SenseWalk Navigation System for the Visually Impaired

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***Abstract* — The visually impaired community is limited to very few means of independent navigation throughout their day to day lives. The SenseWalk console is a means to improve independent navigation by acting as a simple console to strap onto a white cane, an aid frequently used by such individuals. The SenseWalk console hopes to improve this tool by implementing sonar and GPS technology to better guide the user by alerting them of upcoming obstructions in their path in addition to providing audio instructions as they go about a given route.**

***Index Terms* — Audio systems, computer engineering, electrical engineering, flyback transformers, global positioning system (GPS), microcontroller , sonar detection.**

I. Introduction

According to data provided by the American Foundation for the Blind, there are 1.3 million Americans that are classified as legally blind, meaning that they experience significant vision loss[1].Of those 1.3 million Americans, it is estimated that about 10,000 use a white cane to go to work, school, and run their errands [1]. How the white cane is used is that the person using the cane taps the ground as each step is taken to ensure that there is no obstacle in their path that may cause them to trip or collide into. The cane is used to get a sense of "feel" for the terrain around them. The SenseWalk console is designed to optimize the white cane by offering additional functionality and portability to the user.

In order to better detect incoming obstacles to the user's path, sonar detection is implemented by sonar transducers wired to the SenseWalk console. As an obstruction comes within a given proximity with reference to the user, the transducers will pick up that there is something in the path and alert the user via a pager motor that is attached to the user's wrist as the sense of touch is typically heightened for the visually impaired.

The use of a global positioning system (GPS) is to incorporate a navigation feature in addition to the sensing feature previously outlined for the SenseWalk. The GPS keeps track of the user's position in reference to a stored route that the user has provided to the console. As the user begins a route, they are fed audio instructions to a headset that the user wears. As the user comes to a point in the path where they must change direction or have met their destination, an instruction is sent to the headset, thus notifying them of their status along the route.

The console itself is designed to implement or limit all of the functionalities listed. It will be up to the user themselves to decide whether they want to use only one feature such as sonar or all of the features. They can make this decision by switching them on and off on the console by their respective switches.

II. Design Components

In order to have the system meet the design requirements, the overall SenseWalk design has been divided into 6 sub-systems: power supply, sonar, audio, GPS, pager motor and microcontroller. Together, all of these sub-systems amalgamate to a working system with certain divisions relying on the other. Figure 1 below outlines the sub-system design where each component is meant to communicate with its necessary neighbors in order to employ functionality.

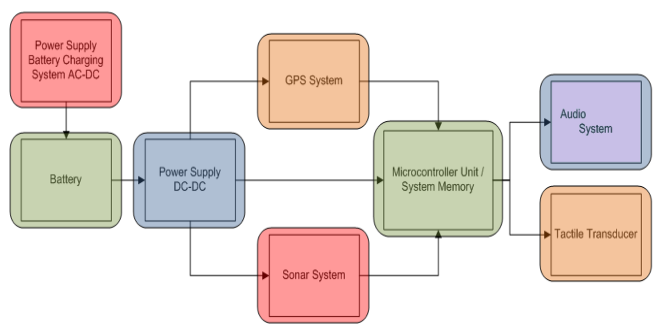

Fig.1. Mid-level block diagram of SenseWalk sub-systems

A. Microcontroller

The microcontroller serves as the functioning backbone of the SenseWalk. It needs to be able to communicate with the sonar, GPS, audio and pager motor in order to facilitate proper implementation while demanding low power from the battery supply. The microcontroller that was chosen by the group was the Atmega 2560. The Atmega 2560 offered capabilities that would allow it to meet the demands of the SenseWalk design requirements. These capabilities include a 256 KB memory which is more than enough memory to compromise programming code that would incorporate controls for the GPS and audio modules via the serial peripheral interface (SPI) bus while receiving information from the sonar in order to process the decision of whether to notify the user via the pager motor. The microcontroller's clock frequency operates at a maximum of 16 MHz, allowing a proper speed for processing and executing instructions in accordance with these peripherals communicating with the microcontroller in real-time.

In addition to this, the Atmega2560 operates at a low voltage of 5 V, which the battery is capable of supplying while remaining energy efficient. The 54 digital I/O pins available on the chip are more than accommodating to the SenseWalk design while offering a SPI interface to the needed peripherals. The microcontroller is lastly incorporated into the main PCB circuit design mapping to all designating sub-systems thus rendering communication.

B. Sonar

Sonar detection is done through the usage of sonar transducers that detects by emitting sound waves. A sonar transducer is used as a receiver to detect the reflected sound wave. The strength of the received signal will be vastly lower than the strength of the transmitted signal, because the sound wave is losing energy as it propagates through the medium. For this reason, the received signal passes through an amplification block. Once the signal has been amplified to the desired level, it is then filtered. The filter network is necessary to remove any coupled noise that the signal could have picked up during the course of its transmission path. The filter network is designed based on the transmitting signal frequency. This signal can then be compared to the original transmitted signal to validate that a sound wave has been transmitted and received successfully. Finally, the microcontroller can record the time of flight and then calculate the object distance.

For this design, the group constructed a sonar module on a separate PCB. This module uses the sonar transducers to send out a ping and receives a pulse back. The transducers themselves are driven by an input square wave at a frequency of 40 kHz. The sensor module consists of an amplification block and filter network that allows it to compare the received signal to the transmitted. The pulses received are read in as amplified and filtered voltage signals. Signals over a corresponding threshold from the input square wave driving the transducers are read as obstructions. For such signals, time is recorded from when the original input signal transmitted to when the higher voltage signal was received by using the sensor's own built-in microcontroller. This time is then incorporated into the following equation

$$\text{Distance} = (\text{Speed of sound}) * (\text{elapsed time}). \qquad (1)$$

This calculation is done on the microcontroller. The information that is read into the microcontroller is elapsed time between the two voltage signals previously mentioned. The range for this sensor works from 2 centimeters to 3 meters which is within exact range of the user's needs. The sensor is programmed to constantly check the surroundings ahead for obstructions by "pinging" consistently within a specific timing and inspecting what distance is read into the microcontroller.

C. GPS

The GPS module will determine its location by contacting the Global Positioning satellite network. The network currently consists of 24 orbiting satellites. Three satellites are needed to determine the latitude and longitude of the SenseWalk user. The satellites and module then use triangulation to determine the exact position of the module and sends the appropriate information back to the module. From then on the module does internal calculations and will relay the results back in the standard NMEA formatted string. The NMEA protocol is used for output data formatting, which is the standard in the GPS industry and around the world. The microcontroller does not do any calculation relating to the coordinates and measurements of the GPS. Everything is done onboard in the GPS driver and firmware which is integrated into the standalone module. This allows for reduced resource allocation to the GPS design and helps in reducing system complexity.

The GPS module of choice was the LS20031 GPS receiver. GPS accuracy must be within at least 3 meters so that accuracy is not lost for the user's sake. The LS20031 GPS receiver utilizes a GPS antenna in accordance with its own receiver circuits. This module outputs position information five times a second which constantly keeps all positioning information with respect to the user in real-time. In order to use the route navigation feature, the user must plan the route, load the route data, and then the SenseWalk guides the user in real-time. In order for this to happen, the Google Maps API on the user's desktop to create the route is used. An SD card is used to store these routes by delivering waypoint data and other information from the user's home computer to the embedded microcontroller on the SenseWalk console as shown in figure 2 below.

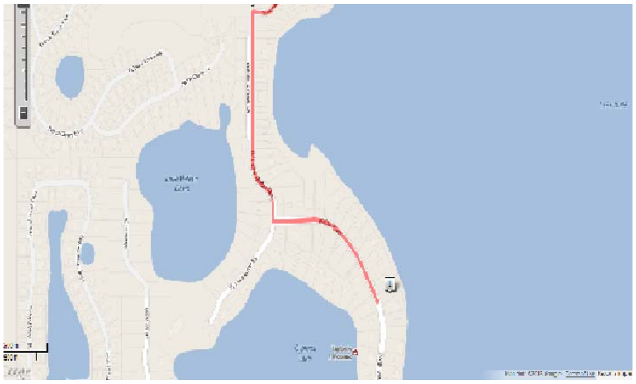

Fig.2. Route creation using Google Maps API

The use of GPS in the SenseWalk requires the need for a compass to help in the navigation of the user. Without a compass, the orientation and direction the user is facing would be unknown to the SenseWalk and could potentially cause errors in real-time direction and decision making. Thus, the LSM 303 compass was chosen for its ease in integration with our microcontroller because of its I2C interface that outputs 16-bit serial data at a time. The LSM 303 uses 3-axis accelerometers to keep orientation of the user as they change their direction. In addition, this digital compass uses 3.3 V, which is within range of the power supply demands we have established for all of the SenseWalk sub-systems.

Both the GPS module and digital compass send the data using the appropriate transmission protocols to the microcontroller for analysis through SPI. Using the GPS module and digital compass, the microcontroller uses its onboard software algorithms to determine the proper actions to be taken at all times with respect to the chosen route stored upon the SD card. Efficient and effective algorithms are used to ensure that the user is always routed correctly.

D. Audio Playback

In order to implement audio functionality into the final design, the group is using MP3 playback to relay audio instructions to the user's headset. In order to do this, the main PCB design consists of a microSD card slot to hold MP3 files of instructions to be played during certain times. The microcontroller determines when to play a given track, for example the message to "turn right" based on the information given to it to the microcontroller by the current GPS coordinates with respect to a route. When the microcontroller decides to play such a message from the microSD card, the chosen MP3 file is sent to an audio decoder that decodes this digital audio file into an audible format that is lastly relayed to a headphone jack to play.

The group is using the VS1053 audio decoder that can decode MP3 files so long as they are sent in a serial format on the SPI. The results of the decoder are then sent to the audio jack, which also resides on the PCB. From there, the user just needs to simply plug in headphones into the jack in order to hear instructions.

E. Power Supply

One of the design requirements for SenseWalk is to maintain portability for the user by having the console run on an independent, battery-chargeable power supply. The group decided to use a 7.2 V lithium-ion battery due to it being lightweight with an efficient energy ratio and fast charge time. To charge the battery, the power supply is split into two components: the AC-DC flyback converter which in turn supplies the switch mode lithium-ion battery charger. In order to generate the variety of voltages needed for the various sub-systems, voltage converters will be used. These will drop down the voltage to power the microcontroller, GPS unit and the audio module. Linear regulators provide all the DC-DC step-down conversions. A boost regulator is implemented to provide DC-DC step-up conversions. For example, the sonar transmitter needs a voltage of 10 V, which the boost regulator provides. The entire power supply distribution is detailed in the flowchart shown in figure 3.

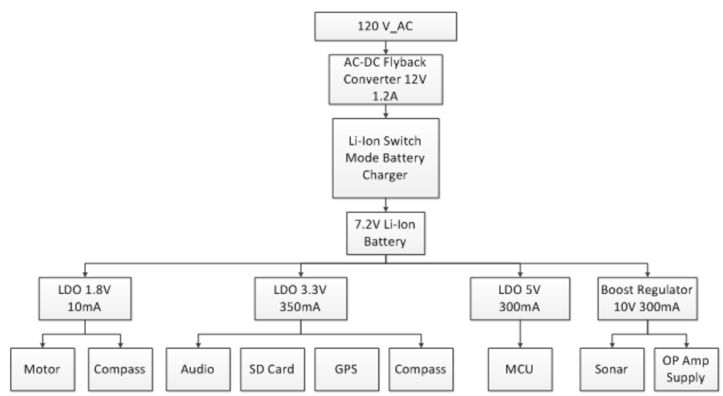

Fig.3. Flow chart of power supply distribution amongst various sub-systems

F. User Interface

The SenseWalk console contains the PCB boards that hold the GPS, audio, voltage distribution, charging unit and microcontroller sub-systems. On the outside of the box are three toggle switches that allow the user to select which features they'd like to use. The user may select to either turn on or off the sonar, GPS, or audio. This allows the user to have their own preference of how they'd like to use the SenseWalk for their own personal needs. There is one SD card slot located on the side of the console that allows the user to load an SD card with the routes they would like to be navigated by.

The sonar transducers need to be at the tip of the white cane so they are wired from the console to where they are strapped at the tip. To make the console mountable on any white cane, regardless of height, the group used a GPS mounting unit that is typically used for cars. The mounting unit was modified so that it can be attached to a cane. There is a platform that is raised at a tilt so that the user can easily place the SenseWalk console there. An LCD screen outputting current GPS coordinates is also on the outside of the console for testing and verification purposes.

III. Electronic Design

A. Flyback Topology

As discussed above, the SenseWalk utilizes a rechargeable Li-Ion battery. The battery charger is composed of two circuits; an AC-DC converter, followed by a CCCV battery charger. This section will focus on the design of the AC-DC converter.

In power supply design, efficiency has become the primary design consideration largely due to international regulatory bodies such as Energy Star. For this reason, the group decided to implement a switch mode topology for the AC-DC converter. The Flyback topology was chosen because it offers high efficiency (70+ % capable) and it is the least costly of all isolated switching power supply topologies. The electrical schematic for the SenseWalk AC-DC Flyback converter is shown below in figure 4.

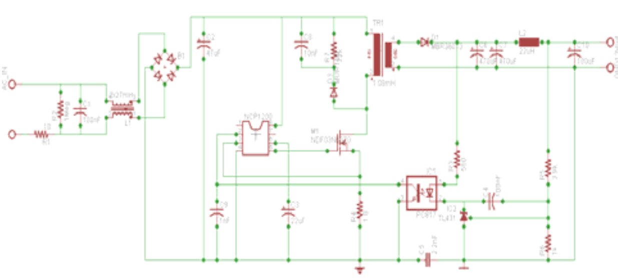

Fig.4. AC-DC Flyback converter schematic

The main design considerations for the Flyback converter were transformer design and controller/power MOSFET selection. A brief snippet of the transformer design equations are shown below in equations 2 through 6. These equations correspond to a transformer operating in discontinuous conduction mode (DCM). It was decided to operate the Flyback converter in DCM because DCM offers a smaller transformer due to lower energy in the transformer [when compared to a transformer operating in Continuous Conduction Mode (CCM)]. A smaller transformer requires less windings which equates to lower I^2R losses. It is also important to mention that DCM operation greatly simplifies the control loop, in comparison to CCM. This is due to the fact that CCM creates a Right Half Plane zero in the transfer function of the control loop.

$$L_p = \frac{(2)(P_{in})}{\left[\frac{(2)(I_{in(avg)})}{100/(V_{\min(DC)}+100)}\right]^2 (F_S)} = 1.078mH \tag{2}$$

$$I_{in(pk)} = \sqrt{\frac{(2)(P_{in})}{(L_p)(F_S)}} = 0.75A \tag{3}$$

$$I_{in(RMS)} = \left(I_{in(pk)}\right)\sqrt{\frac{D_{Max}}{3}} = 0.32A \tag{4}$$

$$I_{out(RMS)} = \frac{(2)(I_{out})}{\sqrt{(3)(1-D_{Max})}} = 2.08A \tag{5}$$

$$\frac{N_1}{N_2} = \frac{V_O'}{V_{out}+V_d} = 8.94 \tag{6}$$

It was decided to select ON Semiconductor's NCP1200 for the Flyback controller IC. The NCP1200 offers over-current protection, secondary side regulation, and a switching frequency at 60 kHz. Also, the NCP1200 can be directly powered from the high voltage DC line of the Flyback, instead of requiring an auxiliary winding for power.

The final major design consideration for the Flyback converter was the power MOSFET selection. This is a vital process in order to optimize overall efficiency. The SenseWalk Flyback converter required a 600V, 2A Power MOSFET. The two losses that occur in the power MOSFET are switching losses and conduction losses. Switching losses dominate over light loads and conduction losses dominate over heavy loads. To decrease switching losses, the FET should have low parasitic capacitance, and fast rise and fall times. To decrease conduction losses, the FET should have low $R_{DS(on)}$. Multiple power MOSFETs were tested to find the best fit for the SenseWalk Flyback, with respect to efficiency. The final selection for the power MOSFET was the NDF03N60ZG from ON Semiconductor.

The SenseWalk Flyback converter was tested for efficiency from 0 to 1.3Amps, with a max efficiency of 78%. The efficiency vs. load is displayed below in figure 5.

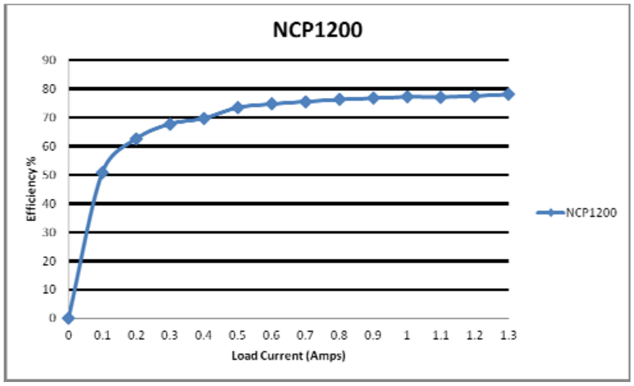

Fig.5. Efficiency versus load comparison for NCP1200

B. Lithium-Ion Battery Charger

The output of the Flyback converter supplies power to the Li-ion battery charger. The battery charger is implemented with a step-down switching topology. The circuit is controlled by the BQ24123 from Texas Instruments. The circuit has three stages. The first stage is referred to as ‘pre-conditioning’. This stage supplies a minimum voltage and current to regenerate deeply depleted batteries. The second stage is referred to as constant current. This stage supplies a constant current of 1.3Amps (set by an external resistor) as the voltage is linearly increased until reaching the max charging voltage. The third and final stage is referred to as constant voltage. This stage holds a constant voltage (equal to the max battery charge voltage) and exponentially decreases the charge current. The electrical schematic is shown below in figure 6.

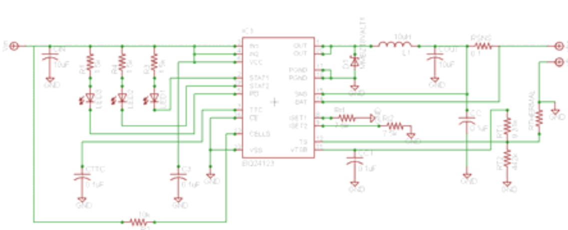

Fig.6.Schematic of battery charger

C. Boost Converter

For the hex inverter and the operational amplifier, 10V are needed to power these devices used for the sonar transmit and receive circuit. The 10 volts is generated from the 7.2V battery. This is done by a boost converter. The IC for the boost converter is the LM2578 from Texas Instruments. This IC allows for the charging and discharging of the inductor which in turn boost the voltage on the output. The voltage is controlled by the resistors.

The on/off switching of the power to the inductor is controlled by a FET inside the LM2578. This part was chosen because of the high efficiency of 70%. The FET switches at 50 kHz which allows steady DC voltage that is set by an external compactor. The part also has over current protection to prevent damage to itself and other components. The IC is circuited with compactors, resistors and the 300uH inductor boost the 7.2V to 10V. A schematic is shown in figure 7.

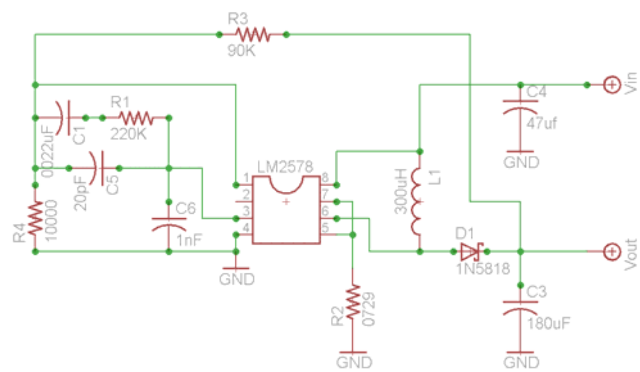

Fig.7. Boost converter schematic

D. Linear Regulators

In our design 3.3V, 1.8V and 5V are needed for the GPS, digital compass, the pager motor and for the microcontroller. The disadvantage with going with the linear regulators is the efficiency is very low. The advantage is that they use much less parts and are a much simpler design. Because the power consumption is small, the linear regulators are the best option for our design. The LM1963A was picked to do the DC to DC drop down from the 7.2V battery. This LDO regulator supplies 1.5A which is more than enough for our application.

E. Sonar

The sonar transmitting circuit generates a 40 kHz square wave at 10 volts and a 50% duty cycle. The wave is generated by a 40 kHz crystal oscillator. The crystal oscillator has two 30 pF capacitors to ground and connected through a couple of resistors. The signal then goes through three inverters to generate the square wave. The ground on the other side of the transducer will be switched on and off through a MOSFET controlled by the microcontroller. The transducer will be turned on for a set period of time to allow a set of pulses to be sent out. This is shown in below in figure 8.

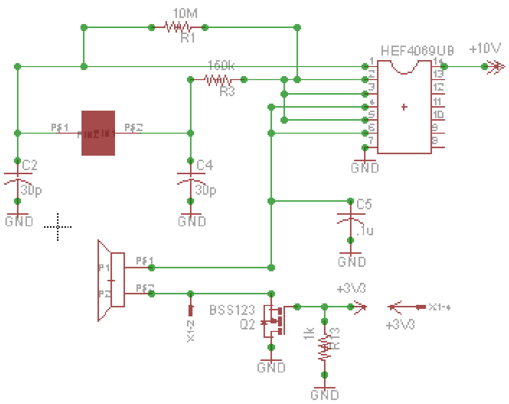

Fig.8.Transmitting circuit design for sonar transducer

The sonar receiving circuit takes in the signal, amplifies it and sends it back to the microcontroller. The sound wave from the transmitter bounces off an object and is received by the transducer. It then goes through a two operational amplifiers to amplify the signal from a few mill volts to at least 2 volts. Each of these operational amplifiers has a gain of 11. This can be calculated using

$$R2/R1+1 = \text{Gain} \qquad (7)$$

with R2 = 10k Ohms and R1 = 1k Ohms. Two amplifiers are needed because the max gain from a single one is not large enough. With a gain of 121, this can cause some problems because the signal received can have different magnitudes relative to distance and the size/shape of the object it hits. This problem is solved by using a 3V Zener diode connected from output to ground so that the voltage does not go above 3V and possibly damage the microcontroller. The transducers will only vibrate at 40 kHz have a drop off of 1dB per ±2 kHz. Thus, the transducers act as a very good band pass filter. The schematic for this is shown below in figure 9.

$$a = \sin^2(\Delta\varphi/2) + \cos(\varphi_1).\cos(\varphi_2).\sin^2(\Delta\lambda/2)$$
$$c = 2.\text{atan2}(\sqrt{a},\ \sqrt{(1-a)})$$
$$d = R.c$$

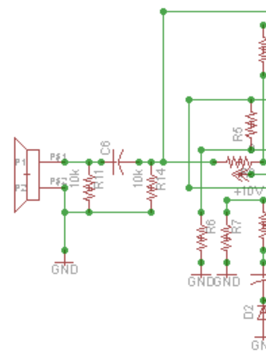

Fig.9. Receiving circuit for sonar transducer

Fig.10. Oscilloscope results of sonar waveforms

Figure 10 shows an oscilloscope image of the sonar wave forms. The yellow wave is the 40 kHz square wave with amplitude of just under 10V. The small amount of noise on the top and bottom of the square wave is due to the load of the transducer. The blue wave is the signal from the receiving transducer before amplification. This signal has amplitude of 140mV. The green signal is the receiving signal after amplification that is sent back to the microcontroller. Since the gain from the amplifier is larger than 3V, it is cut off from the Zener diode. Because the distance calculation is done by the difference in time from the signal being sent to the signal being received, the amplitude being cutoff is not a problem.

IV. Software Design

The SenseWalk software is broken down into different classes for each of the respective subsystems. The main SenseWalk class calls the specific functions of each of the individual modules and determines what exactly to do with the information in the main SenseWalk class. In the main class all of the calculations are performed and dictates the actions of the system. The main body of the code is written in a loop that constant checks the validity of each of the subsystems and routes the user. The sonar subsystem is interrupt based. The system class diagram of the SenseWalk is shown in figure 11.

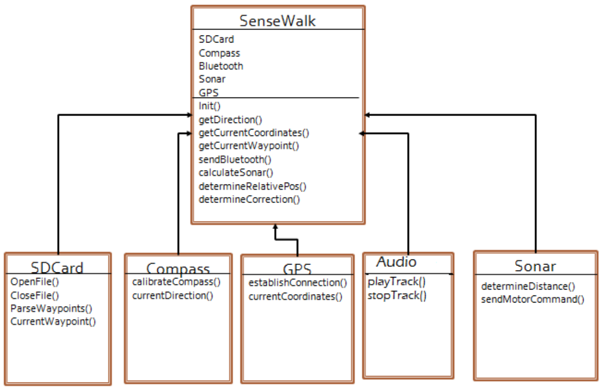

Fig.11. Software Block Diagram

Because the microcontroller is the central processing unit that works with its peripherals to obtain a necessary behavior, software programmed to meet these requirements are needed. This includes programming the microcontroller with relation to the audio and the GPS modules, in addition to the sonar signals that are being sent to the microcontroller. Thus, all code is compiled by the Arduino IDE into a lightweight sketch and stored on the Atmega 2560's flash memory.

Both audio and GPS utilize access to SD cards, which are both implemented through the microcontroller using open source SD card-type libraries. All code for the SenseWalk was written in the C++ programming language. In addition to SD card-type libraries, the group is utilizing libraries for GPS, MP3 decoder and sonar that will provide functions applicable to the design.

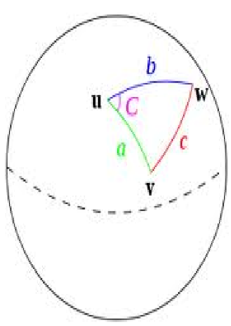

Fig.12. Haversine Visual

(8)

(9)

(10)

The navigation subsystem of the SenseWalk uses a few different trigonometry calculations and the Haversine formula to determine position in relation to stored waypoints already loaded onto the SenseWalk. The Haversine formula was used to ensure that the route calculations were as accurate as possible to eliminate error with an ellipsoid based Earth [1]. The Haversine formula is displayed in figure 16 and 17. Corrections were made to the TinyGPS libraries to improve location detection as the standard library truncated floating point numbers and thus cost the GPS between 1-2 meters accuracy. WAAS is turned on to ensure that output of the GPS is corrected for any inconsistencies. The LSM303 digital compass is used for bearing calculation. The compass was calibrated and found to be accurate to 3-5 degrees effectively. All bearing calculations are converted and based upon a 360 coordinate system. The bearings are relative to due North and compensated for magnetic declination due to the wandering of the magnetic poles. Figure 18 shows the bearing calculation in degrees.

(11)

$$\theta = \mathrm{atan2}(\ \sin(\Delta\lambda).\cos(\varphi_2),\ \cos(\varphi_1).\sin(\varphi_2) - \sin(\varphi_1).\cos(\varphi_2).\cos(\Delta\lambda)\ )$$

The program is coded so that the microcontroller constantly checks the difference between the waypoint of a route to the user's current position. Navigation is accurate to roughly 3 meters on a perfect day outside. Audio is preloaded onto the SD Card to dictate where to go. This audio is decoded by the VS1053 decoder and sent to a set of headphones the user is wearing. As the user gets closer to a waypoint, then an algorithm is in place to determine which audio instruction to relay to the user in order for the users direction to change so that they may keep going along their route. If a user wanders too far off from the correct bearing of the next waypoint then the SenseWalk will go into a redirection mode. In this redirection the SenseWalk will attempt to point the user in the correct direction of the next waypoint. Once the user reaches the final destination the SenseWalk will play audio accordingly.

The remaining focus of the code is set on sonar detection. The sonar library that is being used by the program takes the time between when a ping is sent by the sonar transducers to when a ping is received back. This time is then calculated into the distance equation (1) to determine how far away an obstruction in the user's path may be. If the distance returned to the microcontroller happens to be greater than a 60 centimeter value, there is no need to alert the user. If the distance read however is less than 60 and greater than 30 centimeters, the user is alerted by a constant vibration delivered by the motor. Any distances read less than 30 centimeters mean that this obstacle is extremely close to them. This information is relayed through a rhythmic pulsing from the motor.

To program this method of alert, the code is written so that voltage from a general purpose digital pin on the microcontroller is set as a high. This pin is wired to the gate of a MOSFET wired to the pager motor. The pin is written as high every time the pager motor needs to vibrate. For the 1 to 2 meter range, the pin is held at a constant high so that the pager motor holds a steady vibration. For obstacles that are within 2 to 3 meters, the pin is toggled at high and low so that the motor is turned on and off, thus having a rhythmic vibration that the user should be able to decipher as different from the constant vibration used to alert upcoming obstacles in the 1 to 2 meter range.

V. CONCLUSION

It is the duty of the engineering profession to improve society. Engineering design applications that are helpful to humanity and affect individuals in a positive manner are one the reasons of why the engineering profession exists. This group wanted to design a product that can be used to help others in need that cannot help themselves and might not have constant support. It is the group's hope that the SenseWalk will give the millions of members of society who are visually impaired a new method of navigation. Using modern technology, the SenseWalk is able to navigate a visually impaired person while helping them avoid obstacles. This device will greatly help the visually impaired members have the freedom of movement that the rest of us take for granted.

BIOGRAPHY

Mark Applegate is an electrical engineering student at the University of Central Florida, graduating May 2013. His primary technical interests are in power electronics and related semiconductor devices. After graduation, he will be working as an applications engineer with a Power Supply Design Group at ON Semiconductor in Portland Oregon. He also plans to complete his Masters degree within the next 2 to 3 years.

Sara Belichki will be graduating from the University of Central Florida in the spring of 2013 with a B.S. in computer engineering. Her interests include optics, embedded systems, processor design and algorithms. She is currently pursuing a masters degree at UCF while working as a graduate research assistant for CREOL under Dr. Ronald Phillips and Dr. Larry Andrews.

Matthew Czarniak will be graduating from the University of Central Florida in the spring of 2013 with a B.S. in computer engineering. His interests include embedded systems, computer network security, nanotechnology, and algorithms. He is currently pursuing a masters degree at UCF while working as a CWEP at Lockheed Martin.

Nicholas Heintze will graduate from the University of Central Florida with a Bachelors of Science Degree in Electrical Engineering. His interests include design of analog circuits. He has accepted an offer from Lockheed Martin in Orlando, Florida for an electrical design position.

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