# Smart Mobility Cane: Design of Obstacle Detection



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Dedicated to the 37.5 million visually challenged individuals in world.

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## Abstract

Among many constraints faced by a blind person, the challenge of independent mobility is the paramount. Widely, the white cane is the most popular tool for mobility aid, but it also has constrains too. For example, when it is used to detect obstacles up to the knee-level, the upper body is left unattended. This leaves the risk of the user of being hit from a raised platform or from high horizontal bars. The SMC's Obstacle Detection division has implemented a cane to detect and measure the distance of any obstacles present in knee-above areas. This is based on an Ultrasonic Range Finder sensor which can acquire range data's between any obstacle and the user within 2.5 meters. Using the LABVIEW (visual programming language), the URF sensor (SRF05) is triggered with minimum 10uS pulse every 250 millisecond to start the range. Simultaneously, data of echo pulse generated from the output of the sensor is acquisitioned to calculate the distance of the obstacle. At the end, the range of distance is numerically displayed in real-time on the LABVIEW block diagram. The distance of the obstacle is then used by SMC's Signal Integration division to alert the user depending on the range. In this report, detailed description of the hardware aspect of the Ultrasonic Range Finder sensor, the LABVIEW's visual block programming of triggering pulse periodically and echo pulse analysis from sensor, and the experiments on reducing beams width are elaborated.

Keyword: Smart Mobility Cane (SMC), Ultrasonic Range Finder (URF), LABVIEW

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# **Chapter 1**

# Introduction

In 2002, according to the World Health Organization research, there was 36.9 millions visually impaired individuals globally [1].Generally, a blind user carries a white cane or a guidance dog as their mobility aid. But, due to the high expenses and the maintenance difficulty of a dog, many blind people prefer white canes. The inexpensive white cane device is used to detect obstacles on the ground, holes, uneven surfaces, steps and other hazards. Its light weightiness and the capability to be folded into a small piece can be advantages to carry around when not required.

The main problem with the use of the white cane is its inability for a user to detect obstacles beyond the cane's reach (1.25 -2 meters) [2] and therefore the user is limited to perceive information about their surrounding environment. In addition, when the user is in motion, they cannot detect obstacles on the ground and above the waist simultaneously. The user of a white cane is also incapable of detecting heat object located within a few meters from them. For example if the user is faced with a hot object (e.g. hot stove) in front of him/her, they cannot distinguish with sense of touch from the cane nor can they feel moderate heat within few meters. So to overcome these

problems, the Smart Mobility Cane (SMC) team has integrated obstacle detection sensor & heat detection sensor on the cane. It will detect obstacles above knee-level area and hot objects within 2.5 meters and alert the user in real-time with a combination of 4 vibration motors mounted on the canes grip.

As of 2009, there are three different mobility canes available in the market. All of them concentrate only on obstacle detection, and the cost of each one of them is above \$700.

| Table1.1: Price of existing Mobility Canes in market |                         |  |  |
|--|-------------------------|--|--|
| Device Name  | Price (Canadian Dollar) |  |  |
| Ultracane  | 1095 [3]                |  |  |
| K-Sonar  | 850 [4]                 |  |  |
| Palm Sonar   | 750 [5]                 |  |  |
|  |                         |  |  |

The advantage between the SMC with existing product is SMC's ability to detect obstacle in front of the user as well as heat objects within the specified range. In addition, SMC would be much cheaper compared to all the other devices. The current estimation of the design and equipment cost is less than \$200. A lower price and its useful ability to detect heat objects will be greatly helpful for visually impaired individuals, which would make it a leading and competitive product in the world market.

The work of this project is divided into three divisions: SMC Obstacle Detection, SMC Heat Detection, and SMC Output Interface. In this report, the work behind SMC Obstacle detection is well explained. In the beginning of the report, the process of choosing appropriate obstacle detection technology is elaborated, where after the hardware design of Ultrasonic Range Finder is analyzed. Afterwards, the project behind LABVIEW to operate the sensor is explained, and then ending with report of the result of trial experiment executed to reduce beams width.

# Chapter 2 Literature Review

The obstacle detection technology is widely used in many industries. For example, from manufacturing to automobile companies, it had played crucial roles. In manufacturing companies the obstacle sensors are used to detect and count moving items before being shipped and in automobile the sensors are used to scan obstacles surrounding the vehicle. In this project, keeping in mind the expectations, three technologies were analyzed: Infrared Sensor, Ultrasonic Sensor and Laser sensor. All these technologies are developed to find the range of obstacle within certain meters. In the following chapter, brief explanation of some of the advantages and disadvantages found in the three sensors provided.

## 2.1 Infrared Sensor

Infrared Sensor uses infrared light to determine the distance to a reflected object. There are two types of infrared sensors. Some sensors are built in circuit to

provide just a binary output, and there are those others which provide analog output and multiple bit output [6].

The IR sensor which provides just binary output is effective for detecting the proximity of the obstacle and not the range. For example, the canes with this sensor will only allow the user to know if an obstacle is present within a certain range and would not be able to distinguish if the obstacle is close or far away from the detecting range and therefore is mainly used for small robot projects. This type of infrared sensor is the cheapest, costing usually between 10 to 20 dollars (\$CAD) [6].

The other IR sensor is effective for ranging that is outputting the distance of an obstacle. The output can be either in analog or digital byte. This type of IR sensor cost between 20 to 30 dollars.

The IR Range finder works by the process of triangulation [6]. A pulse of light (wavelength range of 850 nm +/- 70nm) is emitted and then reflected back by some obstacle or not reflected at all. When the light is reflected, it is detected with a different angle which is dependent on the distance of the object being reflected from the sensor. Correlating between the detection and the angle would give enough information to calculate the distance using the triangulation method.



Figure 2.1: IR Sensor's Triangulation method: Using the angle information the distance of obstacle is calculated [6]

The overall advantage of infrared sensor is it's capability of detecting narrow range with the speed of light. For example, Sharp IR Range Finder's – which is one of the cheapest IR sensors, range of detecting obstacle is between 10-80 cm, and the beam is roughly football shaped with the widest portion in the middle being about 16 cm

wide [6]. The Sharp IR range finder comes with different derivatives, some models only detect the proximity while others can detect at a range of 80 inch. However, since these sensors work with infrared technology, they have many disadvantages as well. The emitting infrared light from the transducer does not work accurately outside. If there is direct or indirect sunlight, the infrared light transmitted from sensor gets distorted and therefore inaccurate reading is produced (although some Sharp IR sensor works somewhat accurately in ambient light). Also an important property of light is that it does not reflect back in same angle for different surfaces. Therefore, the infrared sensor reading is different for different surfaces, different colours, and different shades. Another interesting fact about IR sensor is its incapability to detect glass obstacles, because the emitted infrared does not reflect well, rather it penetrates through the glass.

For this project, the infrared sensor is neglected from the option due to its failure to meet the requirements. The cane would be primarily used outside, and therefore should not hold any restriction working outside. SMC's another crucial requirement is the device should be able to detect any obstacle including glasses. Since the infrared sensor cannot work outside precisely and ranges inaccurately with different colours, surfaces and shades, it was dropped from the option.

## 2.2 Laser Range Finder

Laser rangefinder uses laser to determine the distance to a reflected object. Similar to infrared sensor, it works by triangulation method. These sensors are famous for its ability to generate rich, high resolution, and high frequency data. It gives data with pencil beam viewing at high data rates with roughly millimeter resolutions [7]. Since it uses light, it can measure both rapidly and with an extremely narrow field of view.

Some of the rangefinder is used to scan a particular area, which means it takes a reading and then moves some fraction of the full angular resolution and takes another reading, this process is repeated in a full circle.

Ranger typically has minimum and maximum range where it can measure. In most cases, it is often between a few centimeters to as high as 10 meters.

One of the critical disadvantages of Laser Range Finder is the fact it uses laser for range and therefore it can be dangerous. Since most commercial laser range finder has Class 1 lasers, when using extra precautions are required [8]. For instance, it is known to damage eyes if it's directly aimed at it. Another problem with laser range finder is the cost, usually costing in the range of 2000 to 3000 dollars [7].

Even though the laser range finder was better than infrared sensors, in order to purchase one laser it will be above the projects budget. Also, the device would be used by blind individuals and therefore if the user accidently aims the laser at others without their own knowledge, it can pose great danger to not only to the user, but also to others surrounding the user. So with all these consideration, the SMC has dropped the idea of utilizing the laser technology.

### 2.3 Ultrasonic Range Finder

Ultrasonic Range Finder uses high frequency sound to determine the distance to a reflected object. Similar to how bats detect obstacles by transmitting high-pitched sound and listening to the echoes [9]. These Ultrasonic Range Finders emit series of supersonic pulses and wait for echo pulses to be detected. Since the speed of the sound is constant in the air (340.29 m/s), the time elapse between the transmitted signal and the received signal can be measured and so the distance of the object can be determined.



Figure 2.2: Illustration of how ultrasonic sensor detects object using high frequency sound

Some advantages of the ultrasonic range finder are that it is less affected by target materials, or by colour [6]. Even though it does not have a narrow field of view as the laser range finder, it is still capable of detecting objects within a meter. These ultrasonic sensors are designed to resist external disturbances such as vibration, infrared radiation, ambient noise, and EMI radiation [6]. The cost of ultrasonic range finder depends on the frequency transducer uses. Higher frequency (~255 KHz) ultrasonic range finder costs between 100 to 200 dollars, but with moderate high frequency (40 KHz) it is around 40 to 50 dollars [6].

The only disadvantage of ultrasonic sensor is that they do not operate properly in rooms with wall to wall carpeting and thick drapery. The sound waves from the transmitter gets absorbed by these materials and become too weak to return to the sensor.

Since this sensor is capable of detecting and measuring the range of all the obstacles indefinitely and the cost of each sensor are within the budge proposed for the project, the SMC finalized to integrate ultrasonic range sensor within the cane.

#### 2.3.1 Selection of Ultrasonic Range Finder

There are numerous types of ultrasonic range finder sensors available with key differences in frequency and power consumptions. Ultrasonic sensor with high frequency would have sharper beam width and can detect obstacles in longer range. Also some of the new sensors have similar range detection as previous models but with less power consumption. The SMC obstacle detection range of interest is less than 2.5 meters, with signals transmitted and received in less than 250ms and capable of running with less than 9V supply. Based on these constrains, the appropriate sensor selection was done.

Currently Robot Electronics is known for producing high quality ultrasonic range finder sensors. They are famous for obstacle detector sensor due to the sensor's capability to detect obstacles within a specific distance and for marketing within an affordable price (\$30 – \$100) [10]. As mentioned earlier, the ones that are highly expensive are equipped with high frequency transducer and have a better user interface. For example, Table 2.1 shown below contains most of the sensors with their individual ranging capacities; the SRF10 is capable of outputting on I2C bus and therefore its more expensive compared to the SRF05 which only outputs as digital (TTL pulse). There are other sensors with higher frequency transducers such as the SRF255 which operates at 255 KHz and therefore it is more expensive compared to SRF05 (which operates at 40 KHz). Also, there are other sensors which operate similarly to the previous models but with less current and less power consumption (SRF05 is the next model from SRF04).

| Sensor C | Communication | Range   |         | Anala | Eshaar | Danaina Tima   |
|----------|---------------|---------|---------|-------|--------|----------------|
|          |               | Minimum | Maximum | Angle | Ecnoes | Kanging Time   |
| SRF02    | I2C / Serial  | 15 cm   | 6 m     | ~45°  | One    | 70 ms          |
| SRF04    | Digital       | 3 cm    | 3 m     | ~45°  | One    | 100 µs - 36 ms |
| SRF05    | Digital       | 3 cm    | 4 m     | ~45°  | One    | 100 µs - 36 ms |
| SRF08    | I2C           | 3 cm    | 6 m     | ~45°  | 17     | 65 ms          |
| SRF10    | I2C           | 3 cm    | 6 m     | ~60°  | One    | 65 ms          |
| SRF235   | I2C           | 10 cm   | 1.2 m   | ~15°  | One    | 10 ms          |

Table 2.1: Robot Electronic's Ultrasonic Range Finder sensors

At the end, the selection of sensors was minimized between two sensors, SRF04 and SRF05. These two sensors cost between 40 to 50 dollars [10]. Since SRF05 was the next derivative from SRF04, it had better circuit design to reduce power consumption, required lower current to function, and had increased range. For more information on specification please see the Table 2 & 3.

Table 2.2: SRF 04 Technical Specification

| Voltage:       | 5V only Required                                       |
|----------------|--|
| Current:       | 30 mA Typical, 50 mA Max.                              |
| Frequency:     | 40 KHz   |
| Maximum Range: | 3 meters (~10 ft.)                                     |
| Minimum Range: | 3 cm (~1")   |
| Sensitivity:   | Detect 3 cm dia. Broom handle at $> 2$ m               |
| Input Trigger: | 10 uSec min. TTL level pulse                           |
| Echo Pulse:    | Positive TTL level signal, width proportional to range |
| Size:          | 43 x 20 x 17 mm  |

| Voltage:       | 5V only Required                                       |
|----------------|--|
| Low Current:   | 4 mA Typical!  |
| Frequency:     | 40 KHz   |
| Maximum Range: | 4 meters (~13 ft.)                                     |
| Minimum Range: | 1 cm (<1/2")   |
| Sensitivity:   | Detect 3 cm dia. Broom handle at $> 2$ m               |
| Input Trigger: | 10 uSec min. TTL level pulse                           |
| Echo Pulse:    | Positive TTL level signal, width proportional to range |
| Size:          | 43 x 20 x 17 mm  |

At the end SMC Obstacle Division picked SRF05-Ultrsonic Range Finder sensor to be the obstacle range finder.

### 2.3.2 SRF05 Technical Specification



Figure 2.3: SRF05 Pin Connections

The SRF05 requires 5 voltage supply, ground connection, short trigger pulse and providing an echo pulse.

The SRF05 Timing diagram is shown below. In the trigger input, it only needs a short 10uS pulse to start the ranging [11]. The SRF05 will send out an 8 cycle burst of ultrasound at 40 KHz and raise its echo line to a high level [11]. Once the echo is detected, it lowers the echo line. The pulse width received from the echo output is proportional to the distance to the object. By timing the pulse, range in cm/inches can be calculated. If nothing is detected between 36 mS after the trigger pulse, then SRF05 will lower its echo line [11].



Figure 2.4: SRF05 Timing Diagram

Since SRF05 provides an echo pulse proportional to its distance, the width of the pulse, measured in microseconds can be used by dividing it by 58 obtain the distance in cm, or diving it by 148 to obtain the distance in inches. uS/58=cm or uS/148=inches [11].

The other set of 5 pins on the opposite side of 5 voltage pin are marked for programming pins. It is used only during manufactures to program the flash memory on PIC16F630 chip. It is crucial not to connect anything on these pins, or the sensor will not operate properly.



Figure 2.5: SRF05 with 55 degrees of beam width

The beam (ultrasonic wave) produced by transmitter transducer cannot be narrowed using the sensor. The conical beam pattern with the width of it being a function of the surface area is fixed. Later in the chapter, there are numerous experiments done explicitly to narrow the transmitter and detection beam.

# Chapter 3 Methodology

As of 2009, there were many devices invented to facilitate blind people with their mobility, but most of them are not used and therefore not commercially sold. Even though there have been remarkable technology advancements, the blind people still favor the "good old" white cane. With these considerations in mind, the team decided that the SMC should be capable of integrating the finalized range finder techniques to the current white cane. Since the URF does not function properly in harsh weather condition such as blizzard or storm, it can be easily removed under various circumstances from the white cane.

Initially, a device without the usage of a cane was pondered. The device should be similar to the one depicted in Figure 3.1. For example, a flash light's objective is to produce light from the bulb using the batteries. So instead of bulbs, the advantages of using ultrasonic sensor and thermopile sensor were analyzed. The only factor that did raise a problem is thermopile sensor, because it only reads temperature change within certain meters. However, for ultrasonic sensor, it's capability to produce a range of detected obstacles was not enough information about the environment to the user. For example, the ultrasonic sensor is unable to detect edges, small stairs, or the changes in ground plates. The only obstacle detection technology capable of capturing full details of the surrounding environment was laser. But these laser range finder sensors are very expensive, and therefore the portable device idea was neglected.



Figure 3.1: Sketch of portable handheld device

Another idea that was considered is the array of infrared sensor placed around the user. The sensors would be placed in the variable sized jackets and it would be responsible of detecting surrounding objects. Since IR sensor has narrow bore sight, there needs to be a multiple of IR sensors to scan the environment. Also this device should be capable of detecting the ground level and above the knee level as well. Since the IR sensor is small enough to be placed in front of thighs and heels and most importantly would not disrupt each other's signal, it can be used to detect obstacles above and below the waistline. The main problem with this idea is the trust and intuition the user feels using the device. Personally, after interviewing a couple of blind people, it was evident that many are not interested in this free movement detecting device. They mentioned that the white cane had more secure feelings in terms of detecting the ground level and below knee level obstacles. "The fact that no white cane is used is quite scary" mentioned Srinathar K, one of the blind individuals who were interviewed [12]. But this psychological problem could have been due to the long dependence of the white cane, and the lack of trust in the new inventions. Nevertheless, the team decided to postpone this idea for future development. As for now, the main objective of the project was to detect obstacles above the waist area and at the same time it can be integrated into the white cane.



Figure 3.2: Sketch of multiple of IR sensor array placed around user

The Smart Mobility Cane consists of one Ultrasonic Range Sensor. Since the user has the ability to check which direction the obstacles are detected, it minimizes the use of multiple sensors. For example, if the user is walking straight and notices that the vibration in the grip is activated, the individual must understand that this means that there must be obstacles in front of him. But to actually know exactly which direction the obstacle is present, they must pivot the cane to the right and the left and recognize in which direction the vibration is highly active. If the vibration is active for all direction then the obstacle would be similar to wall.



Figure 3.3: Sketch of Smart Mobility Cane

The Ultrasonic Range Sensor is clipped close to the grip hand, because it has a better optimization for obstacle detection above the waist line. As mentioned from the beginning, the main objective of the SMC is to detect obstacles above the waist line because the obstacle below waist is detected with the cane. Depending on the cane size and the size of the person, the angle of the detection of interest is adjustable by the pivot supporting clip on the sensor. As shown in Figure 3.4, the angle of pivot has only one degree of freedom that is adjustable from top to bottom respect to reference frame to the cane.

As shown in Figure 3.4, the angle of pivot has only one degree of freedom that is adjustable from top to bottom respect to reference frame of the cane.



Figure 3.4: Sensors angle of pivot respect to the cane

Another factor considered for SMC design is the artifact noise from the canes.

Since the noise created from the stick touching the ground are in audible frequency (20 hz to 20KHz) it does not impact the sensor because URF works in the range of 40 KHz [11]. As long there are no noise in between that sensor range frequency, there would be no disruption in the echo signal. Even if the noise presented above and below 40 KHz it can be neglected using the band pass filter.

There are 3 types of white canes. One is long cane and it is known to be the traditional white cane. The second type of white cane is Kiddie cane. It is similar to adult's long cane but designed for children. The last known cane is ID cane. It is lighter and shorter than traditional cane and used primarily to alert the users [13]. The length of all white canes can range in 1.25 meters to 2 meters [2]. Taking all these considerations, the SMC was designed to detect obstacle within 2.5 meters. This allows the user walking in range of 1.38 m/s to be alerted within seconds to react. As for human being it is known to have reaction time 215 millisecond [14]. Therefore the user would be able to recognize the vibration of detected obstacle and make sure which side the obstacles present.

As for moving obstacles it ranges from slow as 5 - 10 km/h of running person to high as 20 - 100 km/h of moving vehicles. Since the sensor was manipulated to retrieve obstacle range in the same time as reacting time (215 milliseconds) it would not detect obstacle moving faster than 20 km/h. Again the fastest range acquisition from sensor is every 30 milliseconds. Therefore it can be adjusted to detect moving obstacles at the speed of 100 km/h. But, since the user takes 215 milliseconds to react to vibration it would be late to react to the moving obstacle. So overall, it would be waste of battery to acquisition faster than human reaction time and therefore the sensor is slowed down to acquisition the range at every 215 millisecond.

The overall design of SMC obstacle detection was finalized with capability to detect obstacles within 2.5 meters and can be adjusted in one direction to point the

sensor in the interested field of view. It is recommended that sensor should be placed parallel to canes axis to reduce the obstacle detection within cane or user itself. It can detect any moving obstacle within speed of 20 km/h properly, and nevertheless it can be adjusted to acquisition every 30 millisecond (which means it can detect moving obstacle travelling in the speed of 100 km/hour). With the faster range acquisition more power would be used and result in less battery life. Therefore depending on the user interest for range acquisition time the SMC can be adjusted.

# Chapter 4 Design Procedure

The SRF05 sensor was designed by Devantech team, which is known to sell the sensor through Robot Electronics. Due to the patent rights, the circuit diagram of SRF05 was not found on the server. But there were many resources which contained information on the hardware design of Ultrasonic Range Sensors. In the following pages, circuit explanation of URF is elaborated.

### 4.1 Hardware Design

The URF sensor is composed of two main parts. One is receiver circuit and the other one is the transmitter circuit [16]. As mentioned before the Ultrasonic ranging is performed by transmitting a pulse of high frequency sound, and then measure how long it takes for its echo to be detected. The high frequency was readily available with ultrasonic transducers. These transducer come as a pair with one being transmission and the other for reception. As shown Figure 4.1, both transducers appear similar and therefore it is important to identify the appropriate one or subsequent result may suffer. Both transducers can be differentiated by the name found on the bottom. T40-16

implies transmitter transducer and R40-16 implies receiver transducer.



Figure 4.1: (a) Ultrasonic Transducers (b) bottom view of the ultrasonic transducer

Since these devices operate at a frequency of 40 KHz, it is three times higher than the human audible. Therefore it does not affect the user with high frequency noise. Also it is above the range of dogs and cats hearing and therefore it does not affect the pets as well.

## 4.1.1 Transmitter Circuit

## 4.1.1.1 Oscillation Circuit

The transmitter circuit is used to trigger continues pulse of 40 KHz every few moments to allow the transmitter transducer to start producing ultrasonic waves. Initially the pulse signals from LABVIEW are outputted to the oscillator circuit as shown in Figure 4.2. Whenever the pulses are high it will cause the Timer chip (555) to output 40 KHz pulses.



Figure 4.2: Ultrasonic Oscillation pulse [15]

In the Figure 4.2 circuit, RA and RB resistors are used to adjust the duty cycle of the pulse oscillation. In the following case, when RB>RA the oscillation wave close to 50% duty cycle. The frequency of the ultrasonic is adjusted to the resonant frequency of the ultrasonic sensor by allowing the RB resistor to be variable.

The LABVIEW signal is connected to the reset terminal of the 555 chip. When reset pin is high level, the timer starts the 40 KHz oscillation. The time of the oscillation pulse can be calculated by the following formula.

The resistor and capacitor values: RA = 1.5K-ohm, RB = 15K-ohm. C = 1000pF

$$T_{L} = 0.69 \text{ x RB x C}$$
  
= 0.69 x 15 x 10<sup>3</sup> x 1000 x 10<sup>-12</sup>  
= 10.35 x 10<sup>-6</sup>  
= 10 µsec  
$$T_{H} = 0.69 \text{ x ( RA + RB ) x C}$$
  
= 0.69 x 16.5 x 10<sup>3</sup> x 1000 x 10<sup>-12</sup>  
= 11.39 x 10<sup>-6</sup>  
= 11 µsec  
$$f = 1 / (T_{L} + T_{H})$$
  
= 1 / (( 10.36 + 11.39 ) x 10<sup>-6</sup>)

$$= 46.0 \times 10^{3}$$
$$= 46.0 \text{ KHz}$$
Figure 4.3: Frequency calculation of the oscillation pulse

rigure 4.5. riequency calculation of the osemation pulse

The alternating method to create the 40 KHz is within the LABVIEW. If the sampling rate is increased double the 40 KHz then it can be directly wired to the transducers. But many old computers will run out of memory if many samples are taken within seconds and therefore timer chip is safer method to create 40 KHz pulses.

#### 4.1.1.2 Ultrasonic sensor drive circuit



Figure 4.4: Inverter circuit: twice the voltage created [15]

The inverter circuit shown in Figure 4.4 drives the ultrasonic sensor. The two inverters are connected in parallel to increase the transmission electric power.

The capacitor is used to cut the direct current from the signal and causes 180 degrees phase shift between voltage applied to positive and the negative terminal. At the end, twice the applied voltage is received to the ultrasonic transducer.

#### **3.1.2 Receiver Circuit**

#### 4.1.2.1 Pre-Amplifier Circuit



Figure 4.5: URF: Receiver Circuit [15]

The ultrasonic range finder receiver circuit is composed of two inverting amplifier. Since the signal picked from the ultrasonic transducer are in hundredths of micro voltages. It is extremely small to analyze and therefore requires amplification.

Once the echo wave is detected in the receiver transmitter it is sent to coupling capacitor to eliminate DC offset and allows only the alternating current to pass. Usually there would be no need of coupling capacitor for input because the transducer can be thought as a type of capacitor and therefore resistive load is not present. In this design the capacitor is placed in the front to make sure once again the DC offset is eliminated.

After that the AC signal is passed through inverting amplifier. Using the equation found in Figure 4.6 (b), the gain from the amplifier can be measured, which in this case 100.

Vout/Vin = - Rf/Rin =  $-10M\Omega / 10K\Omega = 100$ 



Figure 4.6: (a) Inverting amplifier circuit (b) Output Voltage equation

Since the signal is sent to inverting amplifier, it becomes inverted and therefore opposite of original signal. To retrieve back the original signal it is once again transmitted through another inverting amplifier. In this case the gain of signal is 10 (Gain = 100K/10K). Overall the gain of the pre-amplifier circuit is 100 \* 10 = 1000.

Generally positive and negative power supply is used for the operation amplifier. Since we are only interested in working with single power supply of +5 V, it is necessary to build circuit without the need of negative supply. Therefore, "Floating ground" method is used. The two resistors (10 K) and capacitor wired to positive voltage terminal form a potential divider that supplies the op-amps with half the voltage rail. When using the negative feedback in the operational amplifier, the voltage of the positive input terminal and the voltage of the negative input terminal become approximately equal. So, by using biased voltage (2.5V), the positive and negative side of the alternative current signal can be equally amplified. If the biased voltage is not used, the alternating signal can be distorted.

#### 4.1.2.2 Detecting Circuit



Figure 4.7: Half-wave rectification circuit with Shotty barrier diode [15]

Once the signal is amplified to hundreds of millivolts, it needs to be rectified. Since the signal is modulated, it contains both positive and the negative voltage. But when the signal is analyzed for time delay between transmitter and echo signal, only positive voltage is required (this would be explained later). In order to eliminate the negative voltage, the signal is sent through a half rectification circuit as shown in Figure 4.7. In the beginning of the circuit, capacitive coupling is used to eliminate any DC offset and then it is wired parallel and series to Shotty barrier diode. The Shotty barrier diode parallel to capacitor works by reverse biased, and if the negative voltage exceeds the diodes voltage drop it is grounded. The diode series to capacitor works in forward bios and allows only positive voltage to follow. Once the positive signal are retrieved it would have gap between zero voltage. In order to smooth the signals into one, another capacitor is used at the end. Since the diode is low resistance both diode and capacitor can be analyzed as RC circuit. Adjusting the time constant with the certain capacitance there would be slow discharging. This allows the two positive spike voltages as shown in figure 12 to become one. In the detecting circuit it is important to use shotty barrier diode compared to normal diode. The normal diodes are used to rectify alternating current into direct current in a moderate frequency range. Since the signal from the transducer is in high frequency, the normal diode does not rectify properly. This phenomenon is known as "reverse recovery characteristic". When opposite voltage is suddenly applied to forward-baised diode, current will flow in forward direction for brief moment. The time until the current stop flowing is called the Reverse Recovery Time. The Shotty barrier diode has a short reverse recovery time, and therefore ideally used in the high frequency rectification.



Figure 4.7: Half-rectified signal

#### 4.1.2.3 Signal Detection

Once the negative voltage is eliminated the signal is sent to circuit which detects the ultrasonic. The output from the detection circuit is directed to the amplifier shown in Figure 4.8.



Figure 4.8: Operation amplifier designed to work as comparator [15]

In this circuit, the operation amplifier of single power supply is used for the comparator. Since the operational amplifier is know to amplify the signal and outputs the difference between the positive input and the negative input, it is capable to work similar to the comparator. In the case where operation amplifier does not have negative feedback, at a little voltage difference the output is in saturation state. This is due to the tens of thousand of mu factors found in operational amplifier. When the positive input becomes little higher than negative input, the difference is tens of thousands of times amplified and therefore the output is same as the power supply which is the saturation state. And oppositely, if the positive input is little lower than negative input, the difference is tens of thousands of times amplified and the output of times amplified and the output of times amplified and the output is of thousands of times amplified and the output is of thousands of times amplified and the output is of thousands of times amplified and the output is of thousands of times amplified and the output is the saturation state.

the similar to the comparator. But since the inner circuit of comparator and operation amplifier is different, the comparator can not be used as the operational amplifier <sup>[6]</sup>.



Figure 4.9: Output from Signal Detection circuit [15]

Since the output signal from Figure 4.7 is wired to the negative terminal of the operation amplifier found in Figure 4.8 circuit, it makes the voltage of the positive input constant.

$$Vrf = (Rb * Vcc) / (Ra + Rb)$$
  
= (47<sup>K-ohm</sup> x 9<sup>V</sup>)/(1<sup>M-ohm</sup> + 47<sup>K-ohm</sup>)  
= 0.4 V  
Figure 4.10: Calculating the Vrf

So when the rectified signal as shown in above Figure 4.10, becomes more than 0.4V, the output from operation amplifier becomes low level (approximately 0 V) as shown below Figure 4.10.

Another part of the Figure 4.10 circuit is the elimination of the artifact signal aroused from triggered transducer. When the transmitter transducer emits high frequency wave, it causes vibration within the sensor and therefore the detector transducer detects false reading. Hence diode and capacitor are used to increase the Vrf cut off as shown in Figure 15. The diode is used to allow only the positive signal from the signal generated from the LABVIEW to pass. The positive voltage from transmission pulse increases the Vrf. Therefore the input voltage would not exceed the Vrf cut – off, and the output from the circuit would be Vcc. Since transducer takes few moments to trigger the pulse, a capacitor is added to make sure the Vrf does not suddenly drop to normal. Hence, the Vrf would be above the transmission crowed

signal and the output would be high.



#### 4.1.2.4 Time measurement gate circuit

The circuit shown in Figure 4.12 is a Set Reset (SR) Flip Flop. It is used to measure the time between the trigger pulse from transmitter and the detected echo waves. The set condition (A) is the time which the ultrasonic is triggered from the transmission transducer. The reset condition (C) is the time when signal is detected from Signal detection circuit (Figure 13).



The transmission timing pulse is wire into the both NAND gate inputs. Therefore when

both inputs is set high to NAND gate the output would be low and if the both inputs are set to low then the output would be high. In Figure 4.13, once the transmission timing pulse is set high (A) the output from the circuit is low (B). The low voltage applied to the set input (B) causes the (D) to be high and puts the flip-flop in the set state. When both inputs (B) and (C) go to low, the output (D) is high.



Figure 4.13: Signal Generation from SR Flip Flop

| Set (B) | Reset (C) | Output from | Output from |                 |
|---------|-----------|-------------|-------------|-----------------|
|         |           | (B) = (D)   | (C)         |                 |
| 1       | 0         | 0           | 1           |                 |
| 1       | 1         | 0           | 1           | After Set =1    |
|         |           |             |             | and Reset $= 1$ |
| 0       | 1         | 1           | 0           |                 |
| 1       | 1         | 1           | 0           | After Set = $1$ |
|         |           |             |             | and Reset =0    |
| 0       | 0         | 1           | 1           |                 |

There have been many methods to create oscillation circuit. In the following paper, only the method with timer chip is elaborated. It is crucial that the transducer receives 40 KHz frequency of pulse or the range from the oscillation would not work properly.

#### **4.2 Software Design: LABVIEW**

LABVIEW is a platform and a development environment for a visual programming language [18]. The programming used in LABVIEW is referred to as G – dataflow programming language. It executes structural of a graphical block diagram on which different function-nodes are connected by drawing wires.

In this project the oscillation of pulse and the generated of pulse width from the output of Figure 4.13 are programmed using LABVIEW 7.0. Using BNC-2110 shielded connector blocks the functionality of data acquisition between analog input, analog output, digital input, digital output and counter/timer signals was achieved. As shown in Figure 4.14, the BNC-2110 is connected to the DAQ device card with the shielded wire. In order for BNC-2110 Data Acquisition to work in LABVIEW, the NI-DAQ software must be installed and it needs E-Series DAQ board installed and configured using Measurement and Automation Explorer (MAX) [18]. All the LabVIEW programs/subroutines are called virtual instruments (VI). Each VI is composed with three components: a block diagram, a front panel, and a connector panel. The controls and indicators on the front panel allow the user to input data into or extract data from virtual instruments. It serves as a user interface, when a node is dropped from the block diagram. Overall it defines the inputs and the outputs for the given node through the connector pane.



Figure 4.14: Connection between BNC-2110 to DAQ device

The block diagram contains the graphical source code. Basically, the front panel objects appear as terminals on the block diagram. Additionally, the block diagram contains functions and structures from the built-in LabVIEW VI libraries. The wires can be connected with each node in the block diagram, including control and indicator terminals, functions and structures.

Since the project required complex algorithms, it is important that the programmer possess extensive knowledge of the special LabVIEW syntax and the topology. LabVIEW learning is easily done with the help of tutorials found in the main window. There are some "getting started" documents which allow the user to experience the basic fundamentals behind graphical programming.

### 4.2.1 Front Panel of the project

As shown in Figure 4.15, the Front panel of the project is divided into two main components. In the left side of the panel are the variable controls to create the oscillation pulse. In the right side of the panel are the variable controls to measure the pulse width from the output signal of Figure 4.12.

The continuous pulse generation required 5 inputs from the user: Frequency,

duty cycle, idle status and counter physical channel (output pin from BNC-2110). The counter is a digital timing device, and typically used for counting, frequency measurement, period measurement, position measurement, and pulse generation. In the case of pulse generation, it required frequency, duty cycle and the idle state (this determines if the pulse would start from high to low or vice versa). In the case of pulse measurement, it also required three inputs: Minimum value (the minimum size of pulse width evaluation), Maximum value (the maximum size of pulse width evaluation) and starting edge (calculates the pulse width once the rising edge is detected). Overall if the pulse width is not between minimum and maximum value it will not work properly.

| <b>Xajan.vi Front Panel *</b><br>jle <u>E</u> dit <u>V</u> jew <u>P</u> roject <u>O</u> perate <u>T</u> or | ols <u>W</u> indow <u>H</u> elp                               |                                    |
|--|---|------------------------------------|
| 다 🐼 🔘 🔢 13pt Applica   | tion Font 🔹 🚛 🖬 🕮 🕇   | 2 🖻                                |
| Counter(s)   | Physical Channel  | Measured Pulse Width (ser)         |
| Duty Cycle<br>Duty Cycle<br>D.1000<br>Idle State<br>Low  | Maximum Value (sec)<br>0.830000000<br>Starting Edge<br>Rising | 0.004288612<br>Distance<br>73.9416 |
| STOP HERE FIRST  | STOP  |                                    |
|  |   |                                    |

Figure 4.15: Front panel of the project

### 4.2.2 LABVIEW: Block diagram of continuous pulse generation

The nodes found in the block diagram are similar to functions found in other programming, where inputs are given and appropriate outputs are returned. In Figure

4.16, it can be seen that the DAQmx of the first node is dragged to CO pulse frequency. In this case, the counter will output pulse with the given frequency, duty cycle and idle state. The whole system is continuous and therefore to stop the program it can be done by pressing the stop button found in front panel.



Figure 4.16: Block diagram to generate continuous pulse



Figure 4.17: DAQmx Creating Virtual Channel

As shown in Figure 4.17, the DAQmx can create a virtual channel or set of virtual channels then output through the task out. It contains multiple of functionalities such as counting, frequency measurement, period measurement, position measurement, and pulse generation. The user at the end selects the interested functionality by clicking on the drop down menu. In this project the pulse generation and pulse width calculation were done using the DAQmx counter. Another node known as DAQmx Assistant found in block diagram makes the pulse generation much simpler. Rather than wiring each values and channels it automatically ask the user to fill all the information about the pulse and outputs the same as found in Figure 4.16. This method is good for beginners but once more advanced algorithm is required it would not be helpful.



rigure 4.10. Driquix rinning

In order to generate samples of pulse waves it needs to be driven by DAQmx Timing node. The DAQmx Timing configures the number of samples to generate or acquire and creates buffer when needed. There are two sample modes: continuous and N number of samples. For this project the square pulse generated from Counter Output Pulse Frequency need to be in continuous sampling and therefore exact wave generated DAQmx should output to the sensor.



In LabVIEW there are some DAQmx given to allow the user to "smart" code. For example, the DAQmx Start Task found in Figure 4.19 is used to start the task in running state and thereby initiating the measurement or generation. Typically many user neglects to use the Start Task DAQmx because the autostart found in LabVIEW does the same work. But when the DAQmx start task and the DAQmx Stop Task are not used in VI where multiple of inputs are read and wrote, such as loop; it will cause the automatic task starts and stops repeatedly. When the application is continuously starts and stops it reduces the performance.



Figure 4.20: DAQmx Is Task Done

The square box that covered Figure 4.20 in Figure 4.16 is the loop. It functions to check if the user has pressed stop button or if there were any error from previous VI. Every continuous pulse is passed down to all the nodes and only sends to output if DAQmx Is

Task Done is not activated.



Once the loop is stopped the task information is sent to DAQmx Clear Task. This VI stops and clears the task. Since the project requires real time operation, nothing is saved at the end.



Figure 4.22: Simple Error Handler

If there were any errors between the operations, the loop would be stopped and simple error handler VI will indicate what error has occurred.

As it can be noticed there are two stop buttons on the front panel. Since pulse generation and pulse width calculation are done simultaneous each required stop button. When experimented with one stop button, it caused time difference between both operations. As a result, when one of operation is done the other one begins. This caused long time delay and therefore stop button for each were created. It is also important to take consideration that pulse generation loop needs to be stopped first because it is initially responsible to start the range in sensor. So if pulse width operation is stopped first an error would appear.

## 4.2.3 LABVIEW: Echo Pulse Calculation

The pulse width generated from receiver circuit is the input for Echo Pulse Calculation VI. Since the pulses are in digital format it is wired into digital input of the BNC-2110. By calculation of pulse width the distance of the obstacles can be calculated. Every pulse width (microseconds) divided by 58 would equal to the distance in centimeter to the obstacle. Therefore calculation of each echo pulse width and distance are executed inside the loop.



Figure 4.23: Block diagram to calculate echo pulse width



Figure 4.24: DAQmx Create Channel (CI-Pulse-Width)

The DAQmx channel in Figure 4.24 is responsible for measuring the width of a digital pulse. The Starting edge status determines if the high pulse or low pulse need to be measured. The size of pulse width to examine can be adjusted using minimum and maximum value. For example, if the user is interested in acquiring pulse width that is bigger than 10 microseconds (minimum value) and less than 1 milliseconds (maximum value) a constant value can be placed in both inputs.



Figure 4.25: DAQmx Read (Counter DBL 1Chan 1Samp)

Similar to the Pulse Generation VI, the echo pulse distance VI has DAQmx timer for continuous sampling and DAQmx Start Task and Clear Task to control the -36-

start of the program. Once the pulse width information begins to acquire it is set to the DAQmx Read found in Figure 4.25. Inside the loop, the DAQmx reads a single floating-point sample from the counter task. The single floating-point pulse width is then multiplied by 1 million to bring the microseconds to seconds. Then it is divided by 58 to generate the distance in centimeter.

# Chapter 5 Experiments and Results

The SRF05 sensor is very sensitive to the objects not in boresight, which is the angle the sensor is aimed. Since SRF05 has conical beam pattern at 55 degrees, it tends to detect obstacles that are not in field of view to the user. In average humans shoulder width is 23 inches. The SRF05 was able to detect obstacles that are 30 degrees off from the user at 2.5 meters ahead. In the following paper, an experiment of narrowing the beams width is explained.

Since SRF05 operate with 40 KHz the ultrasonic wave tend to spread wide compared to the 255 KHz higher frequency sensor SRF235. As shown in Figure 5.1, the different conical shape between two sensors, the narrow the angle the better the boresight.



In this project, the main goal is to detect obstacles that are 2.5 meters away from user and neglect obstacles that are more than 15 degrees from the canes position. As the distance between the obstacle and user increases the detection field of view also increases. For example, as shown in the Figure 33 the angle that is required to cover 0.9m by 2.5m is 10.2 degrees.

$$\tan (angle) = 0.45/2.5$$
  
angle =  $\tan^{-1}(0.45/3.5) = 10.2$  degrees

But if the angle is narrowed to 10.2 degrees it would not scan wide enough for the user when the obstacle is between 1.5 meter.

$$\tan (10.2) = (x/1.5)$$
$$x = 0.26 \text{ m} * 2 = 0.53 \text{ m}$$

In the range of 1.5 meters with 10.2 degrees spread, the wide field of view is 0.4 meters, which is smaller than average humans size shoulder. So in order to optimize the angle, the calculation was done with 0.45 m by 1.5 m, and the outcome angle is 16.7 degrees. Since the SRF05 sensor cannot change narrowness of beams pattern, external materials was placed around the transducer to reduce ultrasonic waves travelling off the boresight.



Figure 5.2: Range of boresight

The conical beam patter is not symmetric. The sensor is more sensitive to objects below boresight. Therefore it is best to mount the sensor vertically and not side by side to the cane.



Figure 5.3: Graph of Boresight Experiment

In the experiment of reducing the sensitivity off boresight there was two

materials used. Using normal line paper and thick soft tape, it is placed around both transducers with 0.35 inch height. In the Graph 1, the demonstration of different method to cover the transducer so that detection ranges (degree) and distance (meters) of obstacles to sensor can be reduced. Table 5.1 has the exact value found from each experiment.

|                      | Meters from |                  |
|----------------------|-------------|------------------|
|                      | sensor      | Detection degree |
| No Tube              | 0.5         | 10               |
|                      | 1           | 11               |
|                      | 1.5         | 13               |
|                      | 2           | 17               |
|                      | 2.5         | 20               |
|                      | 3           | 25               |
|                      | 3.5         | 30               |
| Paper Tube           | 0.5         | 6                |
|                      | 1           | 7                |
|                      | 1.5         | 9                |
|                      | 2           | 11               |
|                      | 2.5         | 15               |
|                      | 3           | 19               |
|                      | 3.5         | 22               |
| Thick duct tape tube | 0.5         | 4                |
|                      | 1           | 5                |
|                      | 1.5         | 7                |
|                      | 2           | 8                |
|                      | 2.5         | 12               |
|                      | 3           | 16               |
|                      | 3.5         | 20               |

Table 5.1: Boresight Experiment (angle and distance)

Important factor considered for all the experiment is maintained the size of the tube. It is noticed that once the tube exceeds 0.5 inches it started to disrupt the signal and inconsistent reading was established. The optimized size of the tube is 0.35 inch in height and transducers radius.

In the experiment thick duct tape tube is better ultrasonic wave observant than paper because it eliminated the waves that are not in the range of boresight much more. Therefore only the waves that propagated in narrow angle to the sensor were reflected from the obstacle to be received. For better reduction of beams width it can be done with thicker fuzz material because it is a better sound absorber. In the experiment, the tube was in flare like trombone shape. This helped the waves that are initially tried to go off the boresight are absorbed by the tube and at the same time it increased the degrees of detection as well.

For this project paper tube was used to eliminate the detection of obstacles out of user range. It is crucial that the sensor detect obstacles in range up to size of person shoulder within 1.5 meters. Even though the angle of detection increases with distance, the detected obstacles way off the boresight can be alerted to the user in less priority.



Figure 5.4: Thick duct tape tube on the transducer

# **Chapter 5**

# Conclusion

The Smart Mobility Cane is an integration of obstacle detection sensor, heat detection sensor, vibration grip and white cane. It allows blind people to recognize any obstacles or heat objects in the direction where cane is pointed and it allows real-time feedback to the user with the vibration transducers attached on the grip. Using the Ultrasonic Range Finder sensor, the obstacle within 2.5 meters away from the cane is detected. With the four vibration transducers the user is alerted to recognize the amount of distance between each obstacle. For example, the first vibration is active when obstacle is in the range of 1. 5m to 2m and the third vibration is active when heat object is detected.

There are 3 famous sensor used for obstacle detection. They are infrared sensor, ultrasonic sensor and laser sensor. Since laser sensor was expensive it was neglected from the start of the project. The other two sensor outputs similar result but infrared sensors are known to be disturbed by sunlight and dark objects. Since the sensor is required to detect obstacles within person size, the ultrasonic sensor was chosen. The

infrared has very narrow boresight compared to ultrasonic sensor and therefore multiple of IR sensors required to cover person's size field of view.

The Ultrasonic range finder consists of two main circuits. One is for transmission and the other one is for reception. In the transmitter circuit, it composes timer chip to create 40 KHz pulse with respect to external counter pulse produced from the LabVIEW. In the receiver circuit it composes of pre-amplifier, half-rectification, comparator and flip-flop circuit to create the pulse between transmission and the detected echo wave.

The LabVIEW is replaced with microcontroller to initiate range in the sensor and calculate the pulse width created from receiver circuit. Since the pulse width is related to the distance of the detected obstacle, either pulse width or distance can be calculated given either one of the variable. Both square pulse generation and pulse width calculation are programmed in LabVIEW to give the result graphically in the block diagram. The frequency of pulse generation can be adjusted to change the speed of detection. In this project the frequency is kept to 5 to 6 hertz because it is similar to human reaction time. The reaction time of normal person is 215 milliseconds, and therefore it would be waste of battery when it is acquisitioned faster.

The SRF05 Ultrasonic Range Finder sensor has conical beam pattern at 55 degrees. This causes obstacle that are not in the boresight range to be detected. In order to reduce the narrow beam it must be done externally because changing circuit would not help unless the 40 KHz transducer is changed into higher transducer such as 255 KHz. By placing paper tube or thick duct tape tube around each transducer it helps to increase the boresight. It is found that as the distance of obstacle is moved further from sensor is capable of being detected even when it is not in the pointed in the sensor range. Since paper tube around the transducer optimized the approximate beams range of detection with respect to distance of the obstacle it was used in the project. The size

of tube is also important because if it is longer than 0.35 inches it will cause error reading between the transducer.

Overall the Smart Mobility Cane would cost less than 100 Canadian dollars and it can be integrated to existing white canes. Since the SMC is capable of detecting obstacles and heat object, it is unique compared to existing models. The only drawback of SMC is the inability to use in extreme weather conditions and therefore the user can simply unclip each part and pack it in small bag.

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