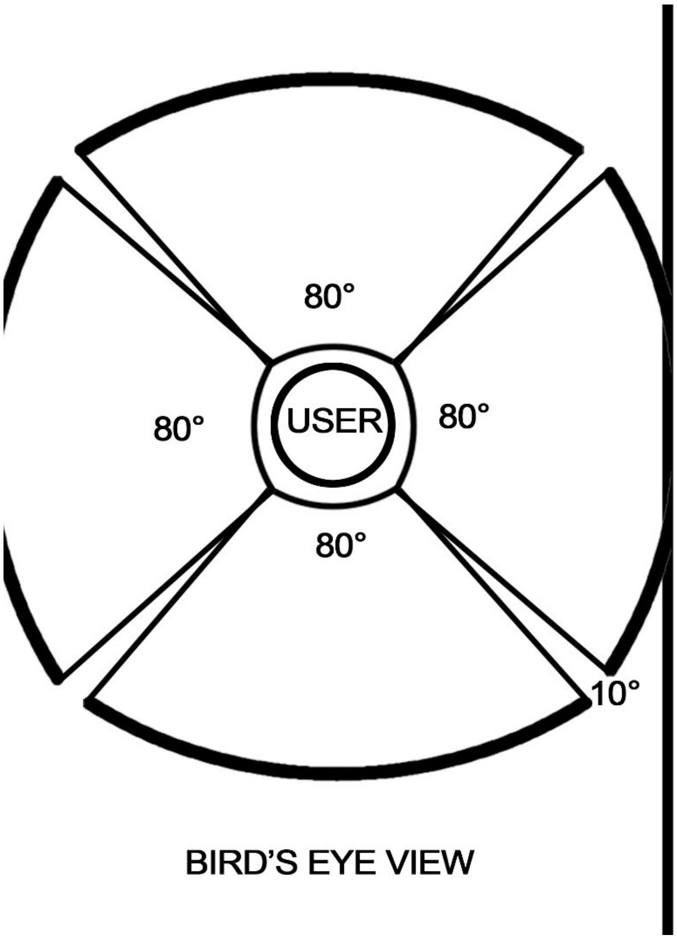

Figure 2: Emitter Coverage

The beacon consists of a microcontroller, a radio transceiver, and 2 receiver nodes spaced 4 meters apart from the microcontroller apart as shown in Figure 3. Additional nodes can be added to the microcontroller as long as they are mapped correctly in the NavU. Each node will have a specific ID that is used for triangulation purposes.

Figure 3: Beacon Setup

The LGS must accommodate the LGS user as defined in the glossary, which will be referred to as the user from this point on.

2.2. System Functionality Justification

The functionality of the system was designed around the fact common technology, such as GPS, has poor performance towards indoor navigation or navigation around dense areas. Although indoor navigation tends to be of little issue for the average person, the visually impaired tend to have issues navigating large public buildings.

The goal for the LGS is to be a low-cost indoor navigation solution that can be scalable to any public building and provides ample feedback to the user of the system. The scalable component (the beacon) had to be cost effective and use low power. Since our system is to work with the visually impaired, audio feedback about the user's location would be the most appropriate.

The original project conception involved using only radio to triangulate the user, but because of the incredibly fast traveling speed ($300 * 10^8$ m/s) of radio, a slower wireless signal had to be paired with radio because no suitable microcontroller can process radio input and output fast enough to discern a time difference in the short distances the LGS is designed for. Ultrasound was chosen due to its much slower flight speed compared to that of radio (340 m/s). The two different flight speeds of ultrasound and radio allow for a time of flight calculation of the wireless signals, which will enable distance measurement.

3. Overall System Design

A high-level overview of the entire proof-of-concept model is covered in this section. Because the LGS consists of two main components, the following subsections will be divided to accommodate the design details respective to those components. Our design approach involves looking at the several categories of requirements such as hardware, firmware, and power, thus our sub-subsections are divided accordingly for each component.

3.1. Beacon

The purpose of the beacon is to detect any ultrasonic signal of 40 kHz at the receiver nodes from any angle that the ultrasonic emitter is expected to operate in. The beacon has to be capable of communicating with the NavU unit through radio. Since the beacon and receiver nodes are required to be placed in a position of 2 meters of height, the ultrasonic sensors have to be positioned in such a way that it has full 180° reception on the horizontal plane and at least 90° reception on the vertical plane (see Figure 4).

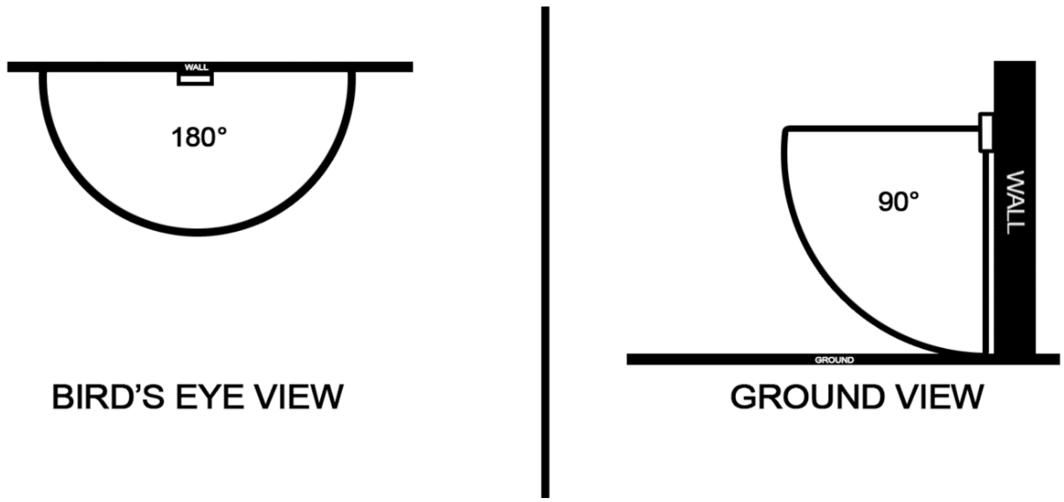

Figure 4: Beacon ultrasonic reception angle coverage

There are two options to calculate the distance of the ultrasonic emitter. One method is to calculate the signal strength of the ultrasonic wave and the other is to compare the arrival time of the ultrasonic wave to another signal. We decided that comparing the ultrasonic wave arrival time to the arrival of a radio signal from the emitter would be ideal since the radio signal would arrive relatively instantaneous.

3.1.1. Hardware and Electronic Design

To accommodate the functional requirements of the beacon, we had to explore the hardware and electronic design of each step of transducing an ultrasonic wave to a digital signal for the beacon to calculate time of flight of the ultrasonic wave. (see Figure 5).

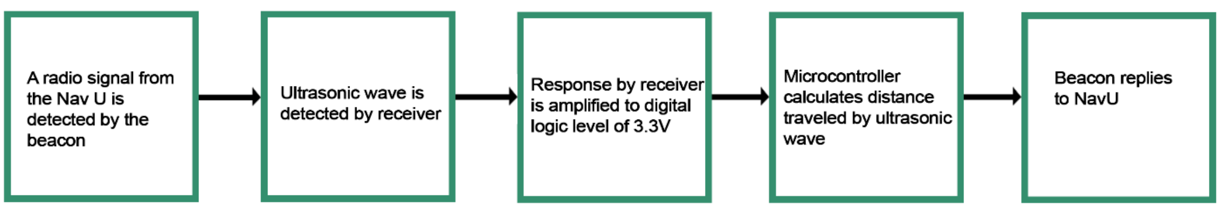

Figure 5: Block Diagram of Signal Process at Beacon

- For our design, the first step in the whole triangulation process on the receiver side is for the beacon to receive a radio signal from the NavU to start listening for ultrasonic waves. When the radio signal is received, a timer begins and when the ultrasonic wave arrives, the timer is stopped. If an ultrasonic signal is never received, the beacon times out. This means the microcontroller at the beacon requires a radio transceiver and also has to process input quickly enough to discern a time difference between the arrival of the radio signal and ultrasonic wave. To fit this requirement, we chose the Raspberry Pi (RPi) model A+. It processes input quickly enough to fit our accuracy resolution of 1 meter and is small enough to be easily installed. A general radio transceiver that is capable of communicating on a frequency received by the NavU is used. All beacons will use the same frequency so that the NavU only has to tune into one frequency for data.

- After the radio signal is received, the 40 kHz ultrasonic wave arrives at the ultrasonic receiver sensor. Most ultrasonic sensors on the market currently combine the emitter and receiver on the same unit, making it difficult to separate the receiving and emitting functionality. The sensor we have chosen to use is the Murata MA40S4S [2]. Murata was the only vendor we found that sold separate sensors and emitters, which suited our purpose. At 4 meters, the sensor has a maximum sensitivity of -63dB and produced an analog sinewave DC response when a 40 kHz sound wave is detected. The voltage level of the response is proportional to the strength of the detected ultrasonic wave.
- The next stage requires the receiver signal to be amplified to reach the detectable logic levels of the microcontroller. Most microcontrollers consider 3.3V as a logic '1' value, therefore our operational amplifier has to amplify our received input from all detectable distances to reach at least this voltage. Another aspect of this amplification stage to consider is that the amplification has to be saturated so that the sinewave becomes a square wave. A final consideration is that the amplifiers used must have low output impedance so that the microcontroller does not get damaged from high input current entering its input pins.
- The ultrasound response is detected by the microcontroller and the timer is turned off. Because sounds travel at roughly 340 meters per second, the distance can be calculated from the recorded time. The beacon then sends the data about the distance to the NavU using radio.

To power the microcontroller and gain circuits in the beacon and receiver nodes, two different sets of power supplies are required because the nodes are spaced very far from the microcontroller in the beacon (see Figure 3).

3.1.2. Firmware Design

To reduce latency, all programming is done with C on the RPi with the wiringPi library [3]. The wiringPi library allows the RPi to read input and output data suitably fast and makes programming input/output pins relatively easy compared to the other options using C.

In the LGS, all beacons and the receiver nodes that are part of the beacon will have an individual ID. This is to help distinguish which receiver nodes have detected ultrasound and which beacon is transmitting radio.

Because each emitter from the NavU is pulsed individually, the NavU has to discern which distance calculation correlates to which emitter projection. Therefore, the NavU will include the ID of the emitter in the radio signal to the beacon before pulsing the corresponding emitter.

When the radio signal is received on the beacon side, a time stamp is recorded. If an ultrasonic wave is detected at a receiver node within the next 27 milliseconds, the beacon takes the time difference between when the ultrasonic wave is detected and when the radio signal is received. Multiplying that time difference (in seconds) with 340.29 meters per second will result in the value of the distance traveled of the ultrasonic wave. The beacon then replies to the NavU with the emitter ID value, receiver ID value, and distance in meters to the NavU.

27 milliseconds was decided for the timeout duration to receive ultrasound waves because the beacons were designed to be spaced roughly 7 to 8 meters apart; ultrasonic waves take roughly 27 milliseconds to travel this distance.

If an ultrasonic wave is not detected within the 27 milliseconds, the beacon does not send a reply to the radio.

To ensure that beacons do not overload the NavU by replying at the same time, each beacon will have a unique transmission delay related to their beacon ID.

In the unusual scenario where an ultrasonic signal is detected but no radio signal was received prior, the beacon does not react.

3.1.3. Enclosure Design

There are two separate enclosures for the beacon: one enclosure for the receiver node (See Figure 6) and one for the microcontroller. The enclosure contains the power supplies and their corresponding circuits. The enclosure for the microcontroller and for the receiver node both contain LED lights so that people maintaining the LGS can see from a distance whether power supplies need replacement.

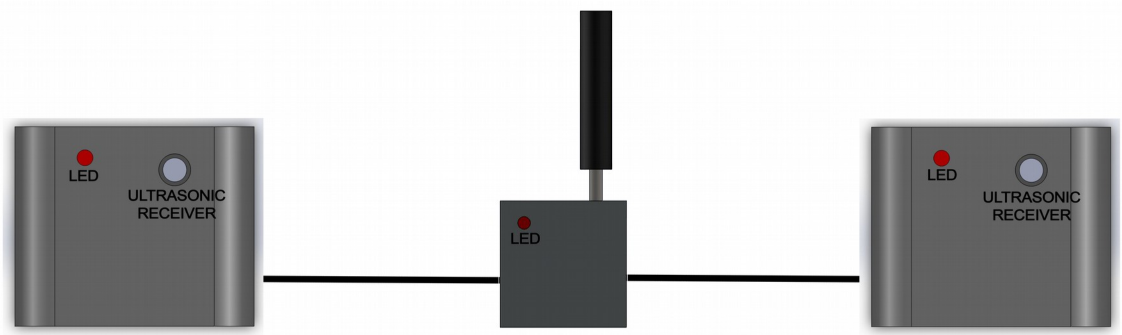

Figure 6: Rendering of Beacon

The enclosure for the receiver nodes will have the ultrasonic receiver protruding (see Figure 7) to prevent obstruction of ultrasonic waves. The enclosure for the microcontroller will have an antenna protruding to allow for clear reception of radio.

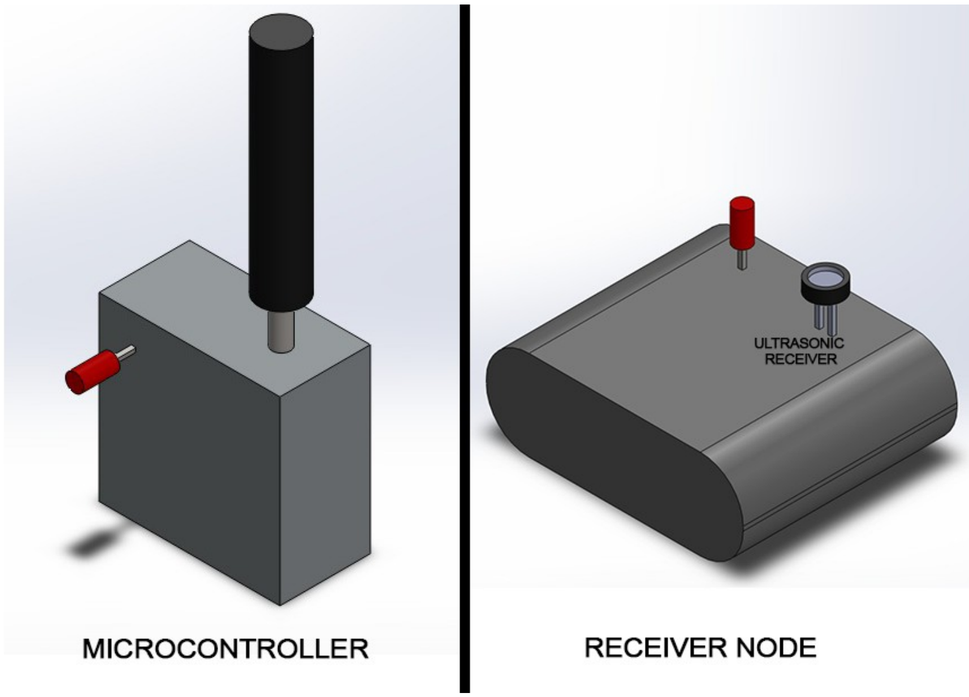

Figure 7: Alternate Rendering of Beacon

3.2. NavU

The NavU was designed to accommodate a few functions in the LGS: ultrasonic wave emission, communication with the beacons, and communication with the user via audio. The main goal of the NavU is to communicate distance and direction of the closest landmark to the user. Since the user carries this system, it also has to be non-bulky and comfortable to carry.

Although the ultrasound emitters were proposed to be worn on the user to reduce obstruction, for the proof-of-concept model, we have simplified this by mounting the emitters onto the enclosure of the NavU due to time constraints. Therefore, the NavU has to be held in a certain way to guarantee accuracy in direction.

3.2.1. Hardware and Electronic Design

For the microcontroller in the NavU, we decided to use the Raspberry Pi A+ because it is small, able to run multiple processes/threads, and has an audio jack to output audio. Since the microcontroller has to switch between transmitting a radio signal and emitting an ultrasonic wave as quickly as possible to reduce inaccuracy, the processor speed has to be sufficient so that any inaccuracy is negligible. The following steps explores how the user's position is triangulated in terms of hardware.

- The user presses a button on the enclosure of the NavU (see Figure 8). This button begins the process of emitting ultrasonic waves from the NavU. This button is part of the three buttons that will interface the user to the NavU, with the other buttons being volume control, which will be explained further on in this section.
- When a button press has been detected, the NavU, using radio, broadcasts to all nearby beacons the ID of the emitter that is to emit ultrasound. The frequency that the NavU broadcasts on is tuned into by all beacons.
- A 40 kHz digital signal is outputted by the microcontroller which is then amplified to 18 volt peak-to-peak to reach a near maximum range of 4 meters with the Murata ultrasonic emitter [2].
- After the timeout period of 27 milliseconds and an additional 2 milliseconds for the beacons to respond with radio, the NavU broadcasts the next ID of the emitter to send an ultrasonic pulse and then the emitter corresponding to that ID sends its signal. This process continues until all 5 emitters have emitted ultrasound. Each emitter will have its own gain circuit in the proof-of-concept model since a demultiplexer/decoder to support such a high peak-to-peak voltage was not found.
- After beacons have replied to the NavU with the values of the distances measured, the NavU calculates direction relative to the closest receiver as well. After calculations have occurred, audio feedbacks is provided to the user. The volume of the audio feedback can be controlled via two buttons on the enclosure (see Figure 8). Volume level will be discussed in the firmware section.

Figure 8: Rendering of the NavU

The purpose for each ultrasound emitter emitting separately is to help determine the direction that the user is facing. Each emitter is mounted onto the enclosure so that they project ultrasound in different directions to cover a near perfect hemisphere. By having each emitter project ultrasound consecutively, the shortest distance detected by the beacons per ultrasound emission will allow the NavU to determine direction as well.

Since the user is to carry the NavU, the power to supply the NavU has to be compact and easy to replace. Therefore we have decided to use two 9V batteries to support the gain circuits and power the microcontroller.

3.2.2. Firmware Design

To reduce latency, all programming is done with C on the RPi with the wiringPi library for the same reasons discussed in Section 3.1.2 [3].

To detect button presses, each button is connected to two pins, where one pin is continuously outputting a digital 1 while the other pin confirms this input. When a button is pressed, the flow of digital 1s are temporarily disrupted, which is registered as a button press and a corresponding function is called.

If the triangulate button is detected to be pressed, the ID of the first emitter is radioed to nearby beacons. Because each emitter operates with a 40 kHz electrical signal, the NavU then outputs a 40 kHz square wave of 5 periods to the corresponding emitter to project ultrasound. After a total of 29 milliseconds has passed, the next emitter ID is broadcasted and the corresponding emitter is given the signal to project ultrasound. 5 periods was decided because an ultrasonic pulse of this length is short enough time to not hurt nearby animals, but long enough to be detected by ultrasonic sensors [5].

After all 5 emitters have emitted and information on the relative distances has been found from each receiver node, the NavU calculates the direction the user is facing and the closest receiver node. The NavU will have the location of each receiver node stored in array as a Cartesian coordinate of two dimensions, with units of the values stored being in meters. Since each receiver node is placed in a position that is approximately 2 meters of height, the NavU has to do some slight trigonometry to find the user's horizontal distance from the receiver node. For the proof-of-concept model, LocalSonic will only be demonstrating that the LGS is able to detect the closest landmarks, which in this case will be mapped to receiver nodes.

After direction and distance has been found relative to the closest landmark, the NavU rounds the distance to the nearest 0.5 meter value (ie. The calculated 3.81 meters is rounded to 4 meters). The NavU then selects pre-recorded sound clips of a person saying the distance and direction of the user. 0.5 meters was selected as the rounding value because we felt that it was an intuitive distance that provided enough accuracy.

If volume buttons are detected to be pressed, the aumix tool is called and the volume is adjusted according to the aumix volume control parameters [6].

3.2.3. Enclosure Design

The enclosure for the NavU will have 5 emitters on top, an on-off switch, an audio jack to connect headphones, 1 button corresponding to triangulation, and 2 buttons corresponding to volume control (see Figure 8).

The emitters are placed in that configuration to cover a near perfect hemisphere. The volume buttons are grouped close together because they control the same property and are slightly distanced away from the triangulation button to avoid accidental confusion between the three buttons. The on-off switch is to conserve battery.

4. Safety Design

There are a few aspects to consider for safety. For the beacons and receiver nodes, they have to be mounted in such a way that they can be safely accessed and will not risk falling on people in the LGS environment. A simple solution to this will be to attach small hooks to attach hooks on the beacon components to hang them off of nails or screws in the desired locations.

Another safety concern is the volume level of the ultrasound. At 18 volts peak-to-peak, the emitters project ultrasound at near 120dB [2]. This is a concern for animals in the environment; long term exposure to sounds of that volume will cause damage. The proposed solution is to pulse the ultrasound sensors as briefly as possible to avoid frightening and damaging animals that can detect that level of ultrasound [5].

5. Sustainability Design

All components of the LGS are designed to consume power over a period of time. This was done by measuring current drawn from the battery supplies to that they last at least a week of constant usage. The enclosures for all components are designed so that power supplies can be easily replaced. Rechargeable batteries can be used in the system providing that they meet the voltage requirements of the components.

6. Test Plan

In order to ensure the system is functioning properly, LocalSonic has developed a series of tests. Each individual component of the system will be tested separately first before it is integrated. Hence, the team divides this testing plan into two parts: individual component testing and integration testing. The detailed testing process will be shown in the following section.

6.1. Individual Component Testing

6.1.1. Hardware

In the hardware testing part, the team will focus on the response or the output of each component. The test goal, test method, and expect result will be shown under each main component.

Ultrasonic Emitter/Receiver Pair

In order for the correct operation of this system, the ultrasonic emitter and receiver pair should be able to communicate. If the emitter is given an input the receiver should be able to replicate that input, with some signal degradation.

- Using a 40kHz sine wave generated by the function generator as the input of the emitter, the receiver should be able to pick up this signal at a range of 2-4m and an angle of 80°. Both input and output will be viewed on an oscilloscope to confirm these test cases.

Receiver Amplifier Circuit

For correct operation of the receiver circuit, the circuit must produce a digital logic level of '1' (3.3V) when an ultrasonic pulse is produced and a '0' (0V) when no pulse is detected. Additionally, the noise produced by the circuit must be minimal so as not to create false positives or false negatives. When an ultrasonic pulse is detected by the ultrasonic receiver, a small voltage is produced at the terminals, which should then be scaled up to 3.3V for it to be seen by the microcontroller.

- The noise will be tested by oscilloscope and DMM. The expected value of this voltage output should be low enough; ideally 0V.

- To calculate the gain of the receiver circuit, the team will compare the voltage before the circuit and the voltage after the circuit. Two individual op-amp circuits are used in this receiver circuit. The gain of the first op-amp circuit should around 200 and the gain of the second op-amp circuit should around 20.
- The power supply, function generator, oscilloscope and DMM will be used to test the circuit output. The expected output voltage is 3.3V when the receiver detects a signal from the emitter and the output voltage should about 0V when no signal is detected. The current output of the circuit should be very low; 0A ideally.

<u>Microcontroller</u>

The RPi will be used to test many components and though this testing we will determine whether the RPi is in working condition and if it will be able to handle all inputs required of it. Once the receiver circuit has been confirmed working by the previous test cases, the RPi will need to be tested to ensure it detects a '1' when the circuit produces 3.3V and a '0' when the circuit produces 0V.

- When the receiver circuit is connected to the microcontroller, the microcontroller should read ‘1’ when receiver circuit detects an ultrasonic pulse and ‘0’ when no signal is detected.

<u>Emitter Circuit</u>

The emitter circuit will be tested to ensure that the correct signal is produced to be output by the ultrasonic emitter.

- The circuit will be powered up and the output will be measured by an oscilloscope. The signal produced should have a peak to peak amplitude of 10V and a frequency of 40kHz.

<u>Radio Transceivers</u>

The radio transceivers must be able to transmit pings and distance data. To ensure the radios will work for this implementation, communication between microcontrollers will be tested.

- Using two RPis, one way communication will be tested. For this test to be successful a message must be sent from one RPi to the other with very low latency time (less than 1 µs). The microcontroller should read out the signal from radio transceivers and calculate the distance between them.

6.1.2. Firmware

In this system there are two firmware versions, one for the beacon and one for the NavU. Each version will have to be tested individually (if possible) and together in the integration tests.

<u>Ping Signal</u>

Once all hardware components have been tested, the firmware can be tested. The most critical part of this is the ping signal. This involves all components of the system.

For the test to be successful the following sequence of events must be completed:

- The NavU will send a radio signal indicating that an ultrasonic pulse is about to be sent.
- The beacon will receive this radio signal and start counting until it receives an ultrasonic pulse.
- When the beacon receives an ultrasonic pulse, the distance will be calculated using the time taken and the speed of sound
- This calculated distance will be radioed back to the NavU along with the beacon's ID

User Input/User Feedback

In order for the LGS to be usable by the visually impaired the UI should be completely touch/audio driven. A push button will activate the system and audio feedback will be provided to the user via headphones.

- In this test the system will take input from the push button and output a sound to the headphones.

Volume Buttons

- The user feedback will also be able to be volume controlled by two buttons indicating volume up and volume down.
- Simply, a tone will be played every time a volume button is pressed and this tone will increase or decrease in volume depending on which button is pressed.

6.2. Integration Testing

In the integration test, the entire system will be tested. In order for the system to be considered performing correctly the following sequence of events will occur:

- The user will push the activation button on the NavU
- The system will acknowledge that the user has pushed the button and will send out a ping signal (as defined in 4.1.2)
- The NavU will receive distance measurements from all beacons in range of the ping signal and determine the closest beacon
- The user will be notified via audio feedback which beacon they are closest to and what landmark that corresponds to
- All audio feedback generated by the system can be controlled in volume by the volume buttons

7. Conclusion

The Local Guidance System provides a simple way for visually impaired people to navigate public spaces. The proof-of-concept version of this product is a scaled down version of the envisioned final product, only including distance measurement and triangulation functionalities.

This document has provided the design specifications for the Local Guidance System and all individual components within along with justifications for the design choices made. All design specifications have been set out in accordance with the functional specifications given in the previous document [1]. This document will be used by the LocalSonic team as a guide through the creation and testing of the prototype system.

References

[1] LocalSonic. (2015, October). *Functional Specification - Local Guidance System* [Online]. Available: http://www2.ensc.sfu.ca/~whitmore/courses/ensc305/projects/2015/ifunc.pdf.

[2] Farnell. (n.d.). *MA40 Series Datasheet* [Online]. Available: http://www.farnell.com/datasheets/484560.pdf

[3] J. Pihlajamaa. (2015, February). *Benchmarking Raspberry Pi GPIO Speed* [Online]. Available: http://codeandlife.com/2012/07/03/benchmarking-raspberry-pi-gpio-speed/

[4] Texas Instruments. (2000, August). *LM386 Low Voltage Audio Power Amplifier Datasheet* [Online]. Available: http://www.ti.com/lit/ds/symlink/lm386.pdf

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[6] Jpj.net. (n.d.). *aumix* [Online]. Available: http://jpj.net/~trevor/aumix.html.

Appendix A: Sample Test Form

LocalSonic Test Evaluation Sheet			
Test Summary:			
Test Number:_______		Test Date:__/__/____	
Additional Notes:			
Results:			
Passed	Conditionally Passed	Failed	Retest
Comments:			
I certify that this test has been completed accurately and in its entirety according to the test plan.			
Tester:____________________		Signature:____________________	