Characterization of a Parallax Ping)))™ Ultrasonic Range Finder

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***Abstract* – This paper discusses the abilities and pitfalls of Ultrasonic distance sensors found through the testing of a Ping))) Ultrasonic Range Finder. We focus on the capabilities of the Ping))) sensor for specific examples, then generalize our findings, where appropriate, to characteristics of ultrasonic distance sensors.**

1. INTRODUCTION

Ultrasonic distance measurement does not have a reputation for being precise. Because of the manner in which sound diffuses as it travels – much more rapidly than a beam of light, such as a laser – ultrasonic sensors can detect things which are not exactly in front of them. Sonar provides direct range data at a low cost (both computationally and monetarily) when compared to optical range finders. However, the implementation of ultrasonic sonar sensors gives birth to two major problems as outlined in [1]. Beam width and specularity are the main issues.

The ideal range sensor is one of pinpoint accuracy - regardless of the surface type or orientation - and infinitely small beam width. That is to say, ideally, it should give the exact distance to any single point regardless of the any external factors such as temperature, lighting, surface topology, surface material; this utopian sensor has been deemed the “ray-trace scanner” by [1]. In reality, no distance sensor can have all the “good” qualities of the ray-trace scanner, least of all ultrasonic sonar. Firstly, due to the physics of acoustics which binds the performance of our sonar sensors, a small beam width cannot be achieved.

The ray-trace scanner is also unaffected by the angle of incidence to the face of its target. On the other hand, ultrasonic sonar is prone to specularity. That is, if the angle between the sound wave front and the normal plane to a flat surface is too great, no part of the wave will be reflected back in the direction of the transducer. As a result, that obstacle will be invisible to the sonar. Additionally, there is a possibility the wave could reflect off of multiple surfaces before returning to the transducer, causing a false reading of the true distance altogether.

Now, to take a short second and address why we would ever use sonar, if it is so “bad”. According to [1], some inspiration for the use and development of sonar based sensors originates from the incredible ability of bats to use sonar so effectively. Bats use ultrasonic sensing to know their location and even to hunt their prey, which is very small and agile, to great effect. While bats use ranging techniques such as frequency modulation and Doppler Effect analysis that are far more complex than the time-of-flight (TOF) ping that our rangefinder uses, bats stand as a testament to the capabilities of ultrasonic sensors that robotics has yet to fully realize. Additionally, ultrasonic sensors certainly have their place, even now, in low light environments or maps with glass or transparent obstacles in which optical sensors begin to break down.

While many try to implement actual sensors as the perfect ray-trace scanner, this approach cannot be taken with ultrasonic sensors. Instead, different methods of sensor fusion with sonar arrays have been implemented to overcome the differences between the ray-trace model and the characteristics inherent in ultrasonic range-finding.

Chande and Sharma implemented a hardware circuit to incorporate a calibration technique which enables a sonar to measure distances independent to temperature, humidity, pressure, and other atmospheric conditions that normally hinder the accuracy of sonic sensors in [2]. Additionally, many sensor arrays (both fixed and rotating) have been proven to be useful in specific applications, such as on the move obstacle avoidance in [3].

Leonard and Durrant-Whyte assert that, “to use sonar to its potential, one has to learn to look at the world differently – to think like a sonar sensor.” In [1] they discus in great detail the paradigm they embraced throughout their extensive work with ultrasonic sensors. By creating a model to predict sonar data as a response from different types of objects such as a plane, a cylinder, a corner, or an edge, they were able to conduct localization and map building exclusively with ultrasonic sensors. However, they do note that their process is too slow to be considered feasible in real time.

With this knowledge in hand, we set out to empirically affirm certain acoustic properties as they pertain to our Ping))) Ultrasonic sensor.

2. CODE

In this project we used an Arduino Uno board to read the distance information from the ping sensor. Initially we installed the sample code that came with the Arduino to help us read the information. In order to make the testing process simpler we made a C# program that opened a serial port connection on a 9600 baud rate. Then by using a data received listener we were able to collect the output from the Arduino board. The Arduino board output data in a particular format by appending escape characters to a string rather than printing a new line after every reading. In order for us to use the distance information we set up our C# program to read the input according to the same escape sequences that the Arduino sample code had. After getting the distance information, we used the inches to display a progress bar and update a label with the actual distance information received from the ping sensor. This allowed us to optimize our testing because there was no additional setup required after this initial procedure.

3. SPECIFICATIONS AND OPERATION

The Ping))) emits a 40kHz ultrasonic burst for 200 microseconds and awaits a reply. Parallax advertises that the Ping))) can detect objects from a range of 3cm to 3m. The transducer has a radius of about 16mm and the wavelength at 20 degrees C is 8.56mm given by:

$$\lambda = \frac{v}{f}$$

By following the formula given in [1]:

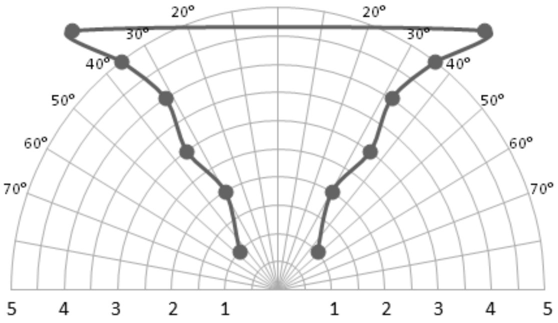
$$\theta = \sin^{-1}(\frac{1.62}{ka}) = 7.93^{o}$$

where a is the transducer radius and $k = 2\pi/\lambda$, we can determine that, at 3dB down, the full beam width of the Ping))) sensor should be about 15.86^{o}. This calculation is further detailed in [1]. Note that this information still does not fully answer the question “at what angles is a target visible?” This depends on the target surface, distance, orientation, and a number of other external factors. Thus, in order to gain a better understanding of the Ping)))’s abilities, we must test.

4. TESTING

Tests were conducted on different objects starting at a radial distance of half a foot from the sensor. From there, measurements were taken at every foot up to six feet away, or until the object disappeared out of the sensors detection. Tests were conducted inside unless otherwise noted, and the objects were placed on the floor while the Ping))) was elevated about an inch due to its location in a breadboard.

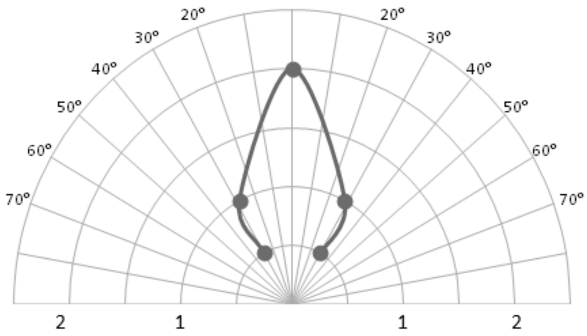
As wall following is an important focus of mobile robotics we tested the sensor at varying distances angles of incidence to a long flat drywall wall (such as can be found in a hallway) to determine the angle minimum angle at which the wall “disappears” from the view of the sensor.



1: Reflection map of a smooth planar wall.

This is a polar plot of the maximum angle at which the wall can still be detected by the sensor at a given distance. Due north on the plot corresponds to zero degrees, or directly in front of the sensor. The radius distance is measured in feet. For example, this graph extends to a radius of six feet and denotes that the wall could be detected at about a 40 degree angle.

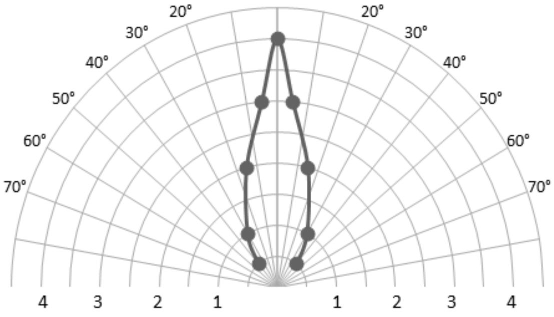
In addition, we also were interested in how the sensor would respond to smaller objects of different shapes. First, we test a 2” diameter spherical plastic ball with an irregular surface at one foot increments to determine the maximum angle of sight at each distance.



2: Reflection map of a plastic sphere.

The sensor was not able to pick up the ball, due to its small size, past two feet. Because of how spherical and rounded objects reflect ultrasonic waves in a dispersed pattern, they tend to be detected at greater angles from the normal, because they can reflect sound back to a source from any angle. However, they also do not reflect a signal as strongly as a planar surface, which contributes to their loss of sight at shorter distances when compared to flat surfaced objects. This can also be observed with a cylindrical tube.

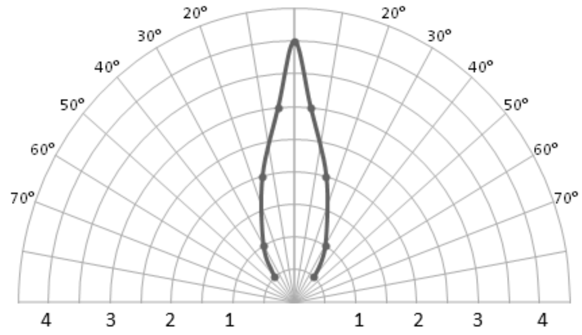
A $2\frac{1}{8}$ inch diameter cylindrical post, measuring 28 inches tall was tested in the same way as the ball.



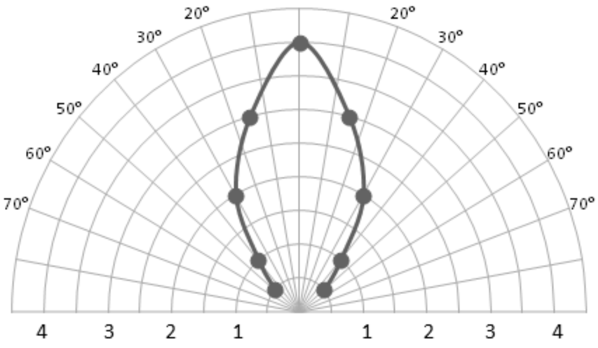
3: Reflection map of a tube.

The plot shows how the sensor's range of sight diminishes with distance until - at about 4 feet away - the sensor no longer sees the cylindrical tube at any angle.

Additionally, a 3in by 3in by $1\frac{3}{4}$in plastic block was tested at two orientations: First, with a surface always parallel to the backplane of the sensor, and second, with a surface always perpendicular to the radius at a given angle. The second method provides a "best case scenario" for the sensor to pick up the object at extreme angles near the edge of the beam width. As the data shows clearly in the plots, the method of placing the block perpendicular to the radius increases the sensors apparent field of view. Keep in mind that any single sensor has no way to know the orientation of the object, but with multiple sensors this information can be discovered.



4: Reflection map of a plastic block (fixed orientation)



5: Reflection of a plastic block (normal to radius)

We also placed the plastic block into a soft cloth bag to determine if the bag would have an acoustical effect on the performance of the sonar. Surprisingly, the same results were achieved with and without the bag on the cube. However, it is worthy of note that just the bag, with no plastic block inside, could only be detected by the Ping))) at distances closer than 6 inches. When testing inside at room temperature, the ping))) measurements were very accurate. But, outside in the 40 degree weather, the speed of sound differs by this relationship:

$$C_{air} = 331.5 + (.6 \times T_c)\ m/s$$

This suggests that sound travels slower in cold air, and indeed, the sensor measured 112 in. when only 110 in. from an exterior wall. As stated previously, there are methods to incorporate temperature fluctuations in sonar measurement.

5. CONCLUSIONS

It is easy to find and purchase a variety of TOF ultrasonic sensors online. MaxBotix Inc., VEX, Devantech, and, of course, Parallax are examples of a few companies that offer a wide range of ultrasonic distance sensors for personal and commercial use. Some, like our Ping))) sensor, interface with a single digital I/O pin via a PWM signal. Others have more complex serial interfaces, such as RS485, or even analog interfaces, where the output voltage corresponds to the object distance. These sensors can range from just shy of $30 to upwards of $65, depending on the range and features they offer. The sensors also offer wider or narrower beam patterns from model to model.

Here, we have gained a better sense of the capabilities of the common TOF Ping))) ultrasonic rangefinder in detecting objects of different sizes and shapes. Additionally, we have touched on the general characteristics of ultrasonic sensors that need to be taken into account when implementing this sensor type that is so different from the ray-trace scanner.

6. REFERENCES

[1] J. Leonard, H. Durrant-Whyte. "Directed Sonar Sensing for Mobile Robot Navigation". 1992.

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[3] H. Hu. "A Transputer Architecture for Sensor-Based Autonomous Mobile Robots". *IEEE/RSJ International Workshop on Intelligent Robots and Systems '89*. 1989.