Development of an Instrument for Road Edge Measurement

N. Latif A. Shaari[1], Ida S.Md Isa[2], Hasnawi S.A[1]
[1]Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka, Malaysia
[2]Faculty of Electronic & Computer Engineering, Universiti Teknikal Malaysia Melaka, Malaysia
latifazyze@utem.edu.my

***Abstract*— Road edge detection was studied by researchers for applications in automated guided vehicles (AGV) and mainly done through the optical images using machine vision laser sensor, LIDAR sensor, laser radar and frequency modulated continuous wave (FMCW) radar. The navigation is focused on the monitoring and controlling the movement of autonomous vehicle to follow line on the road. This paper presents an instrument to detect road-edge for the paint mobile robot that will be use to paint the road line on the new roads. The rotating of ultrasonic sensor will be used as a sensor to measure the range of the road edge. The time of flight of ultrasonic sensor is determined, as well as the distance between the sensor and the road surface. The road surface profile was plotted and displayed on the computer. As a result, the developed instrument has the ability to measure the road edge after completing several experiments. The sensor has 83.59% accuracy of measuring road with 1 lane and 86.05% accuracy of measuring road with road curb. Therefore, the instrument can be used to accurately measure the road width for road line painting industry. The repeatability measurements show the sensor value for road width measurement with 0.99% precision value. Lastly, it shows that the designed low cost instrument can be used to measure the road-edge by the mobile painting robots.**

***Index Terms*— Instruments, Road edge, Robotics, Ultrasonic sensor.**

I. INTRODUCTION

The present studies about road and road-edge detection are mainly based on laser sensor, LIDAR sensor, laser radar, frequency modulated continuous wave (FMCW) radar and machine vision. Laser sensor's method is a rapid collecting of measurement data of road boundary recognition and it also provide an accurate measurement of road width research done by Z. Hu [1]. W. Zhang [2] said road edge detection method using LIDAR sensor offer an interest in road curb detection. This method also used by W. S. Wijesoma et.al. by extending Kalman filtering for fast detection and tracking of road curbs [10]. In contrast, this method is only focusing in the urban environment where along the road has its curb. In 2D laser radar, the result shows the validate efficiency and effectiveness in the algorithm by M. Feng [3]. The method used is different in analyses the road points in term of mathematical approach. FMCW radar is work effectively under any weather condition like raining and snowing. This method still can detect the road even the line markers or road shoulder are in irregular shape. Besides, the system is effectively detected road edge in any shape such as steep road edge and slope road edge. Machine vision is a conventional method in road and road-edge detection research by W. Wu [4]. Unfortunately, the machine vision face problems like weather, road covered with sand, soil. This project is proposed to use the ultrasonic sensor as the method of road and road edge detection. The basic idea is using the method of laser sensor by researcher Z.Hu [1] with different type of sensor which is ultrasonic sensor.

Road edge detection is currently study by many researchers for applications in automated guided vehicles and mainly done through the optical images using machine vision. The study is also an essential component in autonomous vehicle for navigation. The navigation is focused on the monitoring and controlling the movement autonomous vehicle like mobile robot, therefore the research and development of mobile robots have a great future in multi-tasking application. The robot is mainly use in the industry sector to make the task going easily and smoothly. The usage of robot also can save time and cost, hence it may help to increase the working productivity and efficiency. Mobile robot can be found in military, industry and security services but it is not use for the road line painting robot. Recently, this task is done manually by human. The workers pushing the road line painting machine along the road to paint the road line. Another example, the worker drive the road line painting machine to mark the road line. It will do in sunny day because raining will affect the quality of road painting. By using this robot, the task to paint the road line easier and reduces time, cost and also the man power.

Therefore, the instrument that designed in this project is built, to detect road edge and calculate the road width. The sensor that used in this project is ultrasonic sensor. This sensor scans the road 180° to find the road edge and road region. Ultrasound wave transmit the signal to the road regions and received it back after the signal is reflected by road surface. This sensor is rotated with the help of servo motor. The signal is processed and the road surface profile is displayed with the road width measurement.

II. ROAD EDGE INSTRUMENT DESIGN

The instrument was designed in two parts, lower part and upper part. The upper part was designed using 2 servo motors. The design was created using pan and tilt concept. Pan is the rotation in the horizontal plane meanwhile tilt is the rotation in the vertical plane. At the top of servo motor, the ultrasonic sensor was placed. The sensor was mounted at 45o from vertical axis (declination angle). Hence, the lower part was designed as a pole and a base. The design was in a cylinder shape with diameter of 2.5 cm for the pole. The base of instruments was designed in a square shape with length of 40 cm x 40 cm. The sensor is acceptable to be placed on road surface but the surface must be flat. If the surface is not flat, the output will be produced by the sensor may have an error. Figure 1 show the CAD design and Figure 2 show the upper part design.

Figure 1: Instrument CAD design

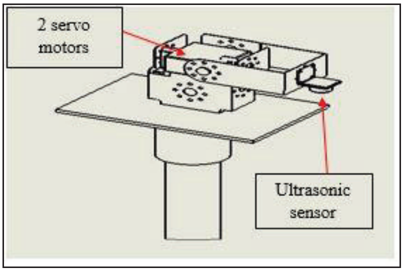

Figure 2: Upper Part of attached sensor

Ultrasonic sensor was chose to use in this project for road detection. The SN LV-MaxSonar-EZ1 is an ultrasonic sensor produce by Maxbotix. According to the datasheet, this sensor is 42 kHz ultrasonic sensor and it operates from 2.5-5.5V. The resolution for this sensor is 1 inch. The detection range is from 0 inches to 254 inches (6.45 meters), it is possible to detect a whole road width. It is small and light module with 45x20x15 mm of dimensions. Furthermore, it is low cost compared to laser sensor and radar. It provides the interface output formats in pulse width output, analogue voltage output and serial digital output. This sensor has 7 pins located on the sensor board. Pin GND is a sensor ground pin. Pin +5V is Vcc, operates on voltage from 2.5V to 5.5V. Pin TX is serial output delivers with an RS232 format. Pin RX is ranging HIGH/LOW for measuring and provide the output data. When HIGH, its allow measuring process while when it LOW, it does not allow the sensor to ranging. The analogue output of sensor has scaling on Vcc/512 per inch. If the power supply is 5V it yields ~9.8mV/in and it located at Pin AN. Pin PW is the pin outputs for pulse width, to calculate distance scale factor of 147 µs per inch based on MaxBotix SN-LV-EZ1 Datasheet 2012.

The instrument used Arduino Uno microcontoller as it data processing device and to produce the output of the ultrasonic sensor. It also produce PWM signal to move the servo motor rotate 180^o.The motor was used to rotate the ultrasonic sensor from -90^o to +90^o when ranging the road area. The ultrasonic sensor is equipped at its bracket and connected with shaft through the motor. The bracket and U-joint are used to construct multi-axis joint with the sensor. With help of the bracket and U-joint, the sensor can rotate in 2 motions, pan and tilt. The pan is the rotation in the horizontal plane and the tilt is the rotation in the vertical plane. The servo motor is used for the rotating task. The motor is controlled by sending them a pulse of variable width. The servo motor is design to have different power source because if they are connected to the 5V supply from the Arduino, it will consume the power supply and cause the ultrasonic sensor output to be unstable. A switch is also designed to on or off the sensor.

Software part plays an important role in this project, processing input to produce the outputs to measure the road width. The sensor is placed on the actuator scans the road 180^o repeatedly when it's moving forward along the road. Pin PW at the sensor will transmit ultrasonic wave to road region to detect road edge. The road surface and road edge will reflects ultrasonic wave and received as an output of the sensor by Pin PW. The process transmitting and receiving the wave will be taken in 0.5 – 1 second for each 1o angle of rotation. This is to ensure the wave was completely received by the sensor. The input of the Pin PW on the Arduino UNO is a pulse width modulation and used to read in the pulse that is being sent by the MaxSonar device. The pulse width detection at microcontroller is representation with a scale factor of 147µs per inch. Therefore, the pulse needs to be rescaling before calculating the range or distance by using Equation 1. After that, the range was calculated by using Equation 2. The computer with helps of software was plotted the graph and display the road surface profile.

$$D = \frac{Pulse}{147} \tag{1}$$

where D is a distance in unit of inch.

$$R = D\,x\,2.54 \tag{2}$$

where R is distance in centimeter.

III. RESULT

In this part, several experiments were performed to measure the performances of the sensor in reliability and accuracy.

There are 3 experiments were conducted to achieve of the objectives of this project. The objectives of the experiments were to evaluate the speed of rotation for the servo motor ranging on the road, to evaluate the accuracy of the road width measured by the instrument and to evaluate the reliability of the instrument compared the road width for road had road shoulder and road had road curb. In the experiment, several apparatus were needed to perform the experiment such as Arduino Uno, 2 servo motors, ultrasonic sensor, laptop, measuring tape and road. The procedures are to setup the apparatus including prepare the instrument and connected to host computer, the road surface must clear and flat before placed the device, because it will affected the scanning process and the output produced. Then, measure the actual road width using measuring tape and determine the centre point of that road. This process was done by using L-shape to ensure the measuring tape was in straight line when measuring the road width. This step was repeated by 3 times and the average value of the reading was recorded. Next, measure the actual road width with the measuring tape and determine the middle point of the road. After that, the sensor will be scanning the road in 180o rotation repeatedly. Road boundary will reflect the ultrasound wave points when the sensor ranging the road. The time interval will be taken for every 1o of angle. There are 180 times of time interval to complete 180^o of angle of rotation. The points are position point of reflected on the road region. The road boundary points are with the smallest distance values between the device and the road surface. Finally, collect the data to plot the road profile graph, estimate the road width and compare the measured value with the actual value to yield the accuracy and the reliability of the instrument.

A. Rotation Speed of Servo Motor Experiment

First experiment that was conducted is to evaluate the speed of rotation for the servo motor ranging on the road using the road model. The aim of this experiment is to determine the suitable speed for the servo motor to rotate when ranging the road surface. The speed of rotation for servo motor was controlled by using time delay function in Arduino. The rotation speed of servo motor for every 1^o degree was controlled using delay function. The time delay functions are 50ms, 40ms, 30ms, 20ms, and 10ms. Delay use to pause the servo motor program in the amount of time before it move again for every 1° of angle. This amount of time delay was also used by the ultrasonic sensor to transmit and receive sound wave when scanning the road surface. The suitable speed was determined by calculate the accuracy of the road model width.

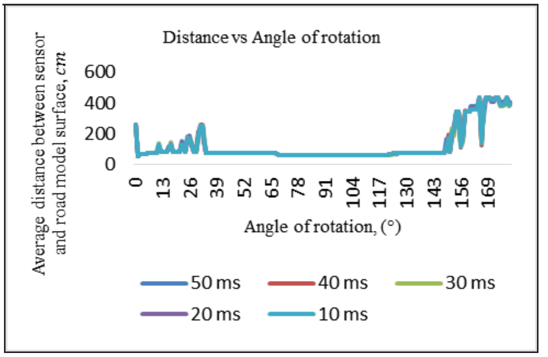

Figure 3: Road model profile

The measure value road model width was calculated by using (3). The actual value road model width is 92 cm.

$$R = d \sin\left(\frac{\theta_f - \theta_i}{2}\right) x\, 2 \qquad (3)$$

Where, **R** is the measured value road model width, **d** is the distance between the sensor and the road model surface at angle $\left(\frac{\theta_f - \theta_i}{2}\right)$, θ_f is the final angle of the road model region and θ_i is the initial angle of the road model region. The percentage of error was calculated using Equation 4 and the percentage of accuracy was also calculated using Equation 5. The precision value was calculated using Equation 6.

$$Error\,(\%) = \frac{Actual\,Value - Measured\,Value}{Actual\,Value} x100\% \qquad (4)$$

$$Accuracy\,(\%) = 1 - \left|\frac{Actual\,Value - Measured\,Value}{Actual\,Value}\right| x100\% \qquad (5)$$

$$\text{Precision} = 1 - \left|\frac{X_n - \overline{X_n}}{\overline{X_n}}\right| \qquad (6)$$

Where X_n is the value of nth measurement and $\overline{X_n}$ is average of measurement.

Table 1
Percentage of error and percentage of accuracy for every time delay function

Time delay function, ms	Measured value, cm	Actual value, cm	Percentage of error, %	Percentage of accuracy, %
50	98.00	92.00	6.52	93.48
40	100.00	92.00	8.70	91.30
30	101.69	92.00	10.53	89.47
20	100.67	92.00	9.42	90.58
10	100.67	92.00	9.42	90.58

From the calculation, for 50ms delay the measured value is 98 cm and 100 cm for 40ms delay. Meanwhile, for 30ms, 20ms and 10ms are 101.69cm, 100.67 cm and 100.67 cm respectively. The percentage of error for 50ms is 6.52 %, for 40ms is 8.70 % and for 30ms is 10.53 %. Then, the percentage of error for 20ms and 10ms are equally to 9.42 % respectively. Hence, the 50ms time delay is a suitable for rotation speed of servo motor to rotate when ranging the road surface. It means the servo motor will delay in 50ms for every degree of rotation and it is also to ensure the sensor can receive completely the reflected wave from the road surface and produce the accurate distance between the sensor and the road surface. Besides, the percentage error is 6.52%, it is the lowest percentage among the others and it also means the accuracy of road width is the highest with 93.48 % of accuracy percentage. As a conclusion, the 50ms delay function was chose to implement on the instrument.

B. Accuracy of Instrument Experiment

Second experiment was conducted to evaluate the accuracy of the road width measured by the instrument. The aim of this experiment is to compare the measured value and the actual value of road width by the percentage of error and the percentage of accuracy. The experiment was conducted on the road with 1 lane and road had road curb along it side. The actual width of road with 1 lane is 4.16 meter and the actual width of road had road curb is 7.05 meter.

1) Road with 1 lane

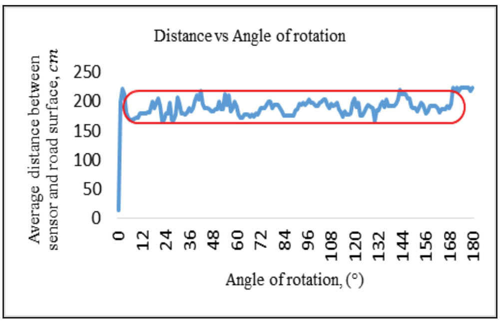

Figure 4: Road profile for average 10 times of data (road with 1 lane)

Figure 4 shows the road profile for road with 1 lane. Form the graph, it shows the road region of that road inside the red rounded rectangle started at 6° and finished at 169°. The distance between the sensor and the road surface is increase and decrease along the road region in the graph. It is because of the road condition, the road surface is rough. Hence, it affects the sound wave generated by the sensor to reflect in a many directions rather than in a coherent manner. Besides, weather condition also effecting the sound propagation between the sensor and the road surface. Windy condition can reduce the sound speed hence its effect the measured value of the road width.

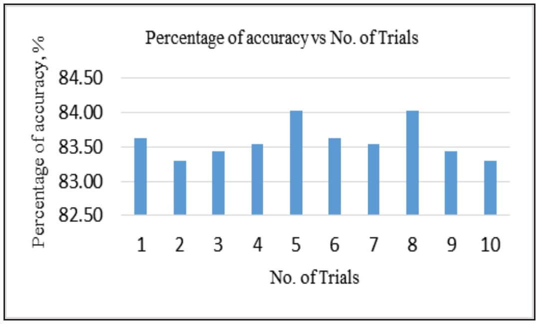

Figure 5: Graph of Percentage accuracy vs number of trials (road with 1 lane)

Figure 5 shows the percentage of accuracy against no. of trials for road with 1 lane. Based on the graph, the percentage accuracy of the instrument for measuring road width is in the range of 83.30% and 84.02%. The highest percentage of accuracy is 84.02%, the lowest percentage of accuracy is 83.30% and the average of percentage accuracy is 83.59%. The average percentage of accuracy of the instrument on the road with 1 lane is merely less 2.46% than average percentage of accuracy of the instrument on the road had road curb. In addition, the road surface on the road with 1 lane is rough compared to the road surface on the road had road curb thus it affect the measured value of road width to become less accurate. As a conclusion, the instrument for road width measurement is accurate as the percentage of accuracy is more than 50%.

2) Road had road curb

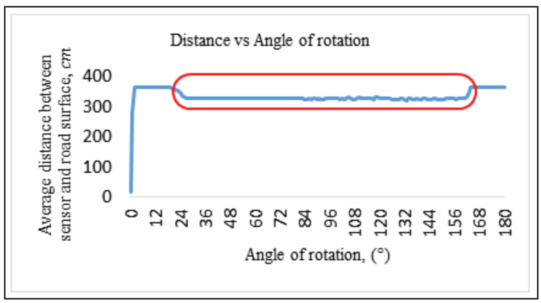

Figure 6: Graph of road profile for average 10 times of data (road had road curb)

Figure 6 shows the road profile for road had road curb along it side. Form the graph, it shows the road region of that road inside the red rounded rectangle started at 27° and finished at 162°. The distance between the sensor and the road surface is steadily along the road region in the graph. It is because of the road condition, the road surface is smooth. Hence, it has affected the sound wave generated by the sensor to reflect in a coherent manner.

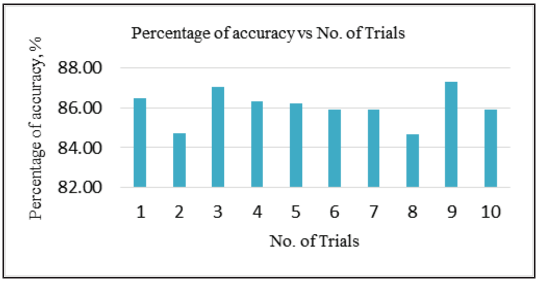

Figure 7: Graph of percentage accuracy vs number of trials (road had road curb)

Figure 7 shows the percentage of accuracy against no. of trials for road had road curb. Based on the graph, the percentage accuracy of the instrument for measuring road width is in the range of 84.68% and 87.31%. The highest percentage of accuracy is 87.31%, the lowest percentage of accuracy is 84.68% and the average of percentage accuracy is 86.05%. There are a slightly 2.46% more accurate in term of accuracy for measure the road width for road had road curb compared to for measure the road width for road width 1 lane. It is because the road surface for road had road curb is smoother than the road surface for road with 1 lane. In short, the percentage of accuracy of the instrument to measure road width is more than 50% hence the instrument is accurate to measure the road width.

C. Reliability of Instrument Experiment

Third experiment was performed to evaluate the reliability of the instrument when compared the road width for road with road shoulder and road with road curbs. The sensor scans the road at both type of roads and the measured value will be collected. The measured value will be compared between both types of roads. . The actual width of road with 1 lane is 4.16m and the actual width of road had road curb is 7.05m. In this reliability testing, 30 data were collected from the output of the ultrasonic sensor when ranging on the road with 1 lane and the road had road curb along it side. From the data collected, the road profile was plotted and determines the road region from the graph.

1) Road with 1 lane

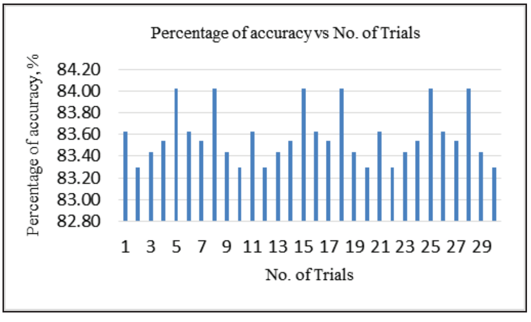

Figure 8: Graph of percentage accuracy vs number of trials (road with 1 lane)

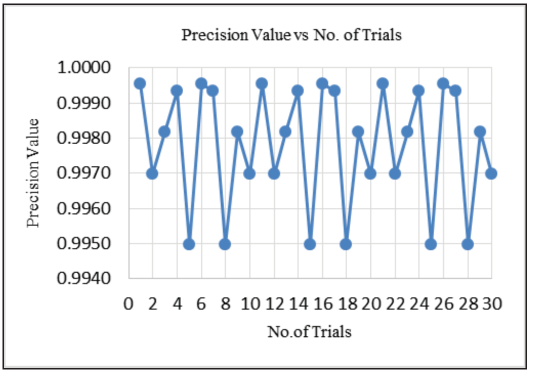

Figure 9: Graph of precision value vs number of trials (road with 1 lane)

Figure 8 shows the percentage accuracy against no. of trials for road with 1 lane for reliability experiment. The data were collected for 30 times to determine the reliability of the instrument for measuring the road width. From the graph, the percentage of accuracy is in the range of 83.30% and 84.02%, the highest percentage of accuracy is 84.02% and the lowest percentage of accuracy is 83.30%. The average of 30 data percentage of accuracy is 83.59%. The average value of precision value for the measurement is 0.99. As a conclusion, the collected data is show that the data is repeatable and reliable on measure the road width of the road with 1 lane.

2) Road had road curb

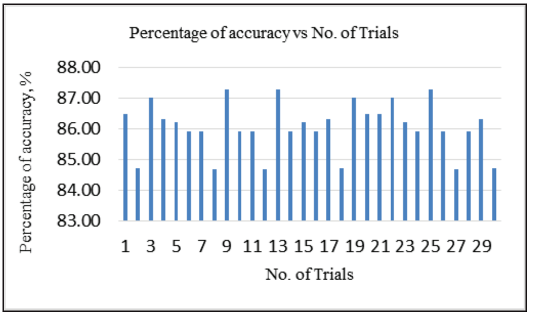

Figure 10: Graph of percentage accuracy vs number of trials (road had road curb)

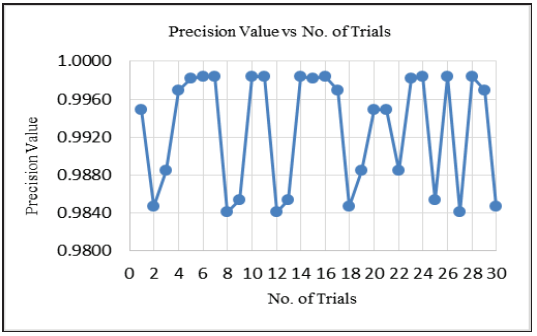

Figure 11: Graph of precision value vs number of trials (road had road curb)

Figure 10 shows the percentage accuracy against no. of trials for road had road curb along it side for reliability experiment. The data were collected for 30 times to determine the reliability of the instrument for measuring the road width. From the graph, the percentage of accuracy is in the range of 84.68% and 87.31%, the highest percentage of accuracy is 87.31% and the lowest percentage of accuracy is 84.68%. The average of 30 data percentage of accuracy is 86.05%. The average value of precision value for the measurement is 0.99, same as the measurement for road with 1 lane. As a conclusion, the collected data is show that the data is repeatable and reliable on measure the road width of the road had road curb.

IV. Conclusion

The instrument can measure the road width for road with lane and road had road curb along it side after the experiment was done. As a result, the percentage of accuracy to measure the road with 1 lane is 83.59% and the percentage of accuracy to measure the road had road curb is 86.05%. Therefore, the instrument is accurate to measure the road width for road line painting industry. In terms of reliability, the measured value from the instrument shows the instrument is able to produce repeatability measured value for road width measurement with 0.99% of precision value. Besides, from the result it shows the signal more reliable for the new road measurement. In future development this instrument is suitable for measuring road surface condition because from the result it shows the difference value of road detection between new and old road.

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