Bachelor Thesis
Electrical Engineering
Thesis no: MCS-20YY-NN
06 2021

Compact Radar System

Chalikonda Nikhil
Naga Viswanth Bonthu

Dept.Mathematics and Natural Sciences
Blekinge Institute of Technology
SE–371 79 Karlskrona, Sweden

This thesis is submitted to the Department of Mathematics and Natural Sciences at Blekinge Institute of Technology in partial fulfillment of the requirements for the degree of Bachelor's of Science in Electrical Engineering. The thesis is equivalent to 10 weeks of full-time studies.

Contact Information:
Author(s):
Nikhil Chalikonda
E-mail:nich20@student.bth.se
Naga Viswanth Bonthu
E-mail:nabo20@student.bth.se

University advisor:
Irina Gertsovich
Dept. Mathematics and Natural Sciences

	Internet	:	www.bth.se/
Blekinge Institute of Technology	Phone	:	+46 455 38 50 00
SE–371 79 Karlskrona, Sweden	Fax	:	+46 455 38 50 57

Abstract

ContextRadar was developed in secret during world war II to detect obstacles or any incoming threat. The term radar was coined in 1940 by United States Military as an acronym for "Radio Detection and Ranging". Using radio waves a radar detects any incoming threat or obstacle [10]. The basic purpose of radar is for monitoring and security. In this work, the ability of an ultrasonic sensor to perform object identification and map reconstruction tasks is investigated.
Objective This project aims to design an affordable and re- liable ultrasonic radar that rotates 180 degrees. Using certain predetermined scenarios the sensor is tested for its accuracy and resolution extensively to know its potential to be used in an autonomous mobile robot. This analysis shall further be helpful to calibrate the sensor and build an autonomous mobile robot used for map reconstruction.
Methods Powered by Arduino Uno, the prototype is programmed via IDE and examined to monitor a void/unknown environment. When the sensor detects an obstacle in its range, the prototype is programmed to alert the user after the scan by displaying it on the plot generated on Matlab.
Results From this work the use of ultrasonic sensors for obstacle detection and ambient map reconstruction is determined. The sensor performed well in accuracy tests for different objects having different physical properties. The standard deviation and correlation coefficient are calculated to determine the uncertainty in the ultrasonic scan. Overall a degree of uncertainty is being observed in the results. One possible cause might be due to the effects of variation in environmental parameters.
Conclusions Overall the sensor is precise and accurate in distance measurements. Although for the application of building a map-making autonomous mobile robot, the sensor has failed to prove reliable alone and further study is required to understand the cause of these uncertain results.

Keywords: Arduino, Matlab, Servo motor, Ultrasonic radar

Contents

List of Figures

List of Tables

Chapter 1

Introduction

Echolocation is a technique bats use to help them cope with their weak vision to survive the wild. The discovery of this technique used by animals such as bats and dolphins had inspired scientists to develop the concept of Radar, a device used for monitoring the surroundings of the user. Radar research is becoming more common and has been on the news lately. According to a Market Research Future (MRFR) analysis published "Global Radar Transmitter Market Information by Type, Application, and Region – Forecast to 2027," the market is projected to reach USD 3.82 billion by 2025 with a "Compound annual growth rate of 6.4 Percent" [15]. In the beginning, the idea of measuring the distance was first tested experimentally.

Radar systems are classified under various categories depending on their functions and purposes. Contact-less distance measuring can be achieved in many ways, depending on the principle used. For instance, infrared light is used by transmitters and receivers for various applications by a sensor to determine the distance using the optical triangulation method, which is precise, yet sensitive and expensive [17]. Ultrasonic sensing is a non-contact measurement method for determining the distance using sound waves [7].

Ultrasonic sensing is a revolutionary technology that senses obstacles in the user's path, is widely used for obstacle detection in autonomous vehicle navigation, construction and ambience exploration for map building purposes [14] [1]. Ultrasonic sensors are more desirable in these applications compared to other sensor types used for similar purposes because they are affordable, light weight and have simple excitation stages. Besides that, the sensors are can be used in different ambient conditions like poorly illuminated surroundings and in presence of fumes [22].

There are some disadvantages experienced while using ultrasonic sensors due to attenuation of ultrasonic sound waves in air, therefore it is necessary for the sensor to work at low frequencies [20]. Changes in temperature, medium of propagation and frequency of the signal also have an effect on the ultrasonic sound wave propagation. The sensor emits ultrasonic sound waves into the air and captures the echo reflected from the surface of the object, time taken by the sensor to capture the reflected wave is used as an input to calculate the distance from the obstacle (time of flight) [22]. This technology plays a crucial role in almost every industry,

like the medical industry, ships, aviation industries, outer space, and automobiles. Thus they are widely used for distance measurement purposes for their accuracy and are available at variable costs depending on the purpose.
In this project the ultrasonic sensor DFRobot UMR37 was used, unlike many other projects where "HC-SR04" is the most commonly used sensor. We studied the accuracy of distance measurement using the sensor to the obstacles of different materials, like wood, sponge and plastic. After that the sensor was used to measure the distances to the obstacles of different configuration, such as a straight wall and wall with the corners.

Chapter 2

Related Work

Various articles and journals had been used for research and analyzing problems to come up with a reliable solution. The ultrasonic sensor has been in the market for several years had proved to be a reliable sensor with wide range of applications. The objective of this survey is to research and check for reliable and innovative ways to experiment on an ultrasonic sensor to compare it's accuracy to that provided by the factory.

Rechie Ranaisa Dam et al. had proposed a way to determine the 2D shapes of an object as shown in figure 2.1. The objective of this work is to build an ultrasonic device which is basically a radar system to get exact distance and approximate 2D shape for fixed objects placed in device's range, using trigonometric rules as shown in figure 2.1. To achieve this the ultrasonic sensor needs to be tested for it's ability to show reliable results [13].

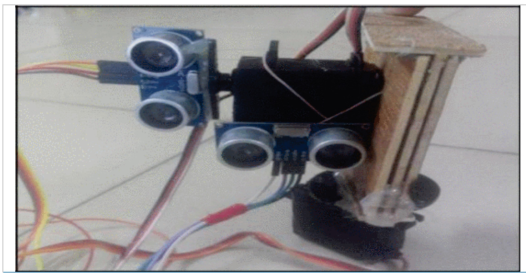

Figure 2.1: A Radar System To Get Exact Distance And Approximate 2D Shape For Fixed Objects [13]

Adarsh S, et al. had conducted a performance test between ultrasonic sensor and infrared sensor measurements using different material with physical properties to check their responses and build an autonomous mobile robot for map building as shown in figure 2.2 [12].

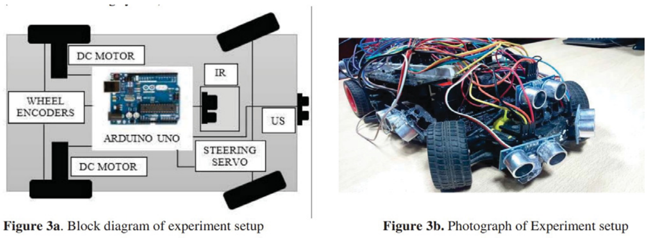

Figure 2.2: Autonomous Mobile Robot For Map Building [12]

Lorant Andras Szolga, had proposed an ultrasonic system for cartography applications powered by Arduino Mega development board and attaching seven servos on an Acrylic-Butadiene-Styrene plate, mounted onto a servo. The drawback of this implementation is the small resolution of the distributed ultrasonic sensors and the imperfection of the servomotor [24].

Figure 2.3: Ultrasonic System For Cartography [24]

Lorenzo Scalise et al. had conducted a comparison test between electro magnetic sensing and ultrasonic sensing used for obstacle detection [23].

All these systems are proposed using an ultrasonic sensor. A study by Esther G. Sarabia et al. states that the sensor is facing with overlapping echos for instance when measuring the corners of a wall [21]. But for a system to be applicable in practical scenarios the system/prototype must be tested extensively and attested for it's potential to be used in real-life applications and overcome it's limitations.

Esther G. Sarabia et al. had conducted a study to investigate the ultrasonic signal's Time-of-Flight between hitting the target obstacle and coming back to the ultrasonic transducer and amplitude to study and understand the signal processing when faced with overlapping echos which is critical for distance measurement and map reconstruction applications while scanning a corner of a room. This model enables the analysis of the ultrasonic response that is generated using a pair of sensors in transmitter-receiver configuration using the pulse-echo technique for recognizing surfaces that simultaneously generate a multiple echo response [21].

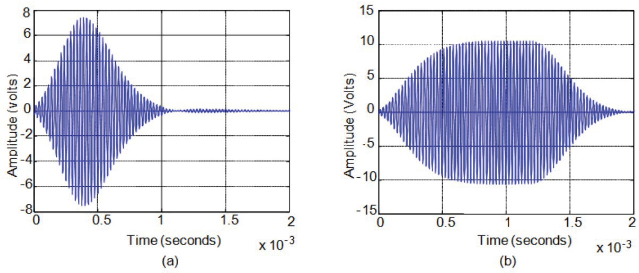

Figure 2.4: Analysis Of Number Of Cycles In An Excitation Pulse [21]

Milagros Martínez and Ginés Benet, had written an article on the wall-corner classification using sonar [19], in this experiment the authors attempt to over come the limitations of a ultrasonic sonar system while measuring the corners of a wall. Experimental results show an enhancement in results of classification rates, when the geometric features of an environment are considered.

Figure 2.5: Piezoceramic Transducer Vertically Aligned And Mounted Onto A Stepper Motor [19]

Chapter 3

Method

3.1 Aim and Objective

Problem statement: Radar systems have many applications, from simple everyday activities such as car parking to exploring the unknown such as space. They can be used to map unknown voids. But for such applications, the system must be equipped with reliable sensors, actuators, and a smooth algorithm to make it possible. The sensors collect physical parameters such as distance information, angle information, and size information and send them back to the system to process. The environment, that the sensor collects information about, can be made of different materials, which can affect the sensor performance. The environment can also have different shapes, for example a straight wall or the wall with the corners, which also might affect the results of the sensor function.
Project objective: This project aims to design a precise distance measuring system using reliable and affordable sensors and actuators and determine whether or not an ultrasonic sensor can be used in a mobile robot for autonomous mapping. There are many approaches to accomplish this task other than an ultrasonic radar which the authors have studied and done their research. This paper also covers the study of ultrasonic sensors and actuators used in modeling the prototype. The ultrasonic sensor and servo motor are programmed in Arduino IDE to synchronize and work together as a radar system and communicate with the Arduino serial pin and read the serial data via Matlab which then plots the distance versus angle graph.

Objectives:

- Program the Arduino controlled ultrasonic radar in IDE to get the distance and servo angle values on the serial monitor of Arduino IDE.
- Record the values extracted from the prototype and check for accuracy with extensive testing.
- Inspect and document the measurements obtained from ultrasonic sensor and compare them to actual scale measurements using different materials with different physical properties (from 0-150 cm, obstacle placed at every 15 cm).
- Inspect and document the ultrasonic readings of ultrasonic sensor to actual scale measurements when the obstacle is placed at every 5 mm (between 15-20 cm).
- Inspect and document the readings obtained from ultrasonic sensor when placed in a symmetric rectangular box where the sensor covers the three walls while rotating 180 degrees.
- Inspect and document the measurements obtained from the ultrasonic sensor when it is made to rotate 180 degrees, while faced with a wall with no corners.
- Inspect and document the measurements obtained from the ultrasonic sensor when it is made to rotate 180 degrees, while faced with a wall with corners.

3.2 Main Contributions

This project is implemented in the following steps:

- Gather the components: Arduino Uno, sensor (UMR037 V5.0) and actuator (Servo Motor) required for the project.
- Using Arduino IDE, program the UMR037 to measure distance and servo motor to rotate 180 degrees.
- Mount the ultrasonic sensor above the servo motor and synchronize the program to gather the distance along with the angle of the servo to illustrate onto the serial monitor.
- Establish a connection between Arduino and Matlab. After the Matlab is able to communicate with the Arduino Uno, prepare serial port of Arduino Uno to serial stream data into the Matlab register.
- Plot the data stored in Matlab, registered as distance and angle acquired from the ultrasonic sensor mounted on the servo motor.
- Measure the dimensions of the box manually, using trigonometry plot the expected graph. Compare the output plot to expected plot.

Chapter 4

Methodology

This chapter is divided into two parts. The first part is about the implementation and system design. The second part describes about the modeling where the list of components and their specifications are mentioned along with a flow chart.

4.1 Estimating Distances Using Ultrasonic Sound

Ultrasonic working There are two types of ultrasonic sensors that operate with air as a medium namely, Piezoelectric ultrasonic and electrostatic ultrasonic. Unlike piezoelectric ultrasonic sensors, the electrostatic ultrasonic sensors are highly sensitive and have higher bandwidth but require higher voltages for operation. Hence Piezoelectric ultrasonic sensors have been used for this project. Piezoelectric ultrasonic sensors require low voltage excitation signals (10-20 VS), they are light, compact, and affordable. The principle operation is to apply a low voltage to the perfectly balanced metal plates placed on either side of the ceramic glass, making it resonate at a high frequency when voltage is applied to the metal plates.

The ultrasonic sensor is equipped with two transducers that are used in transmitting and receiving ultrasonic signals. As shown in figure 4.1 the generated ultrasonic signal is sent out from the emitting transducer, when the signal comes in contact with the target obstacle it is reflected, and the receiving transducer captures the reflected signal. The time taken by the signal to hit the target object and reflect is calculated and then using the "Time of Flight" equation the time measurement is converted into the distance from the target obstacle[18] [11]. For a given position of the sensor relatively to the obstacle obstacle we can predict the distance based on the sensor orientation using the following equation:

$$D = \frac{\upsilon T}{2} \tag{4.1}$$

where, "υ" is speed of sound in air and "T" is the travel time of the ultrasonic sound emitted from the sensor.

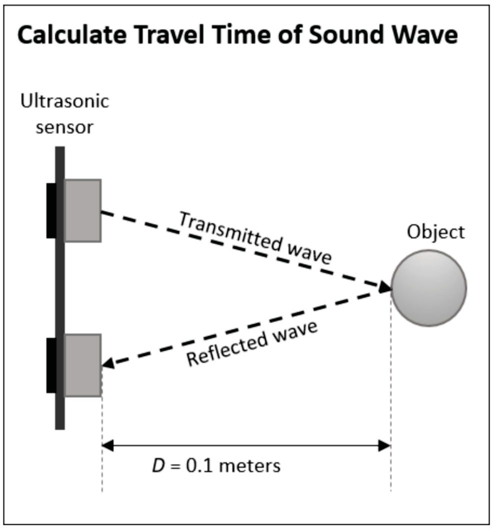

Figure 4.1: Distance Measurement Visualization Of An Ultrasonic Sensor [18]

4.2 System Design

The approach used in this paper is described in the block diagram below (figure 4.2). The Arduino Uno board is programmed using IDE to control the radar system and record the distance measurements along with servo angle values and display it on the IDE serial monitor. As soon as the prototype is connected to the host computer the Matlab software recognizes the Arduino board with the help of the "Matlab support for Arduino hardware" library. This library has to be pre-installed onto the Matlab, so it can communicate with Arduino. Then Matlab attempts to establish a connection with the serial port of the Arduino board and starts to serial stream data from the Arduino's serial port and records the data to plot a map of the surroundings.

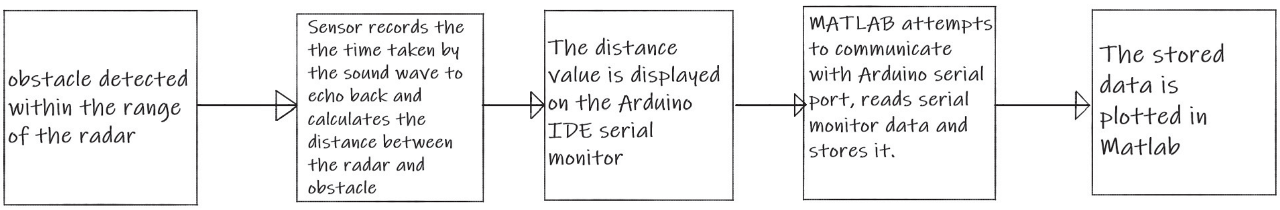

Figure 4.2: System Design

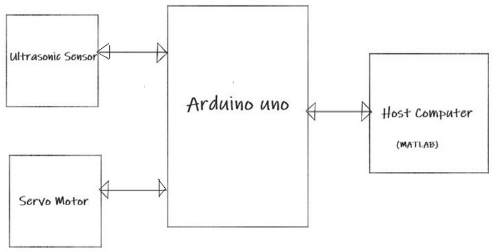

Figure 4.3: Block Diagram

Figure 4.3 shows the structure of information exchange between the hardware components. Arduino Uno draws powers from the host computer and communicates with the sensors and actuators through the circuit (figure 4.4). The ultrasonic sensor and servo motor are powered up simultaneously, as programmed the ultrasonic sensor and servo motor work in synchronization. The Arduino board sends a 5V pulse as a trigger signaling the sensor to send out the ultrasonic wave from the transducer. When the reflected wave hits the transducer the information is sent to the Arduino, which the host computer streams to Matlab.

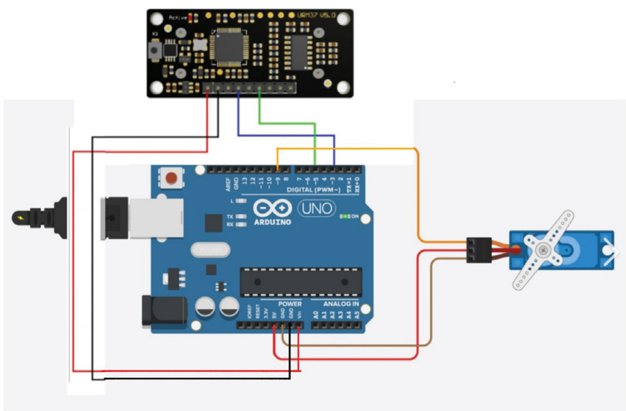

Figure 4.4: Circuit Diagram

Hardware components:

Arduino Uno Arduino is open-source hardware. Arduino microcontrollers are pre-programmed with a boot loader that simplifies uploading programs to the on-chip flash memory. The default bootloader of the Arduino Uno is the Optiboot bootloader. The program code is uploaded onto the board via a serial connection to another computer. Current Arduino boards are programmed via Universal Serial Bus (USB), implemented using USB-to-serial adapter chips such as the FTDI FT232. Arduino Uno is a microcontroller board based on the ATmega328P. The Uno board is the first in a series of USB Arduino boards and the reference model for the Arduino platform [2].

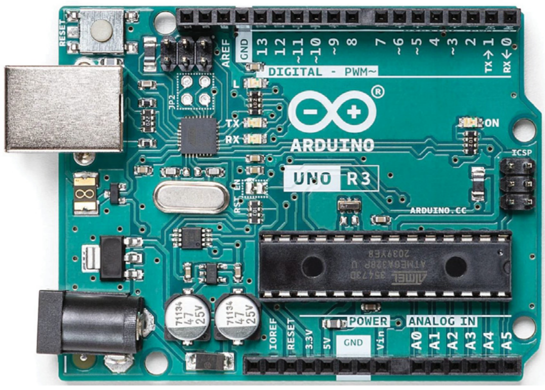

Figure 4.5: Arduino Uno [2]

Pin Category	Pin Name
Power	Vin, 3.3V, 5v, GND
Reset	Reset
Analog Pins	A0-A5
Input/Output Pins	Digital Pins 0-13
Serial	0(RX), 1(TX)
External Interrupts	2,3
PWM	3,5,6,9,11
SPI	10(SS),11(MOSI),12(MIOS),13(SCK)
Inbuilt LED	13
TWI	A4,A5
I2c	SDA, SCL

Table 4.1: Arduino Configuration [2]

Ultrasonic Sensor URM37 V5.0 is a powerful ultrasonic sensor module with bulit-in temperature compensation to ensure accurate distance measurement in the scene of temperature-changing applications. It has rich interface and offers various output: analog output, switch, serial (TTL and RS232 level optional), PWM and so on. The module can be used to measure the rotation angle of the servo. Connected with an external servo, it changes into a spatial ultrasonic scanner [5]. The distance from an obstacle is calculated by using the below formula using Time period of the input signal as input variable obtained from the ultrasonic sensor. In this project the ultrasonic sensor is placed above the servo motor, the servo rotated 180 degrees. The sensor can be used to calculate the distance between the sensor and the obstacle according to the equation (4.1) [8].

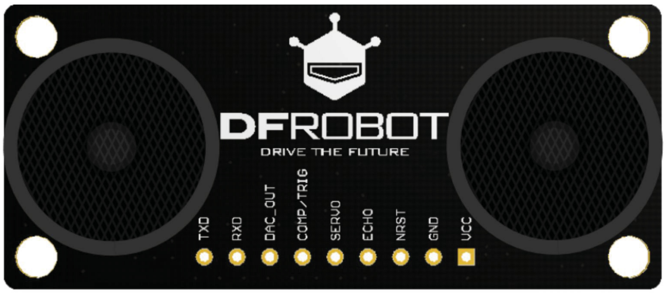

Figure 4.6: UMR037 [8]

Label	Description
VCC	Power input (3.3V-5.5V)
GND	Ground
NRST	Reset
ECHO	Measured distance presented by the data output 0-25000US by PWM mode, 1CM/50US representative
SERVO	Servo Control Pin
COMP/TRIG	COMP: On/OFF mode, when the detected distance is smaller than the pre-set value, this pin pulls low. TRIG: PWM mode trigger input
DAC-OUT	Analog voltage output; the voltage is proportional to the distance
RXD	Asynchronous communication module data receiving pin: RS232/TTL level
TXD	Asynchronous communication module data receiving pin: RS232/TTL level

Table 4.2: UMR037 Configuration [8]

Servo Motor A servo motor is a rotatory actuator or a linear actuator that allows for precise control of angular or linear position. In layman terms the user can rotate the servo in a specific angle or distance. DSS-P05 standard servo high torque servo. This is a special servo without hardware stop, it depends its internal potentiometer to detect the angle. Servos are controlled by sending PWM pulses. Depending on the input power the servos are classified into AC or DC servo motors. A servo motor has 3 input ports: power, ground and signal [4].

Figure 4.7: Dss P05 Servo Motor [4]

Voltage	+4.8 - +6.0 V
Running current (at no load)	20mA@ 4.8V 25mA@ 6V
Stall current (at locked)	300mA@ 4.8V 350mA@ 6V
Rotation Degree	180 Degree
Torque Size	4.5kg · cm (6.0V)
No load speed	0.17 seconds / 60 degrees (4.8V); 0.12 sec / 60 degrees (6.0V)
Operating temperature	0 ℃ 60 ℃
Dead Set	20us
Size	40.2 X 20.2 X 43.2mm
Weight	38±1g

Table 4.3: Servo Configuration [4]

Software used:

Arduino IDE: Arduino Integrated Development Environment (IDE) is a cross-platform application (for Windows, macOS, Linux) that is written in functions from C and C++. It is used to write and upload programs to Arduino boards, also with the help of third-party cores and other vendor development boards.

Matlab: Matlab is a programming platform designed specifically for engineers and scientists to analyze and design systems and products that transform our world. The heart of Matlab is the Matlab language, a matrix-based language allowing the most natural expression of computational mathematics.

4.3 Implementation

This project is about designing an affordable and reliable ultrasonic radar system with 180 degrees range. Using this prototype the sensor is attested for its potential to be used in an autonomous mobile robot by conducting tests for the accuracy of the sensor. There are many ways to achieve this task as discussed above. In this project, both Arduino IDE and Matlab share the work in the designing of the system. Arduino IDE controls the board which collects data from the sensor and commands the servo to rotate. Matlab is used for simulating and analyzing dynamic systems.

Algorithm to acquire the distance from the obstacle: Figure 4.8 shows the algorithm's flow chart. The Arduino board is loaded with a program that controls the ultrasonic sensor and servo motor to work in synchronization and record the respective values and send the data to the serial monitor continuously. In the program Arduino directs the ultrasonic sensor to calculate the time period of the emitted signal, using the time period it calculates the distance from the obstacle while simultaneously the Arduino directs the servo to rotate 180 degrees and the angle of the servo is calculated using the algorithm. The ultrasonic module is equipped with a function to control the servo motor. Under the mode of non-automatic measurement (Serial level TTL Mode), UMR037 can combine with the servo to create a 180 degree measuring module and scan the obstacles at the range of 0-180 degrees. The prototype is set to measure the "ToF" and angle continuously. The data is recorded to the host computer using a streaming algorithm on Matlab that recognizes the Arduino hardware. The recorded data is set to plot a graph for distance versus angle for further study and analysis.

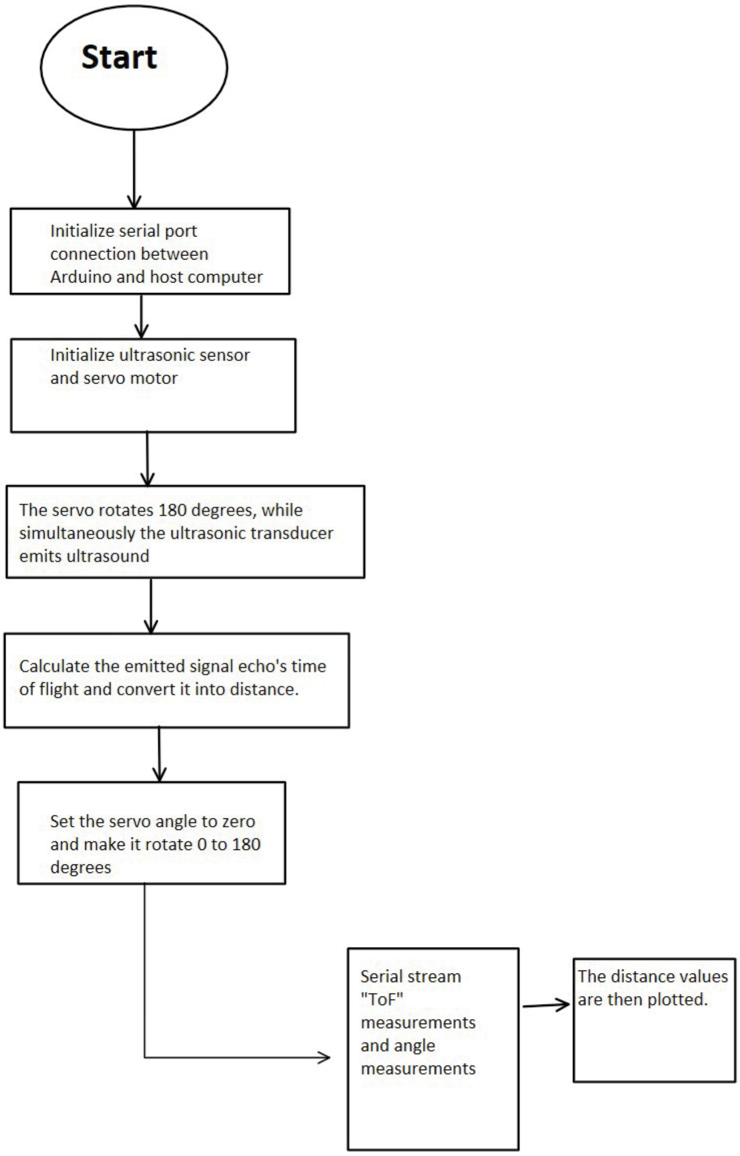

Figure 4.8: Process Of Measuring Distance From The Obstacle

Standard deviation is the measure of spread in simpler terms how spread out a set of data is, a low standard deviation means that the data is closely clustered around the mean and a high standard deviation means the data is dispersed over a wider range of values. For any set of data, the mean and standard deviation can be calculated. This parameter is commonly used to understand whether a specific data point is standard and expected or unusual and unexpected, i.e standard deviation is used to determine whether a result is "statistically significant" or a part of "expected variation". In this project standard deviation was used to express uncertainty in ultrasonic measurements. The standard deviation can be calculated according to [6]:

$$S = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}|A_i - \mu|^2} \tag{4.2}$$

where A_i is the measured data set, made up of "N" scalar observations and μ is the mean of A_i.

$$\mu = \frac{1}{N}\sum_{i=1}^{N} A_i \tag{4.3}$$

Correlation coefficient (r) is the measure of how good the obtained regression model is expected to be, in simpler terms it is the quality of measurement. Often the value of the Correlation coefficient lies between $r = \pm 1$. In this case, it defines the relationship between true value and measured value.
When $r = 1$ it has perfect correlation [9]. Correlation coefficient is calculated according to [3].

$$r = \frac{1}{N-1}\sum_{i=1}^{N}(\frac{A_i - \mu_A}{\sigma_A})(\frac{B_i - \mu_B}{\sigma_B}) \tag{4.4}$$

where, "A"&"B" are two random sets of data of "N" scalar observations and "μ_A","σ_A" are mean and standard deviation for "A" and "μ_B","σ_B" are mean and standard deviation for "B" [3].

Chapter 5

Discussion Of Results

5.1 Study of Sensor Performance with Obstacles with Different Physical Properties

This chapter includes the plots and analysis of the distance values obtained from the ultrasonic sensor under different predetermined scenarios. The obtained values extracted from the ultrasonic sensor are verified via accurate scale measurements. The materials used for testing with different physical properties are wooden plank, sponge sheet, plastic sheet and the distance values are tabulated along with the standard deviation, correlation coefficient (in centimeter scale) calculated using equations (4.4) and (4.6). The parameters "Ultrasonic Distance" and "True Distance" shall provide insight regarding the performance of the ultrasonic sensor. The accuracy of UMR037 ultrasonic sensor is estimated from these tests and compared to the one mentioned by the manufacturer.

Tests for accuracy were performed using different materials having different physical properties, which are recorded and analyzed. Tests were conducted multiple times, the greater is the number of the tests, the more reliable the data can prove to be.

- Figure 5.1 shows distance calculated by ultrasonic sensor when the obstacle is a wooden plank in lab like environment and verified with scale measurements (between 0-150 cm range the obstacle is placed at every 15 cm) as shown in figure 5.2. The ultrasonic readings are steady, the surface of wood is smooth yet uneven on a microscopic level. Although it reflects the sound back well enough to obtain a steady graph. The plot shows low very little variance.

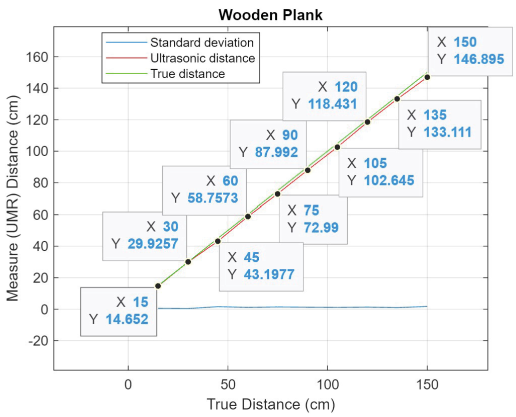

Figure 5.1: Wooden Plank

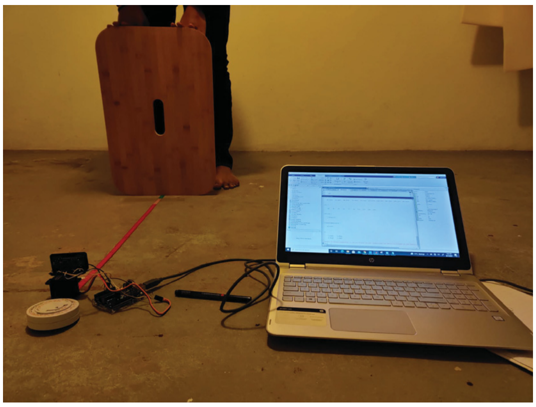

Figure 5.2: Wooden Plank Test

- Figure 5.3 shows distance calculated by ultrasonic sensor when the obstacle is a sponge sheet in lab like environment and verified with scale measurements (from 0-150 cm, obstacle placed at every 15 cm). The ultrasonic sensor's plot shows highly noticeable variations in distance measurements from the beginning and a little smooth in the end (from 105 - 150 cm in actual scale measurement). The cause of this variation might be because sponge being porous, the sound had been absorbed initially and reflected back with a delay. Hence even though the time of flight measurement is correct, the method of distance calculation stands unreliable to be able to recognize when sponge is the obstacle [16].

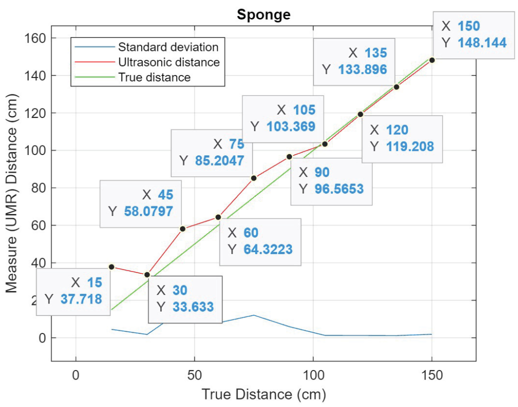

Figure 5.3: Sponge Sheet

- Figure 5.5 shows the distance calculated by ultrasonic sensor when the obstacle is a plastic sheet in lab like environment and verified with scale measurements (from 0-150 cm, obstacle placed at every 15 cm). Figure 5.4 shows the plot is observed to be stable and steady, since the surface of plastic is smooth and even it reflects most of the sound waves.

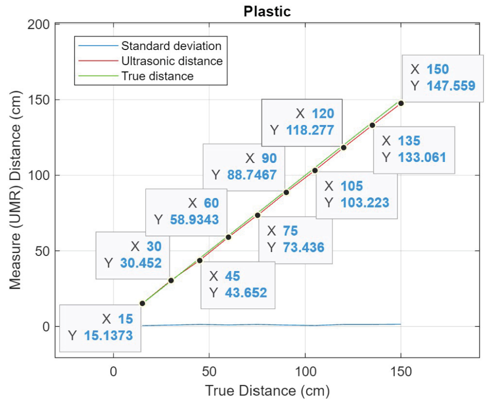

Figure 5.4: Plastic Sheet

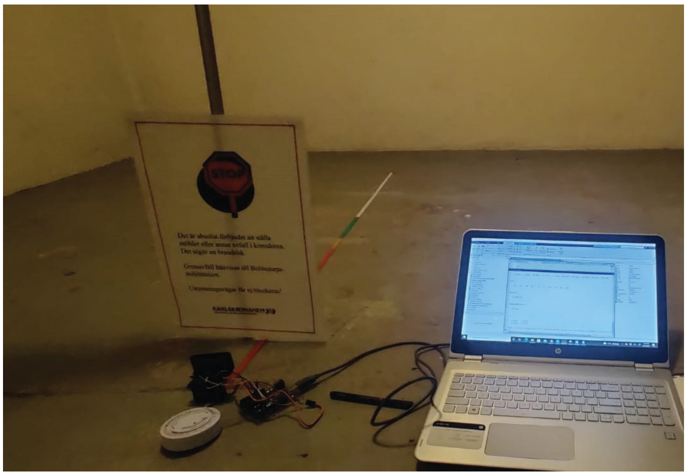

Figure 5.5: Plastic Sheet Test

- Distance calculated by ultrasonic sensor when the obstacle is a cardboard box in a lab environment (figure 5.6) and verified with scale measurements (from 15-20 cm, obstacle placed at every 5 mm). This plot shows represents how well the sensor is able to differentiate changes in input. The sensor shows good response to change is obstacles position on the scale.

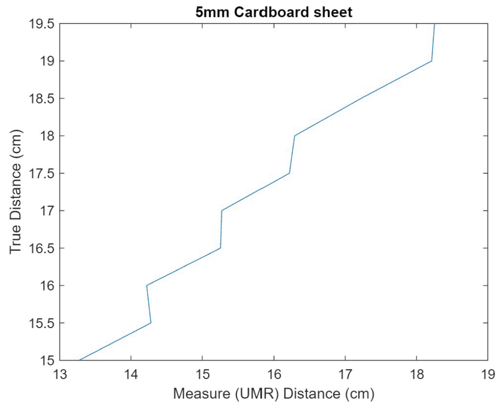

Figure 5.6: 10 mm Cardboard Test

- This graph (figure 5.7) represents the comparison between different materials that were used to perform the experiment. Wood and plastic respond well to ultrasonic scanning unlike sponge.

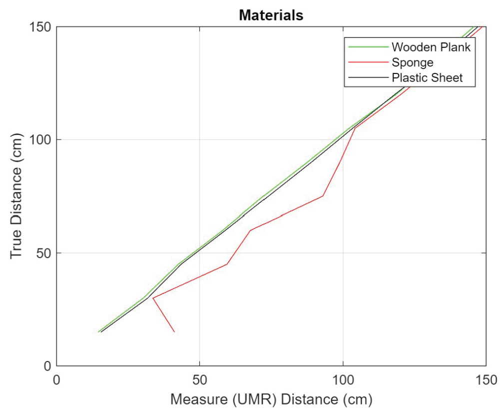

Figure 5.7: Comparison Between Materials

Each experiment has been conducted ten times and the mean values of the Ultrasonic scans have been used to plot the graph as shown in figure 5.1, 5.3 and 5.4 that represent the plots of the experiment that was conducted to measure the distance from the sensor to obstacle with different physical properties to check the effects different materials have on ultrasonic sound.

Mean of Distance's acquired (in "cm")

True Distance	***15***	***30***	***45***	***60***	***75***	***90***	***105***	***120***	***135***	***150***
Ultrasonic scan (Wood)	14.6520	29.9257	43.1977	58.7573	72.99	87.992	102.6447	118.4313	133.111	146.8947
Ultrasonic scan(Sponge)	37.718	33.633	58.0797	64.3223	85.2047	96.5653	103.3693	119.2083	133.8963	148.1437
Ultrasonic scan (Plastic)	15.1373	30.452	43.652	58.9343	73.436	88.7467	103.2233	118.2773	133.061	147.559

Figure 5.8: Mean of Distance's Acquired in "cm"

Statistical analysis of sensor data for different obstacles		
Material	Standard deviation "s"	Correlation coefficient "r"
Wooden plank	±1.1380	±0.9996
Sponge	±5.2587	±0.9391
Plastic sheet	±0.9987	±0.9998

Table 5.1: Standard Deviation and Correlation Coefficient

- Standard deviation parameters were calculated (for individual data sets), this parameter was calculated to express uncertainty in ultrasonic scan. Using different materials having different physical properties these results help express uncertainty in ultrasonic scans.

- Correlation coefficient was measured between measured and actual distance values. The benchmarks set for the readings are 0.9 and above very high correlation; 0.7 to 0.9 high correlation; 0.5 to 0.7 medium correlation; 0.3 to 0.5 low correlation; 0.3 and below low correlation.

5.2 Scan of the box

- Figure 5.9 shows how the the dimensions of the box were estimated and angles were calculated.

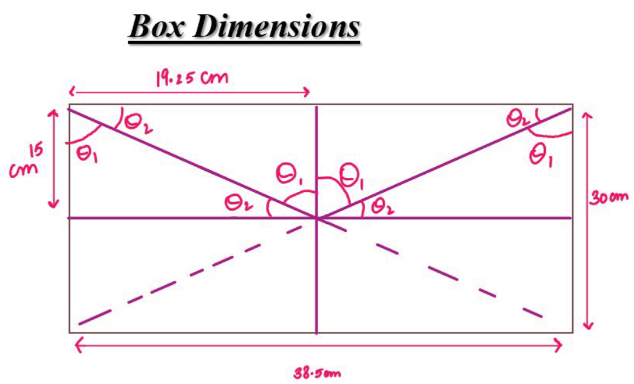

Figure 5.9: Trigonometric Approach Visualization, Dimensions (in "cm")

- Figure 5.10 shows how the sensor is made to scan the 3 walls of the cardboard box (rotating from 0 to 180 degrees).

Figure 5.10: Prototype Scanning The Three Walls Of The Box

- This plot (Figure 5.11) represents the expected graph of the ultrasonic scan which is an assumption of how the plot is expected to be when placed in a symmetric box. The sensor scans the three walls of the box it is placed in while rotating 180 degrees.

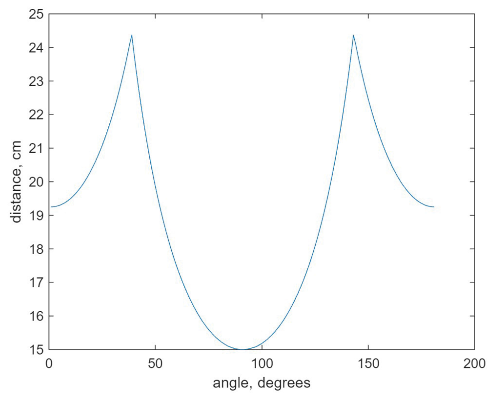

Figure 5.11: Expected Plot For A Box

- Figure 5.12 is the resulting plot obtained from the ultrasonic scan . In this graph it can be observed that the radar rotates 180 degrees twice to check for it's repeatability.

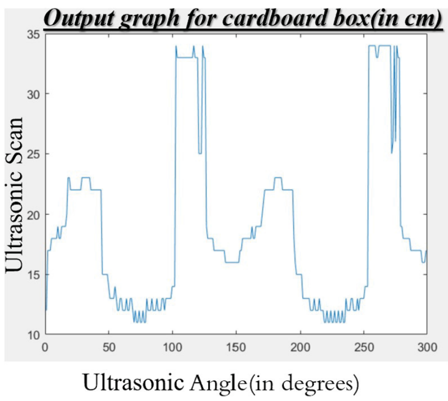

Figure 5.12: Ultrasonic Scan Plot For A Box

The sensor seems to show some degree of uncertainty while plotting the wall measurements of the box, especially at the corners of the box. To observe this uncertainty another experiment was conducted, where the sensor was made to plot two different scenarios of a wall, one that has corners and one that has no corners.

- Figure 5.13 shows the plot for distance measurement when the ultrasonic sensor is placed 20cm away from a wall, making sure the corner of the wall is observed by the sensor when the sensor is made to rotate 180 degrees for a scan.

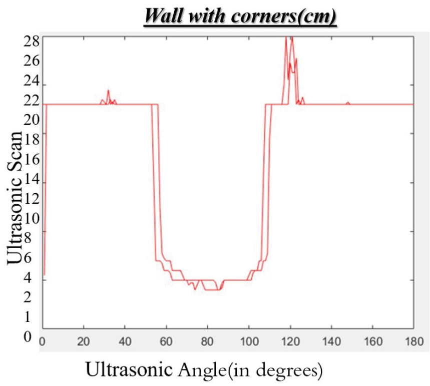

Figure 5.13: Scan Of A Wall With Corner

- Figure 5.14 represents the plot for distance measurement when the ultrasonic sensor is placed 20 cm away from a wall with no corners and made to rotate 180 degrees.

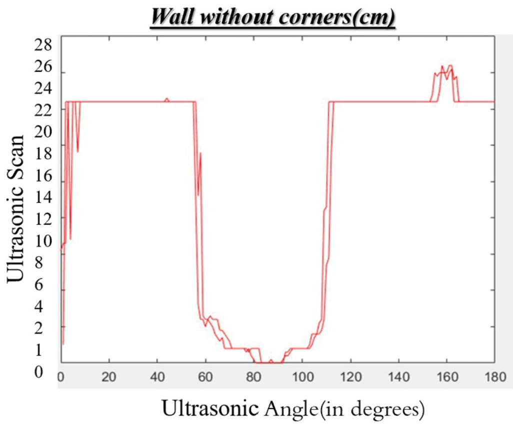

Figure 5.14: Scan Of A Wall Without Corners

Initially before reviewing the plots the authors expected to obtain the graph similar to the expected graph(figure 5.9), although as shown in figure 5.15 that is not the case. According to the dimensions of the box when the sensor is placed in the center of the cardboard box the plotting must start at 19.25 cm, but according to the output graph of the ultrasonic scan it starts at 12 cm which raised concern (1) and the peak at concern (3) which is about 34cm when it should be 24cm. Sharp drops in plotting can be observed in concerns (2,4).

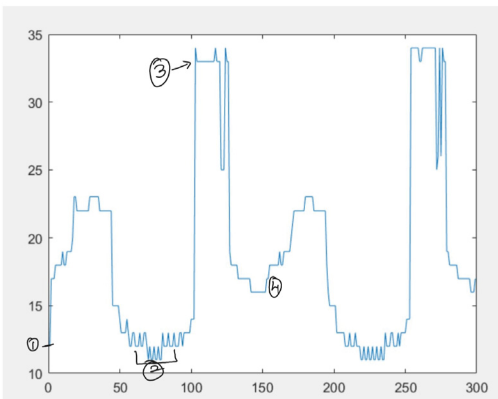

Figure 5.15: Concerns Regarding The Ultrasonic Scan

After some research, few factors affecting the plot of the ultrasonic scan were determined:

1. Angle of rotation seems to have an affect on the ultrasonic scan, the range of coverage is about "60 degrees" and when the sensor is set to zero degrees it covers "30 degrees" extra from the origin.

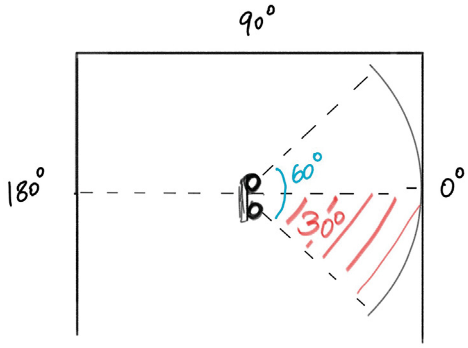

Figure 5.16: Ultrasonic Range

2. Sharp changes are observed in the scanned plot (figure 5.12), further investigation is required to determine the cause of this phenomenon [20].

3. While measuring the corners of the box in particular seem to affect scans by echoes. Authors assume that the delay in time of flight calculation might be the cause of this problem. In order to solve this problem would require a further study [19]

.

Chapter 6

Conclusions and Future Work

Conclusions: In this paper, an experimental study concerning the capability of an ultrasonic sensor radar system to detect obstacles in a short-range scenario has been carried out. The aim was to investigate its potential to be used in an autonomous mobile robot for map construction.

The ultrasonic sensor is displaying uncertainty in some cases of measurement, above mentioned causes need further investigation and study to rectify the issues to build an autonomous mapping robot. An IR sensor with similar experiments shall also be used to determine it's potential to be used in an autonomous robot for map building.

The proposed system can be considered applicable when:

1. The system is attested with different experiments and it's limitations are known.
2. An advanced multi-sensory design is implemented (sensor fusion) for perceiving the same feature of the environment using different physical parameters without relying on a single sensor for mapping environmental features, hence help overcome each others limitations.
3. Smooth signal processing is achieved to improve system reliability and robustness.

Future work: The sensor's performance must be investigated when scanning features of environment such as corner of a wall, apply signal processing techniques for smooth map building. Lidar sensor must also be attested with similar tests to investigate it's potential to be used in an autonomous mobile robot using sensor fusion techniques. This will help the mobile robot perceive the environment better by measuring same features of the environment based on different parameters.

References

[1] ACCIDENT PREVENTION, DETECTION AND REPORTING SYSTEM USING ARDUINO | Electronics workshop electronicsworkshops.com/2021/07/05/accident-prevention-detection-and-reporting-system-using-arduino/.

[2] Arduino Uno Rev3- store.arduino.cc/products/arduino-uno-rev3.

[3] Correlation coefficients - https://in.mathworks.com/help/matlab/ref/corrcoef.html.

[4] DSS-P05 Standard Servo (5kg)-DFRobot- https://www.dfrobot.com/product-236.html.

[5] Fermion: URM37 Ultrasonic Sensor (2800cm) (Breakout) - opencircuit.es/producto/fermion-urm37-ultrasonic-sensor-(2800cm).

[6] Standard deviation - MATLAB std https://in.mathworks.com/help/matlab/ref/std.htmlbune5v9-9.

[7] Ultrasonic Distance Sensing www.sensorsone.com/ultrasonic-distance-sensing/.

[8] URM37_v5.0_ultrasonic_sensor_sku_sen0001_-DFRobot- https://wiki.dfrobot.com/urm37$_v$5.0$_u ltrasonic_s ensor_s ku_s en$0001.

[9] Correlation coefficient https://en.wikipedia.org/w/index.php?title=Correlation$_c oefficientoldid$ = 1059450152, $December$2021. $PageVersionID$: 1059450152.

[10] Radar (radio detection and ranging) link: https://en.wikipedia.org/w/index.php?title=Radaroldid=1093086092, June 2022. Page Version ID: 1093086092.

[11] Ultrasonic transducer https://en.wikipedia.org/w/index.php?title=Ultrasonic$_t ransduceroldid$ = 1087902829, May2022. $PageVersionID$: 1087902829.

[12] S Adarsh, S Mohamed Kaleemuddin, Dinesh Bose, and KI Ramachandran. Performance comparison of infrared and ultrasonic sensors for obstacles of different materials in vehicle/robot navigation applications. In *IOP Conference Series: Materials Science and Engineering*, volume 149, page 012141. IOP publishing, 2016.

[13] Rechie Ranaisa Dam, Hridoy Biswas, Shuvrodeb Barman, and Al-Quabid Ahmed. Determining 2d shape of object using ultrasonic sensor. In *2016 3rd International Conference on Electrical Engineering and Information Communication Technology (ICEEICT)*, pages 1–5, 2016.

[14] Lou Frenzel. Ultrasonic Sensors: A Smart Choice for Shorter-Range Applications, March 2018.

[15] Market Research Future. Radar Transmitter Market to Touch USD 3.82 Billion by 2025 - Report by Market Research Future (MRFR), August 2021.

[16] Nansha Gao, Liling Tang, Jie Deng, Kuan Lu, Hong Hou, and Kean Chen. Design, fabrication and sound absorption test of composite porous metamaterial with embedding I-plates into porous polyurethane sponge. *Applied Acoustics*, 175:107845, 2021.

[17] Sanjeev Kumar, Prabhat Kumar Tiwari, and S.B. Chaudhury. An optical triangulation method for non-contact profile measurement. In *2006 IEEE International Conference on Industrial Technology*, pages 2878–2883, December 2006.

[18] W Manthey, N Kroemer, and V Magori. Ultrasonic transducers and transducer arrays for applications in air. *Measurement Science and Technology*, 3(3):249–261, mar 1992.

[19] Milagros Martínez and Ginés Benet. Wall-corner classification using sonar: A new approach based on geometric features. *Sensors*, 10(12):10683–10700, 2010.

[20] Milagros Martínez and Ginés Benet. Wall-Corner Classification Using Sonar: A New Approach Based on Geometric Features. *Sensors (Basel, Switzerland)*, 10(12):10683–10700, November 2010.

[21] Esther G Sarabia, Jose R Llata, Sandra Robla, Carlos Torre-Ferrero, and Juan P Oria. Accurate estimation of airborne ultrasonic time-of-flight for overlapping echoes. *Sensors*, 13(11):15465–15488, 2013.

[22] Esther G. Sarabia, Jose R. Llata, Sandra Robla, Carlos Torre-Ferrero, and Juan P. Oria. Accurate Estimation of Airborne Ultrasonic Time-of-Flight for Overlapping Echoes. *Sensors (Basel, Switzerland)*, 13(11):15465–15488, November 2013.

[23] Lorenzo Scalise, Valter Mariani Primiani, Paola Russo, Desar Shahu, Valentina Di Mattia, Alfredo De Leo, and Graziano Cerri. Experimental investigation of electromagnetic obstacle detection for visually impaired users: A comparison with ultrasonic sensing. *IEEE Transactions on Instrumentation and Measurement*, 61(11):3047–3057, 2012.

[24] Lorant Andras Szolga. Ultrasonic scanning system for cartography applications. In *2022 9th International Conference on Electrical and Electronics Engineering (ICEEE)*, pages 417–422, 2022.