Performance Improvement of Contactless Distance Sensors using Neural Network

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Abstract: - Sensor is used to detect an object and determines the distance between sensor and the object. The distance measured by the sensor is sometimes inaccurate, leading to distance errors. Two types of sensors used in this research project are Sharp GP2D12 and ultrasonic LV-Maxsonar EZ1. The output voltage will change based on the distance between the sensor and the object. The sensor's performance is measured by comparing the actual value with sensor's measurement value. The method is used to determine the sensor's performance by using a neural network approach. Neural network applications which help to improve the performance of the sensor as the output value from neural network shows near approximation to the actual value. Mean squared error (MSE) value produced in the learning process shows the distance errors. Next, the testing process is performed to determine the accuracy of the distance sensor indicating the percentage of accuracy is inversely proportional to MSE value. Experimental results demonstrate that Sharp GP2D12 distance sensor showing a higher percentage of accuracy with 95.57% compared to LV-Maxsonar EZ1 sensor which resulted only 90.91%. These results prove that the GP2D12 Sharp distance sensor is more accurate than ultrasonic LV-Maxsonar EZ1 sensor.

Key-words: - Sensor, Sharp GP2D12, ultrasonic LV-Maxsonar EZ1, neural network, mean squared error (MSE), performance.

1 Introduction

Sensor is a device, which is used to detect an object in its environment. The robot uses sensor to avoid collision with objects. The two sensors which often used by the robot detecting objects are ultrasonic sensor and infrared sensor. Ultrasonic sensors are used to measure distances in automotive applications for smart car application [1]. Ultrasonic sensors are too sensitive to noise and vibration making ultrasonic sensor could not achieve high precision on determining actual distance to detect moving objects [2]. Sensor is also used in a smart wheelchair application so that it can detect the obstacles to prevent the occurrence of collisions [3]. The use of infrared sensors prevents the robot from moving beyond the planned track and eventually increases the efficiency rate of cleaning done by a robot [4]. A new technique of artificial intelligence is seen as a potential technique to replace the current techniques. Usually, researchers in the field of artificial intelligence applying their studies to replace the conventional techniques such as mathematical formula method are widely practiced in calculations. The concept of neural network is generally used for classification of papaya maturity levels [5] and face recognition [6]. Ultrasonic and infrared distance sensors are the key component in the development of this project. The two sensors are used to detect and measure the distance between the object to the sensor. Distance sensors are susceptible to noise when detecting an object causing the measured distance to be inaccurate. Neural network is applied to reduce errors that would be occurred and determine the distance of the sensor's performance range. Neural network is also used to improve the performance of the sensor's distance and compare the distance detected by the sensor with the actual distance. The accuracy rate of the distance sensor to detect objects can also be determined. An error occurred in the distance will be reduced by using neural network.

2 Proposed System

Neural network is one of the uses of artificial intelligence that can function like a brain. Artificial neural network will operate as the brain and function similar to learning and operation techniques. There are two types of neural network architecture. There are feedforward neural network and feedback neural network [7]. The feedforward neural network gives fast results compared to the feedback neural network because the signal is moving in one direction only, without the need for feedback any output [8]. The use of neural network in this research is to reduce errors that occur due to the distance from the voltage produced by the detector distance that is less accurate. The error occurred will cause the distance measured by the sensor is not precise as the actual distance. Network architecture will be determined and the algorithm that can produce small mean squared error, MSE will be selected. No determination of the amount of data will be used as learning and testing data. However, 80% of the total data will be used in the learning part, while the remainder will be used in the testing part [9]. MATLAB software is used to run the neural network.

3 Learning Process

A parameter of the learning process will be determined depending on the learning algorithm that will be used. MSE values are obtained after the trained network. The training process will be repeated to get a small value of MSE. The accuracy of the sensor can be determined from the testing part. Levenberg-Marquardt algorithm, BFGS quasi-Newton algorithm and Gradient descent with momentum and adaptive algorithm are used in this research to compare the results that can give the small value of MSE. In the learning process, the parameter for the value of the targets set by 0.01. Algorithms that yield the lowest MSE value will be used for neural network applications. The formula will be used to obtain the MSE is as Eq. (1).

$$\mathrm{MSE} = \frac{1}{N}\sum_{i=1}^{n}(Y_i - \overline{Y})^2 \qquad (1)$$

Where:
Y_i = Measured value
$\overline{Y}$ = Actual value
N = Total sample
n = Number of observations

Neural network will be trained repeatedly to get the small MSE value so the accuracy of the sensor will be higher.

4 Training Process

Neural network will be tested after training process is completed. The testing neural network is to determine the accuracy of the data to be generated. The calculation of the error percentage is shown in Eq. (2) and Eq. (3), which is used to calculate the accuracy percentage of the data.

$$\text{Error percentage, E (\%)} = \frac{|Y-\overline{Y}|}{\overline{Y}} \times 100\% \qquad (2)$$

$$\text{Accuracy percentage, A (\%)} = 100\% - E\% \qquad (3)$$

Where:
Y = Measured value
$\overline{Y}$ = Actual value

The data used in the testing process is not the same as the data used in the learning process. The MSE result value is different when the learning process occurs. These conditions affect the accuracy percentage of the data on the testing process. MSE value is inversely proportional to the accuracy percentage of the distance sensor.

5 Data Samples

A set of data is crucial in the development of neural network for distance sensors. Two sensors are used, Sharp GP2D12 sensor and ultrasonic LV-Maxsonar EZ1 sensor. Prior to the distance measured, the sensor will be calibrated to get the first distance value that can be measured by the sensor. Calibration is carried out as the distance sensor has a certain minimum value that can be measured depending on the type of distance sensor. Distance values are obtained from two types of distance sensors used which become the input data while the target is the actual measured value. Neural network will use this data set in the learning and testing process.

Fig. 1 shows the methods in acquiring the distance. Objects will be placed as a barrier so the distance can be determined. Distance sensors will detect objects, and each reading of the distance measurement is recorded. Experiments will be conducted for five different angles of 90°, 85°, 80°, 75° and 70° which the distance is from 1 cm to 100 cm.

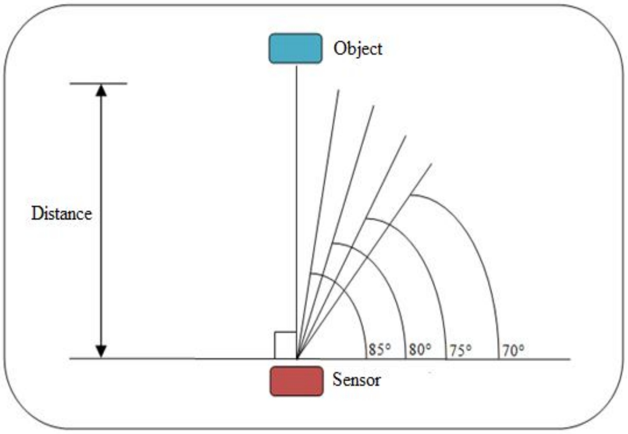

Fig. 1 Acquring the distance using a sensor

6 Results and Discussion

Levenberg-Marquardt (LM) algorithm is used to model neural network because this algorithm produces smaller MSE value than BFGS quasi-Newton (BFG) algorithm and Gradient descent with momentum and adaptive (GDX) algorithm as shown in Table 1.

Table 1 MSE results for three different training algorithm

Learning algorithm	MSE
LM	0.8059
BFG	8.8799
GDX	4.7048

Time taken for learning process of the LM algorithm is short and the parameter for epoch depends on the value of the specified MSE target is 0.01. The angles are fixed to 90°, 85°, 80°, 75° and 70° but the Sharp GP2D12 distance sensor can only detect objects at the angle of 90°. This is one of the weaknesses of Sharp GP2D12 sensor because it cannot detect objects with angular distances while ultrasonic LV-Maxsonar EZ1 sensor is able to detect objects with different angular distance. The increase in distance will result in the distance measurement errors. The difference between the distance measured by the sensor and actual distance value is shown in Fig. 2.

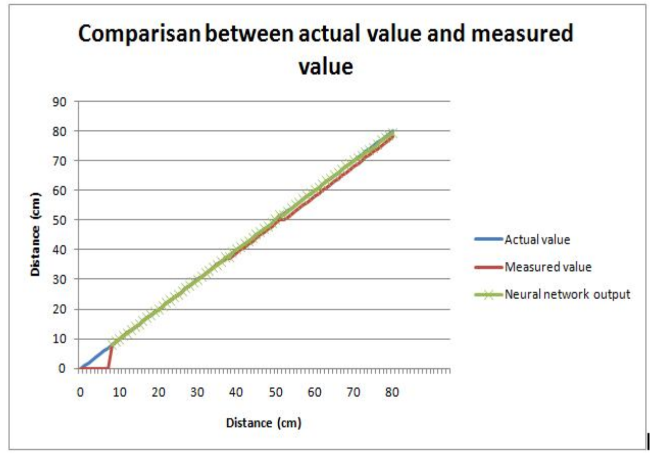

Fig. 2 Comparison between actual value and measured value for Sharp GP2D12 at 90°

The second distance sensor is ultrasonic LV-Maxsonar EZ1 sensor. Fig. 3 shows the difference between actual distance with the distance measured by the ultrasonic sensor at the angle of 90°. Ultrasonic sensor is able to detect objects from 17 cm to 100 cm. Ultrasonic sensor cannot detect the object which is between 1 cm to 16 cm as an analog output voltage is not stable.

Fig. 4 shows the difference between the actual distance with the distance measured by the ultrasonic sensor at angle of 85°. The change of angle causes the ultrasonic sensor cannot give accurate readings on distance measurements to detect the object. The obvious difference between distance measured by the ultrasonic sensor to measure the actual distance lead to distance errors thus the performance of ultrasonic sensor also has been reduced.

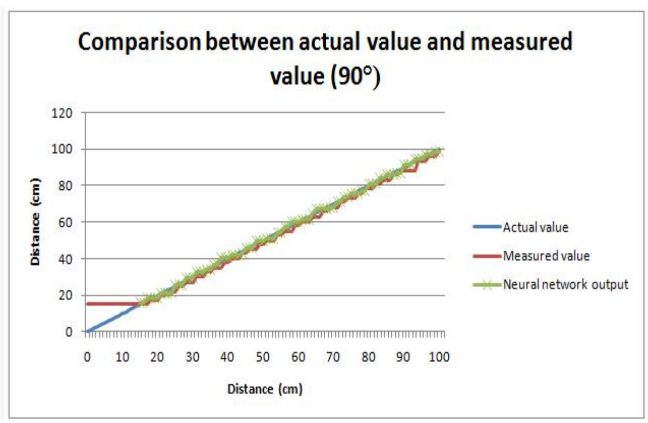

Fig. 3 Comparison between actual value and measured value for LV-Maxsonar EZ1 at 90°

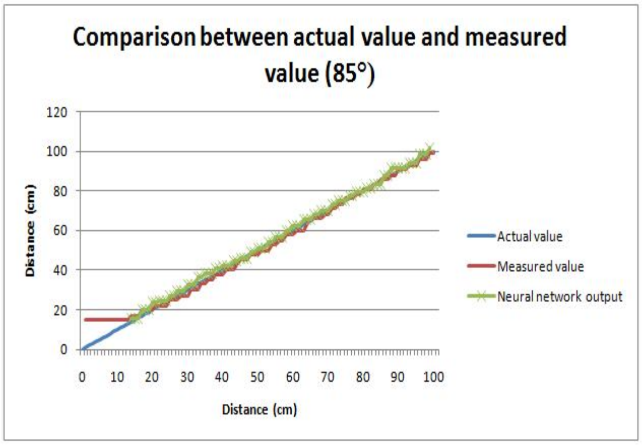

Fig. 4 Comparison between actual value and measured value for LV-Maxsonar EZ1 at 85°

The distance error increases when the angle is reduced to 80°. Ultrasonic sensor cannot detect the object when it is placed between 1 cm to 12 cm and more than 84 cm as shown in Fig. 5. This result shows ultrasonic sensor only can identify the object that is between 13 cm to 83 cm at angle of 80°. The distance error occurs at 80° is greater than the distance error that occur at angle of 90°. The accuracy of ultrasonic sensor decreases when the angle is less than 90°.

The ability of ultrasonic sensors detecting objects decreases when angle is reduced to 75°. Ultrasonic sensors cannot detect the object which is between 1cm to 17 cm and 72 cm to 100 cm. The distance error increased when the actual distance and measured distance has a significant difference as shown in Fig. 6.

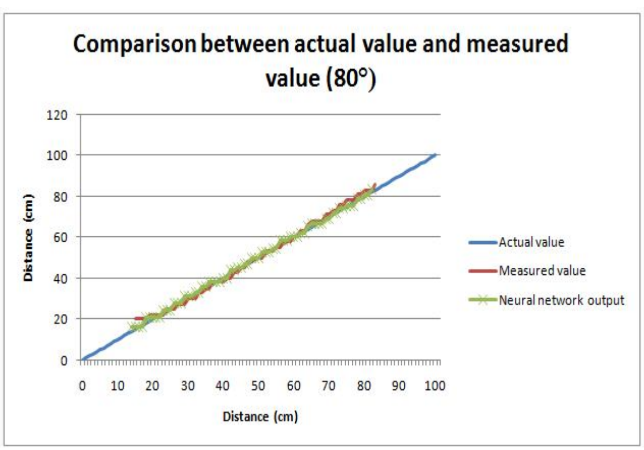

Fig. 5 Comparison between actual value and measured value for LV-Maxsonar EZ1 at 80°

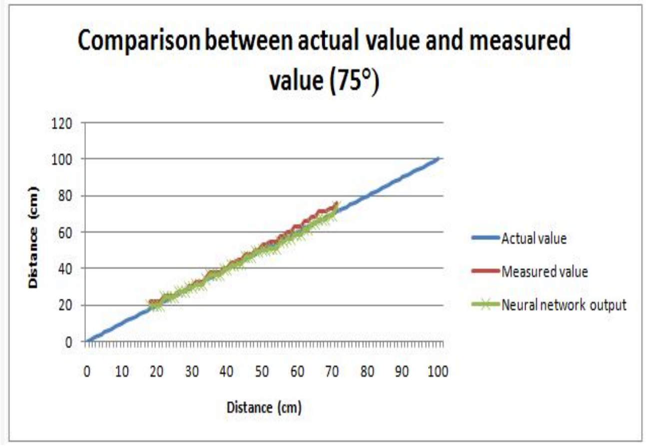

Fig. 6 Comparison between actual value and measured value for LV-Maxsonar EZ1 at 75°

Variations in the angle of ultrasonic sensor make it can only detect objects with a certain distance. At angle 70°, ultrasonic sensor cannot detect the object which is between 1 cm up to 18 cm and 52 cm to 100 cm. The distance error is also high causing the measured distance is not accurate. The difference between the actual distance and measured distance at an angle of 70° is shown in Fig. 7. Neural network was applied to each distance sensor's data set. Neural network is applied to reduce the distance error occurs because the result from neural network output is closer to the actual distance measurement.

Table 2 MSE value results before and after application of neural network and accuracy percentage for GP2D12 Sharp distance sensor and ultrasonic LV-Maxsonar EZ1 sensor

Type of sensor	Angle	MSE (before)	MSE (after)	Accuracy (%)
Sharp GP2D12	90°	1.1579	0.0183	95.57
LV-Maxsonar EZ1	90°	2.3529	0.6978	90.91
	85°	3.7794	1.0267	89.43
	80°	2.2963	1.1211	88.61
	75°	3.3514	1.3565	87.09
	70°	10.5000	1.4236	86.19

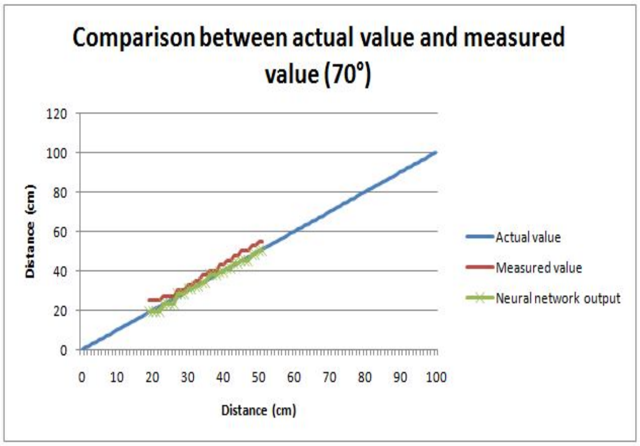

Fig. 7 Comparison between actual value and measured value for LV-Maxsonar EZ1 at 70°

The results obtained demonstrates the performance of two types of distance sensors are Sharp GP2D12 sensor and ultrasonic LV-Maxsonar EZ1 sensor. Distance measurements are based on analog output voltage when the sensor detects the object. Sharp GP2D12 distance sensor has high precision of accuracy compared to ultrasonic LV-Maxsonar EZ1 sensor because the distance error for Sharp GP2D12 is small. Sharp GP2D12 distance sensor is also sensitive to changes in distance for every 1 cm compared with ultrasonic LV-Maxsonar EZ1 which sensitive to changes in distance for every 1 inch or 2.54 cm. The weakness of the Sharp GP2D12 sensor is disability of detecting objects if the distance more than 80 cm while ultrasonic LV-Maxsonar EZ1 sensor can detect objects more than 80 cm. This research only carried out at distance up to 100 cm. Sharp GP2D12 sensor also have limitations in detecting objects because it can only detect objects that angles 90°, but ultrasonic LV-Maxsonar EZ1 sensor can detect objects from different angles. Angular distance causes objects detected by ultrasonic sensor have a higher distance error compared with 90° angled objects. The reduction in angle from 90° to 70° will increase the distance error and lower the accuracy of ultrasonic sensor. Table 2 shows the MSE values before and after the neural network is applied and the use of neural network which can reduce the distance errors and enhance the performance of sensor distance.

7 Conclusion

Neural network determining and improving the performance of different distance sensors has been developed. A distance error occurred can be reduced by neural network touch yet accuracy of the sensor can be improved. The development of neural network systems also helps to analyze the data better than existing conventional methods and can reduce the time required for the calculation of mathematical methods.

This research had used three different algorithms that are Gradient descent with momentum and adaptive (GDX) algorithm, Levenberg-Marquardt (LM) algorithm and the BFGS quasi-Newton (BFG) algorithm. BFG and GDX algorithm gives poor results. Thus, this research suggests the LM algorithm is reliable as it gives better results than the BFG algorithm and GDX algorithm.

The value of mean squared error (MSE) has been reduced by using neural network. The neural network has been developed by using the proposed algorithm of LM algorithm. The distance error occurred can be reduced and the percentage of accuracy to detect the distance of the sensor can be increased successfully improving the performance of the distance sensor using neural network. Two types of sensors used, Sharp GP2D12 distance sensor and ultrasonic LV-Maxsonar EZ1. These sensors have their own disadvantages and advantages. SHARP GP2D12 distance sensor recorded a higher level of accuracy than ultrasonic distance sensor because it has less distance error. The results obtained prove that Sharp GP2D12 distance sensor accuracy is much higher at 95.57% compared with ultrasonic LV-Maxsonar EZ1 sensor only 90.91%.

Overall, the results obtained are able to achieve the objectives of this research, which to improve the performance of Sharp GP2D12 and LV-Maxsonar EZ1 sensors using neural network.

References:

[1] A. Carullo and M. Parvis, "An ultrasonic sensor for distance measurement in automotive applications," *Sensors Journal, IEEE,* vol. 1, pp. 143-147, 2001.

[2] K. Hong-Shik and C. Jong-Suk, "Advanced indoor localization using ultrasonic sensor and digital compass," in *Control, Automation and Systems, 2008. ICCAS 2008. International Conference on*, 2008, pp. 223-226.

[3] P. Veelaert and W. Bogaerts, "Ultrasonic potential field sensor for obstacle avoidance," *Robotics and Automation, IEEE Transactions on*, vol. 15, pp. 774-779, 1999.

[4] C. Chih-Hao and S. Kai-Tai, "Complete coverage motion control of a cleaning robot using infrared sensors," in *Mechatronics, 2005. ICM '05. IEEE International Conference on*, 2005, pp. 543-548.

[5] H. Saad and A. Hussain, "Classification for the Ripeness of Papayas Using Artificial Neural Network (ANN) and Threshold Rule," in *Research and Development, 2006. SCOReD 2006. 4th Student Conference on*, 2006, pp. 132-136.

[6] S. A. Nazeer, *et al.*, "Face Detecting Using Artificial Neural Network Approach," in *Modelling & Simulation, 2007. AMS '07. First Asia International Conference on*, 2007, pp. 394-399.

[7] S. Haykin, *NEURAL NETWORKS : A Comprehensive Foundation*, 2nd ed.: Prentice Hall, 2001.

[8] M. M. C. Nelson and W. T. Illingworth, *A practical guide to neural nets*: Addison Wesley, 1991.

[9] P. Jeatrakul and K. W. Wong, "Comparing the performance of different neural networks for binary classification problems," in *Natural Language Processing, 2009. SNLP '09. Eighth International Symposium on*, 2009, pp. 111-115.

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