Analysis of Obstacle Detection Using Ultrasonic Sensor

Christofer N. Yalung[1], Cid Mathew S. Adolfo[2]

[1]*Military Technological College, Muscat, Oman*
[2]*Military Technological College, Muscat, Oman*

Abstract – *Automation of the car braking system is an important feature in the development of the smart car. The ability of a smart car to detect and classify an obstruction that is in varying proximities from it play a vital role in the system's design. In this study, EV3 Lego Mindstorm equipped with an ultrasonic sensor was used as a model of a large scale vehicle. EV3 Lego MIndstorm was programmed to slow down when it is at a certain distance from the obstruction, and to stop when it is 15 cm away from the obstruction. There were five obstructions: wood, paper, cloth, plastic and metal. The distance measurement of the ultrasonic sensor and the Neural Network was used for the classification of the obstruction and Multiple Correlation was used for obstacle detection. There were 250 samples taken from the distance measurements of five different types of obstruction, each with a different cross sectional area, and a total recording time of 8 seconds. Overall, there is a high correlation coefficient in the distance measurement of the different types of obstruction materials. It is concluded that the ultrasonic sensor was able to detect the five given types of obstruction. Classification performance was very poor, which means that on the basis of distance measurement, the ultrasonic sensor cannot effectively classify the types of obstructions.*

Key Words: Ultrasonic Sensor, Obstacle detection, Artificial neural network, Distance measurement

1.INTRODUCTION

Nowadays, automation in technology is widespread, this can be seen on doors, electronic devices, cars and in various industrial applications. This is made possible by sensing devices, which serve as a medium between the machine and the environment. Ultrasonic sensor is an incredibly useful sensor in the field of automation. For example, a mobile robot receives environmental information, converts it into a signal and performs this signalled task like avoiding obstacles (In this sentence you should mention specifically the function of the ultrasonic sensor). This particular type of sensor produces satisfactory results and is cost effective. The algorithm for distance calculation is based on the measurement of the time of flight of the ultrasonic waves. The distance between two objects can be measured using the ultrasonic sensor. The technique of distance measurement is based on the measurement of the elapsed time between the emission of the wave and the reception of the echo. The propagation of the ultrasonic wave is done at the sound speed in the air (340 m/sec). A typical ultrasonic distance sensor consists of two main elements. One element produces sound, another catches reflected echo. Basically, these pieces are a speaker and a microphone. The device generates ultrasonic impulses and triggers the timer. The other element registers the arrival of the sound impulse and stops the timer. From this information it is possible to calculate the distance travelled by the sound. It is usually not difficult to select a sensor that suits the environmental and mechanical requirements of a particular application, or to evaluate the electronic features available with different models. Still, many users may not be aware of the acoustic subtleties that can have major effects on the operation of the ultrasonic sensor and the measurements being made with them [1]. The basic principle of sound propagation, the effect of a wave when it strikes a solid object and the reception of the reflected sound waves are illustrated in Fig-1[2].

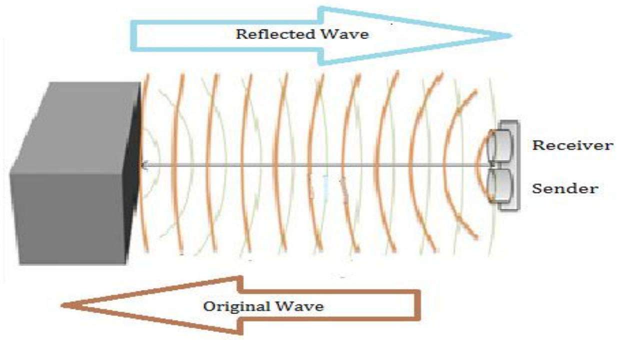


Fig-1: Ultrasonic sensor operations

The velocity of the sound in air is given by the equation (1), this is used to calculate the speed of the sound in air. The distance that sound travels is equal to the speed of sound in the medium multiplied by the time that sound travels[2].

$$v_{sound\ in\ air}\left(\frac{m}{s}\right) \approx 331.4 + 0.6T\left(\frac{m}{s}\right) \qquad (1)$$

The impulse width is proportional to the time required for the echo return. This time is called time-of-flight (TOF) [3]. But there are other factors which may also affect the propagation of sounds such as: ambient pressure, gas density and humidity [4].

1.1 Trends of Ultrasonic Sensor

A research was conducted for the performance evaluation of NXT ultrasonic sensor and Parallax Ping sensor for distance measurement. An efficient method based on piecewise linear regression was proposed to improve the NXT ultrasonic sensor's accuracy of distance measurement. The emitter transmits a burst of ultrasound (inaudible sounds) to the obstacle positioned in front of the sensor. The object reflects back to sensor receiver the signal and when the echo is received the sensor generates an impulse [5]. Two ultrasonic sensors were used to achieve object classification [6]. To complete this task, the authors have proposed a fuzzy expert system having a dual knowledge base - one statistical and the other a standard rule based one. Using this technique, they extracted and used 25 features including parameters like beginning time, mass center, etc.

The task of outlier detection or novelty detection was implemented using Support Vector Machine (SVM), this contributed towards object classification. Human detection is vital to many applications, for example, human-robot interaction, unattended ground sensor systems, smart rooms [7].

The application of a one-class classifier using solely ultrasonic sensors was trialed for human detection. This approach was based on fuzzy rules that are extracted from the signal features in time and frequency domains [8]. A prototype of a mobile robot suitable for mapping was presented. It used an ultrasonic sensor HC-SR04, which is a cheap alternative for sensor mapping instead of an expensive laser sensor. The hardware was based on ROMEO BLE mainboard. The Software consisted of two parts: firmware and application. The firmware part was an Arduino source code project, written in C++ programming language, which was deployed on the robot [9].

The method based on puddle detecting ability was proposed, and the evaluation of the improved method had been implemented according to experiment results. The proposed method can be applied in support systems on wheel chairs and white canes for improving safety. In this research, the road surface condition distinction method was developed considering the puddle condition. The four kinds of road surface conditions were investigated. The effectiveness of the proposed method was verified in all the four conditions [10].

Infusing ultrasonic sensor data and multiple ultrasonic sensor data while a mobile robot moves were proposed in [11]. Another research was developed for improving a grid map of the environment by triangulating multiple ultrasonic sensor data [12]. Related study of using three sensors to distinguish the plan from the corner and then build a map of this environment were carried in [13]. Neural networks were applied to differentiate between different forms of obstacles: plane, corner, edges, and cylindrical shapes [14]. Moreover, a sensing method that classified the target surface as a plane or a cylinder, with a sensing system consisting of 4 sets of ultrasonic aligned sensors were proposed in [15].

1.2 Aims and Significant of the Study

This study is aimed to obtain the distance measurement of a moving vehicle with respect to the presence of five different types of obstruction and in addition to this, to perform a speed reduction at a specified distance from the obstacle and to be able to fully stop the vehicle at a specific distance. Moreover, the study seek to find the significance and impact of the materials used in correlation with the ability of the ultrasonic sensor to measure distance precisely. Furthermore, Neural Network is implemented to classify the different types of obstacles based on the measured distance over time, there were five materials to be classified namely: wood, paper, cloth, plastic and metal. This study could benefit the automotive industry by applying smart algorithm for obstacle detection, precise detection of an object. Road safety could be improved by smart vehicle, through the advanced processes of an automatic brake system applied on the vehicle.

2. Data Acquisition and Analysis

The data acquisition, process and output of the study are shown in Fig-1, necessary equipment and procedures are included.

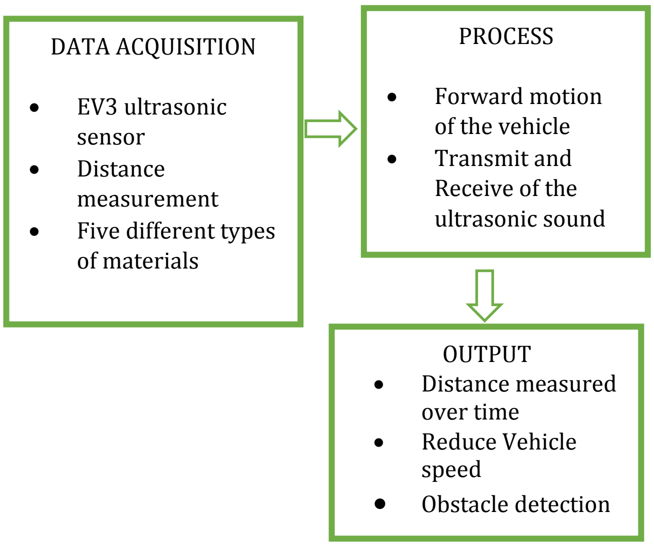


Fig-2: Methodology of the study

To model an actual vehicle, a Lego Mindstorm EV3 was used, it is equipped with an ultrasonic sensor. A program could be downloaded with its processor. Fig-3a and Fig-3b show the Lego Mindstorm EV3 and ultrasonic sensor.

Fig-4 shows the program installed in the processor of the vehicle, it is designed to run the two motors labeled A and B, and reduce the speed of the model at a certain distance from the obstacle. Finally, it must stop when it reaches the distance of 15 cm from the obstruction. Also, data logging is added in the program, so that data in terms of time and distance could be acquired. The sampling rate per second was set to 5, and data logging was set up to 8 seconds

In order to start the data recording, the vehicle is placed at about 80 cm away from the obstacle. Then it traveled in a straight path going to the obstruction. The five different types of obstructions used were wood, laminated paper, cloth, plastic, and metal, with the following area in square centimeter: 375, 300, 2025, 840, 840, respectively.

To see the consistency of the result per each type of obstruction, two trials of data collected.

Fig-3a: Lego Mindstorm EV3

Fig-3b: EV3 ultrasonic sensor

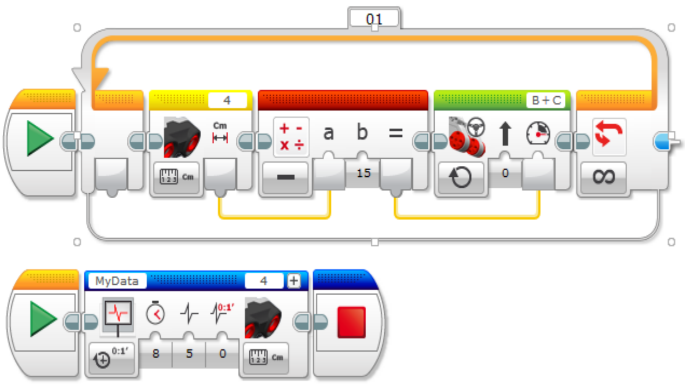


Fig-4: Lego Mindstorm program

Data analysis among types of materials was performed using Multiple Correlation. Artificial Neural Network is carried out to determine the classification of the obstruction.

3. Data and Results

The information provided in Chart-1 shows the distance of the vehicle from the obstruction. There are four obstruction namely: wood, paper, cloth, plastic and metal, different colors were used to represent them in the chart. The initial distance of the vehicle from the obstruction is about 80cm. As the time increases, the distance measured is supposed to decrease because the vehicle is getting closer to the obstacle. Four of the obstructions namely: wood, paper, glass and metal displayed a common pattern. The measured distance is erroneous for the rippled cloth, the sound waves was not reflected efficiently, in return the vehicle failed to execute the condition designed in the program. However, based on our observation, when the cloth is perfectly flattened, the vehicle was able to follow the specified program. Finally, for the wood, paper, plastic and metal, there was a consistency of the distance measured especially after four seconds and onwards.

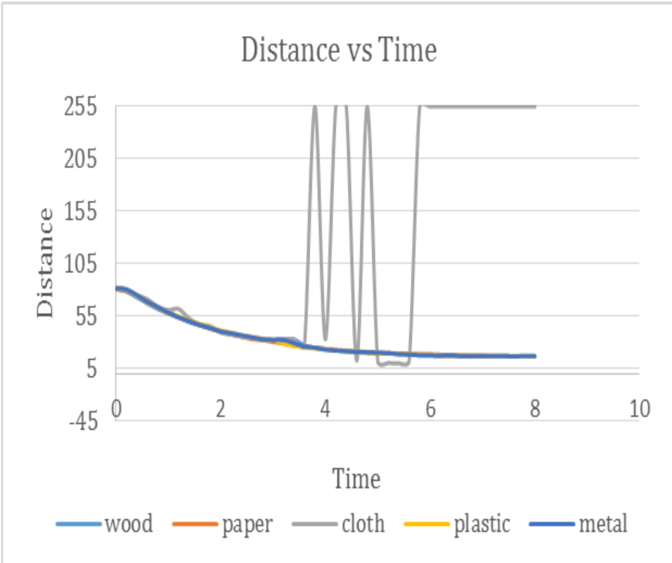


Chart-1: Distance of the vehicle from the obstruction

The information provided in Table-1 shows a positive perfect positive correlation coefficient among the wood, paper, plastic and metal. This means that ultrasonic sensor used in this experiment resulted to the same pattern of distance measurement and obtained approximately the same measured value. This result is with exemption to the rippled cloth which resulted in an almost low negative correlation when compared to the above mentioned materials. This signifies that there was a failure of the cloth to reflect sound waves. On the other hand, the ultrasonic sensor was able to detect the presence of the rippled cloth at a certain time, but after about 3 seconds there was an error to the measured distance.

Table-1 Multiple Correlation among five types of materials

	wood	*paper*	*cloth*	*plastic*	*Metal*
wood	1.00				
paper	1.00	1.00			
cloth	-0.48	-0.45	1.00		
plastic	1.00	1.00	-0.46	1.00	
metal	1.00	1.00	-0.47	1.00	1.00

Furthermore, to determine the consistency of the gathered data, two trials were performed for each type of material, all showed a perfect positive correlation, except for the cloth.

3.1 Neural Network Classification

Machine learning was used to classify the data into five categories such as wood, paper, cloth, plastic and metal. There were 205 samples taken from five different types of obstructions, and 8 seconds of data logging. The neural network architecture is shown in Fig-5, there were ten hidden layer. The samples were divided into Training (75%), Validation (15%) and Testing (15%). Majority of the data was presented to the network during training, and the network was adjusted based on its error. The function of Validation is to stop the training when generalization stops improving. Testing is an independent measure of network performance.

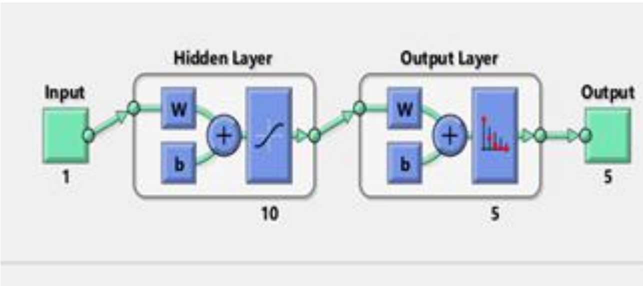
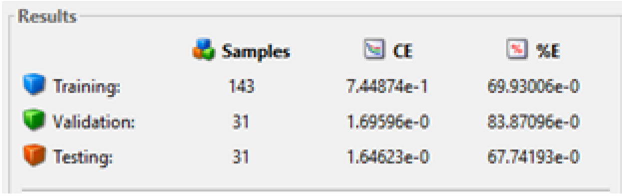


Fig-5: Neural network architecture

Classification was performed using two different network architecture, Fig- 6 shows the result of classification at 10 hidden neurons and Fig-7 shows the result at 20 hidden neurons. Cross Entropy (CE) shows the result in classification, having zero value means no error. Percent Error (%E) indicates the fraction which are misclassified, zero means no misclassification and 100 means maximum misclassifications.

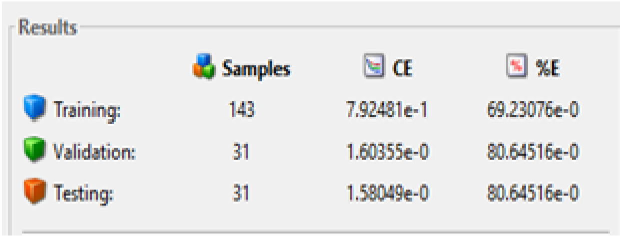
The results shows, there is approximately equal %E for the two different artificial network architectures having, 69.9% and 69.23% for the 10 and 20 hidden neurons respectively. The cross entropy during the training resulted to 0.74487 and .792481 for the 10 and 20 hidden neurons respectively. There was a very minimal improvement on the performance of the neural network architecture by doubling the number of hidden layers based on the given data.

Furthermore, it can be observed that classification was not good as indicated by the higher value of Cross Entropy on training, validation and testing. Therefore, the method of distance measurement for the classification of the types of obstruction using ultrasonic sensor executed poor results.


Results

	Samples	CE	%E
Training:	143	7.44874e-1	69.93006e-0
Validation:	31	1.69596e-0	83.87096e-0
Testing:	31	1.64623e-0	67.74193e-0

Fig-6: Neural network results at 10 hidden neurons


Results

	Samples	CE	%E
Training:	143	7.92481e-1	69.23076e-0
Validation:	31	1.60355e-0	80.64516e-0
Testing:	31	1.58049e-0	80.64516e-0

Fig-7: Neural Network results at 20 hidden neurons

4. CONCLUSIONS

In this study, the data were acquired using EV3 Lego Mindstorm, ultrasonic sensor, different types of materials and software programming. The analysis and interpretation of the data were carried out using Multiple Correlation and Neural Network. The vehicle was programmed to move slowly as it approached near the obstruction, and stopped when reached the distance of 15 cm. There were five types of obstruction namely: wood, paper, plastic and metal. Overall, wood, paper, glass and metal displayed a common pattern based on the measured distance, there was erroneous result for the rippled cloth.

The neural network classification shows poor performance based on the gathered data. The percent error (%E) recorded for 10 and 20 hidden neurons where 69.9% and 69.23% respectively. This means that classification of the types of obstruction was not efficient by distance measurement between the vehicle and the obstruction using the ultrasonic sensor. There is a positive perfect positive correlation coefficient among the wood, paper, plastic and metal. This means that ultrasonic sensor used in this experiment perform the same pattern of distance measurement given these materials. However, for the rippled cloth, results showed an almost low negative correlation when compared to the above mentioned materials.

REFERENCES

[1] D. Masa, "Choosing an Ultrasonic Sensor for Proximity or Distance Measurement Part 1: Acoustic Considerations", Feb. 1, 1997.

[Online]. http://www.sensorsmag.com/sensors/acoustic-ultrasound/choosing-ultrasonic-sensor-proximity-or-distance-measurement-825

Hands-on Activity: Measuring Distance with Sound Waves, AMPS GK-12 Program, Polytechnic Institute of New York University.
[Online].https://www.teachengineering.org/activities/view/nyu_soundwaves_activity1

[2] D. Marioli, C. Narduzzi, C. Offelli, D. Petri, E. Sardini and A. Taroni,"Digital time-of-flight measurement for ultrasonic sensors," IEEE Transaction on Instrumentation and Measurement, vol. 41, pp. 93–97, 1992

[3] D. A. Bohn, "Environmental effects on the speed of sound," Journal ofAudio Engineering Society, vol. 36, No. 4, April, 1988

[4] G. Găşpăresc and A. Gontean, "Performance evaluation of ultrasonic sensors accuracy in distance measurement," 2014 11th International Symposium on Electronics and Telecommunications (ISETC), Timisoara, 2014, pp. 1-4.
doi: 10.1109/ISETC.2014.7010761

[5] J.R. Llata, E.G. Sarabia, J.P. Oria," Fuzzy expert system with doubleknowledge base for ultrasonic classification," Expert Systems with
Applications 20 (2001) 347-355.

[6] Duin, Robert PW, et al. "Feature-based dissimilarity space classification."Recognizing Patterns in Signals, Speech, Images and Videos. Springer Berlin Heidelberg, 2010. 46-55

[7] Sonia, A. M. Tripathi, R. D. Baruah and S. B. Nair, "Ultrasonic sensor-based human detector using one-class classifiers," 2015 IEEE International Conference on Evolving and Adaptive Intelligent Systems (EAIS), Douai, 2015, pp. 1-6.
doi: 10.1109/EAIS.2015.7368797

[8] A. Dimitrov and D. Minchev, "Ultrasonic sensor explorer," 2016 19th International Symposium on Electrical Apparatus and Technologies (SIELA), Bourgas, 2016, pp. 1-5.
doi: 10.1109/SIELA.2016.7542987

S. Nakashima, S. Aramaki, Y. Kitazono, S. Mu, K. Tanaka and S. Serikawa, "Road Surface Condition Distinction Method Using Reflection Intensities Obtained by Ultrasonic Sensor," 2016 International Symposium on Computer, Consumer and Control (IS3C), Xi'an, 2016, pp. 120-123. doi: 10.1109/IS3C.2016.41

[9] H. Choset, K. Nagatani, and N. Lazar: "The Arc-Transversal Median Algorithm: A Geometric Approach to Increasing Ultrasonic Sensor Azimuth Accuracy", IEEE Trans. on Robotics and Automation, Vol.19, No.3, pp. 513-523, 2003.

[10] O. Wijk, P. Jensfelt, and H. Christensen: "Triangulation Based Fusion of Ultrasonic Sensor Data", IEEE Proc, Int, Conf. on Robotics and Automation, pp. 3419-3424, 1998.

[11] Joen, H. J and B.K.Kim: "A study on world map building for mobile robots with trial-aural ultrasonic sensor system",
IEEE Int, Conf. Robot.Autom, pp 2907- 2912, 1995.

[12] Barshan, B., B. Ayrulu, and S. W. Utete: "Neural network-based target differentiation using sonar for robotics applications", IEEE Trans. Robot. Autom., Vol. 16, pp.435-442, 2000.

[13] I. Maâlej, M. Ouali and N. Derbel, "Modular ultrasonic sensor platform for mobile robot," 2012 First International Conference on Renewable Energies and Vehicular Technology, Hammamet, 2012, pp. 477-483.
doi: 10.1109/REVET.2012.6195316

[14] R. A. Dimitrov and D. Minchev, "Ultrasonic sensor explorer," 2016 19th International Symposium on Electrical Apparatus and Technologies (SIELA), Bourgas, 2016, pp. 1-5.
doi: 10.1109/SIELA.2016.7542987 Nicole, "Title of paper with only first word capitalized," J. Name Stand. Abbrev., in press.