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Performance Analysis of Ultrasonic Mapping Device and Radar

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Abstract

This paper deals with the design and development of a device capable of assisting rescue workers with visualizing a room with hazards and limited visibility. The paper focuses on the development of a device capable of creating a simple two-dimensional image of the room using an array of ultrasonic sensors. The final prototype of this device is capable of measuring distances inside a room and sending this data wirelessly to a separate device, which generates the map and displays it to the user. This device is also capable to serve as a radar that can detect obstacle in its path and will show the distance of the object from it.

1 Introduction

There have been numerous advancements in the development of mapping technologies in recent years. These technologies are used in applications such as autonomous robots, which need to map out a room to avoid obstacles before moving forward. The basic concept behind these technologies is that a wave of energy is sent out from a transmitter, reflects off of surfaces, and a receiver then picks up the reflected wave. The distance between the sensor and the surface can be calculated based on the time difference between sending and receiving the wave.

This paper focuses on mapping individual rooms in hazardous environment, where the layout of the room cannot be determined by sight, by using one of these mapping technologies. In many situations, it is not safe for a person to enter a room without knowing the layout of the room or any obstacles that may be in their way. This is especially true in a dangerous situation such as a burning building; firefighters would need to navigate the building as quickly as possible to rescue anybody who may be trapped inside, and seeing the layout of a room before entering will allow them to avoid obstacles that may be blocking their path.

The objective of this paper is to design and prototype a basic 2D mapping device. The prototype must be able to function in a smoke-filled room with limited visibility. It must contain a wireless transmission system to communicate to a computer outside the room, which will generate the map. The main goals of this paper are as follows:

- Construct a device that serves as a radar with a limited range and specified angle of rotation.
- Design a device that can use ultrasonic sensors to measure distances inside a room. It must be able to collect information about the entire room in a short time.
- The device must send this data to a secondary device, which will upload the data to a computer to create a map.
- Construct a prototype device as a demonstration, providing a "proof-of-concept."
- Test the prototype device to ensure proper performance in the intended environment.

2 Principle of Radar Operation

Radar systems use radio waves to determine, among other things, the distance to an object. The frequency used would need to be low enough to not interact with the smoke, but high enough so that it is reflected off of walls instead of penetrating through them. The measurements are performed by sending out an electromagnetic signal, then measuring the signal again when it is reflected back at the source. When the signal is received again, the time between when the signal is sent and received is determined.

This time delay, along with the speed of light, is used to calculate the distance travelled by the wave. Since the speed of the wave will be known, the distance can be calculated using Equation 1:

$$d = \frac{c * t}{2}$$

Equation 1: Distance traveled by a wave

In this equation, t is the elapsed time between when the signal was sent and when it was received, c is the speed of light, which can be calculated by taking the frequency (f) of a wave and multiplying it by that wave's wavelength (λ). The time it takes for the light to travel includes both the time to the object and the time back; this means the distance traveled will be twice the distance from the sensor to the obstacle reflecting the light, which is why it is divided in two[1]. When light is travelling through a medium, its speed will not be the same constant c. The actual velocity can be calculated if the index of refraction of the medium is known as shown in Equation 2:

$$v = \frac{c}{n}$$

Equation 2: Speed of Light through a Medium

In this equation, v is the velocity of light in the medium, c is the speed of light, and n is the index of refraction in that medium. In a medium such as heavy smoke, this will be especially important, as the speed of light will be significantly different than in a vacuum.

3 Existing Works

Electromagnetic mapping itself is not a technology that needs to be developed from scratch; many products available now use lasers or other forms of light to create images. For example, there is a company named 3D Laser Mapping which focuses entirely on using lasers to create maps of areas. One product they have is the ZEB1, which is a hand-held tool which records images using lasers while the user walks through an area, and a 3D map is created based on this data in a short time. The downside of this device is that it does take time; the image is not created instantly, and the user must walk around the area to gather the data. This company does have another similar product, which is mounted onto a robotic platform instead of being held by a person, which means it can be used in potentially dangerous environments without worrying. However, like before, this process takes time to create the image, which means it is not suitable for emergency use.

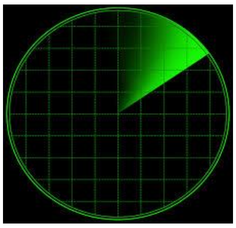


Figure 1: Basic Radar

4 Device Design

The first step in developing a device is creating a set of specifications for the device. Once the specifications have been decided, the device must be designed and built to match them.

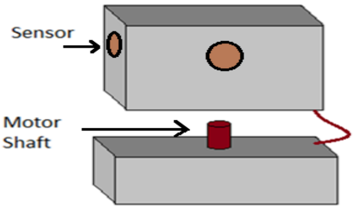


Figure 2: Design of the Device

The overall design of the device went through many changes before the final design was developed. The device consists of the parts: sensors, a processor, a micro servo motor and necessary software in the computer to display the output. All of these components must be chosen to meet the specifications for this device.

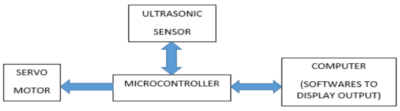


Figure 3: Block Diagram of the module

No power source is included, as the processor is powered through a USB connection to a computer; a standard USB 2.0 port will provide enough power. This module acts as the connector between the main device and the computer which generates the map. It sends a control signal to the main device telling it to start, and receives the range data from the sensors, sending this data over a serial connection to the connected computer.

4.1 Ultrasonic Ranging Module HC - SR04

Ultrasonic ranging module HC - SR04 provides 2cm - 400cm non-contact measurement function, the ranging accuracy can reach to 3mm. The modules includes ultrasonic transmitters, receiver and control circuit. The basic principle of work:

(A) Using IO trigger for at least 10us high level signal,

(B) The Module automatically sends eight 40 kHz and detect whether there is a

pulse signal back.

(C) IF the signal back, through high level , time of high output IO duration is the time from sending ultrasonic to returning.

Test distance = (high level time × velocity of sound (340M/S) / 2.

Figure 4: Ultrasonic Sensor HC-SR04

4.2 Arduino Uno Microcontroller

To control the device, an Arduino Uno was chosen. Arduino microcontrollers are specifically advertised as being good choices to prototype devices; they provide an IDE (integrated development environment) which can use any C code; many components also provide code libraries to work specifically with the Arduino. According to the technical specifications [4], the Arduino Uno board requires an input voltage of 6-20 volts, which is regulated down to a usable voltage. This means the chosen power source for the Arduino can vary as much as required for the other components. The Uno contains 6 analog I/O pins, which are required to read data from the ultrasonic sensors and to control the servo motor. 5 pins are required for the device, as 4 are used for the ultrasonic sensors and 1 is required to control the servo motor. The analog pins output up to 50 mA of current, which is more than enough for the ultrasonic sensors. There are also 14 digital I/O pins, which are required to control the wireless transmission system.

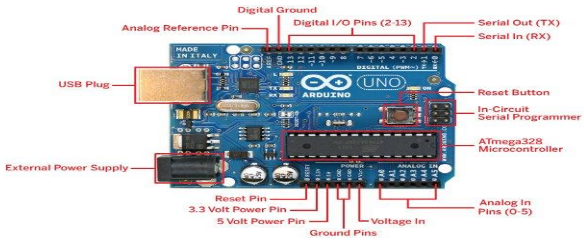
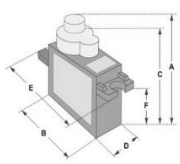


Figure 6: Arduino pin details

4.3 Servo Motor SG90

Tiny and lightweight with high output power. Servo can rotate approximately 180 degrees (90 in each direction), and works just like the standard kinds but smaller. You can use any servo code, hardware or library to control these servos. Good for beginners who want to make stuff move without building a motor controller with feedback & gear box, especially since it will fit in small places. It comes with a 3 horns (arms) and hardware.



Dimensions & Specifications
A (mm) : 32
B (mm) : 23
C (mm) : 28.5
D (mm) : 12
E (mm) : 32
F (mm) : 19.5
Speed (sec) : 0.1
Torque (kg-cm) : 2.5
Weight (g) : 14.7
Voltage : 4.8 - 6

Figure 7: Servo Motor SG90 Data Sheet

4.4 Physical Structure

The individual components of the device need to be held together securely. The structure as shown in Figure. 7 was build by using Arduino UNO, ultrasonic sensor which is mounted on the servo motor for its rotatory movement. These are connected via jumper wire to the breadboard. The microcontroller is connected to the computer which powers it and the data from the sensor is transferred to the computer via USB 2.0 connection.

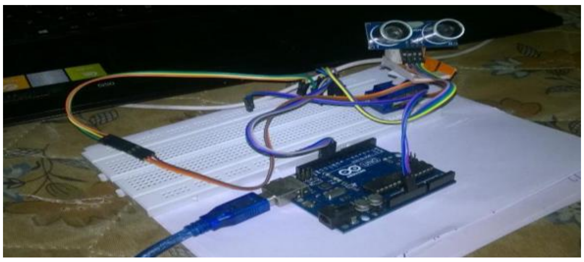


Figure 8: Physical structure of the device

4.5 Generating a Two-Dimensional Map

While the physical device is the main component of this work, it is also vital that the software performs its job correctly. The software being used for this part of the work is MATLAB, which is a program capable of performing complex mathematical calculations with large amounts of data. The entire operation of the device is actually controlled from the MATLAB program.

The MATLAB code runs and fetches the data from the Arduino IDE software through its serial monitor and hence plots the graph between the angle of rotation of the sensor to the distance of the obstacle from it.

4.6 Software Implementation

The software that were used are Arduino IDE, Processing and MATLAB. The microcontroller was being controlled by the Arduino IDE software and the outputs from the ultrasonic sensor was displayed in its serial monitor. The data from serial monitor was further utilized by the processing software which is similar to the Arduino IDE software but can be further used to created GUI and animations , hence the radar animation is created by the processing software that shows the distance of the object and weather it is in the range of 40 cm or not. The obstacle is represented by the red lines and the blue lines represent no obstacle. The angle of rotation and the range of the radar can be changed by slight modifications in the coding part. The maximum range can be up to 400 cm.

5 Outputs and Results

The output from the processing software as a radar output for three different cases is as shown.

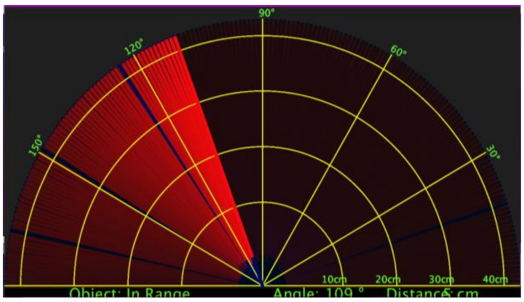


Figure 9: Radar output for obstacle at 5 cm

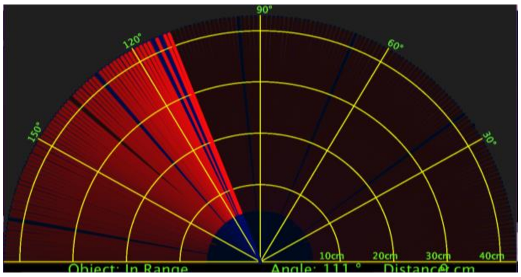


Figure 10: Radar output for obstacle at 9 cm

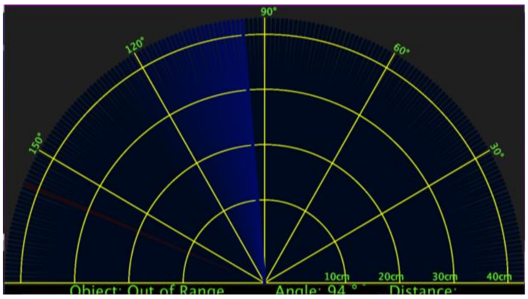


Figure 11: Radar output for obstacle that is out of range

The plot between the angles of rotation to the distance of the obstacle for three different environments is shown.

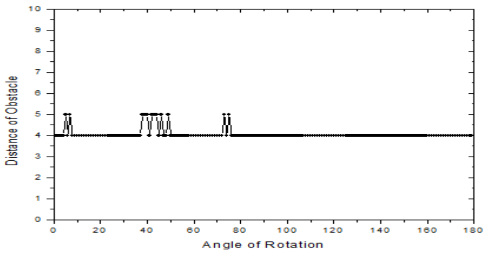


Figure 12: Plot for obstacle at a constant distance of 5 cm

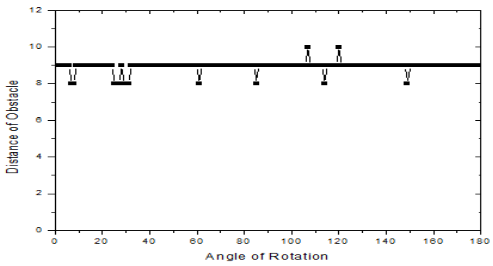


Figure 13: Plot for obstacle at a constant distance of 9 cm

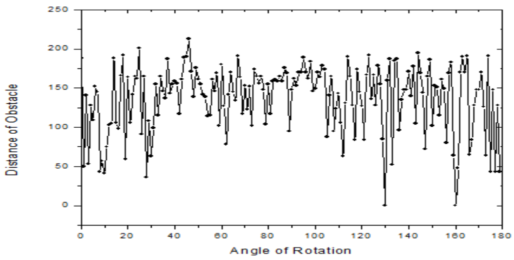


Figure 14: Plot of a room with various obstacles

So one can get the 2-D Plot of a room with different objects in it. This device can serve good for the military purpose, construction and measurement works.

6 Conclusion

Currently, the device is capable of receiving a signal from MATLAB in order to start operation, gather the data from Arduino IDE and report them back to MATLAB, where a 2D plot of the room using the data is created. This plot displayed a degree of inaccuracy, which can likely be attributed to the beam width of the energy transmitted by the sensors: they would repeatedly report the same distance for a single wall, instead of steadily increasing the distance as the angle from the center of the wall increased.

There are many ways this work can be expanded or improved on in the future to accomplish the original goals. First, the inaccuracies in the graph would need to be addressed. This would be done by replacing the HC-SR04 with a much more accurate ultrasonic sensor, with a much smaller beam width. This would almost certainly remove any of the problems that are currently occurring. The device would need to be made fireproof, or at least heat resistant in some way. It is unlikely the device will be used in a room where there is smoke but no other hazards, so it must be able to survive such an environment. The device should also be able to handle being thrown; this is a huge step, as most of the electrical components are fragile, especially the Arduino board. The motor must also be able to survive the impact, which is unlikely. Most of the components would probably need to be encased in shock-absorbent material, or replaced entirely. The device would need to land upright if thrown as well, as it cannot create a map if all of the sensors are facing the floor. Lastly, the device would be expanded to the 3D domain, as discussed previously. With these improvements, an ultrasonic mapping device is certainly feasible.

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