Autonomous Pedestrian Collision Avoidance Using Fuzzy Steering Control

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***Abstract*— This paper presents the autonomous pedestrian collision avoidance using fuzzy steering control. There are three major components used to perform the pedestrian collision avoidance. First, a pedestrian detection using computer vision of TensorFlow SSDlite MonileNet v2, is developed to demonstrate the accuracy of pedestrian detection. Secondly, the Arduino board integrated with Fuzzy Logic System is developed to perform decision-making. Third one is the the fuzzy steering control in which two motors used as steering a brake paddle to perform the actuation. The performance of the developed system is evaluated by testing the Average Precision (AP) of the pedestrian detection, the speed of the pedestrian detection, the accuracy of ultrasonic sensor, the accuracy of speed sensor and the accuracy of Fuzzy Control System. The results are observed as 87% of accuracy on pedestrian detection and 99.97% of accuracy on determining the distance and 88% of accuracy on rpm determination.**

Keywords— ***Pedestrian collision, Arduino, Computer vision, fuzzy logic, Machine Learning, ultrasonic sensor, steering control.***

I. INTRODUCTION

Transporting people from one place to another place in the peak traffic time is very critical in the emergency situations. A lot of major automobile manufacturers are putting effort to develop leading vehicle with several state-of-the-art technologies include collision avoidance, auto-parking, path navigation, etc [1]. Although modern vehicle has made a lot of significant improvement and provided such easement to the driver, the number of road traffic accident does not reduce crucially. In December 2018, Malaysia has been specified as the third highest fatality rate from road traffic accidents in Asia according to The Global Status Report on Road Safety published by the World Health Organization (WHO) and the World Bank. To reduce the number of road traffic accident, collision avoidance system (CAS) has taken up to ensure road traffic safety [2].

In the late 1900s, a collision-avoidance system was initially limited to luxury vehicles. However, nowadays this system has applied to most of the mainstream vehicles. From the literal meaning, a collision-avoidance system is an automobile safety system designed to avoid collision between vehicles and vehicles, vehicles and pedestrians or even vehicles and obstacles [3]. On the automobile industry, experts have defined various type of collision avoidance systems. One of the most popular collision avoidance systems is the Forward-Collision Warning (FCW), which is a system using visual or audible warnings to alert the driver, but the vehicle does not take any action hence driver must decide manually to avoid a collision [4].

A standard collision-avoidance system is using radars, lasers or cameras to sense the vehicle's surroundings to detect other vehicles, pedestrian or obstacles. After detected objects from the sensors, the collision-avoidance system performs calculations to determine the possibility of collision present [5]. The pedestrian detection is the majority part of object detection to ensure pedestrian safety and prevent the collision between vehicles and pedestrians [6]. However, a collision-avoidance system of autonomous vehicles should have the ability to make decisions for the driver, whether to perform brake, lane-changing or other actions to prevent a collision. The action took by the system must be accurate and precise. All the actions taken by the system can be decided by using a fuzzy control system [7].

A fuzzy control system is a system design based on fundamental of fuzzy logic. The fuzzy control system that applies on an autonomous vehicle can be divided into two parts, the steering, and the brake [8,9]. The fuzzy control system is very important towards the autonomous pedestrian avoidance system to perform a high accuracy and high precision of decision making. A good fuzzy control system of autonomous pedestrian avoidance system should have the ability to mimic the driver's behaviour and reaction to overtake the driver's role in an autonomous vehicle [10].

II. BLOCK DIAGRAM AND OPERATION OF THE PROPOSED SYSTEM

A. System Block Diagram

The following block diagram provides description of the system:

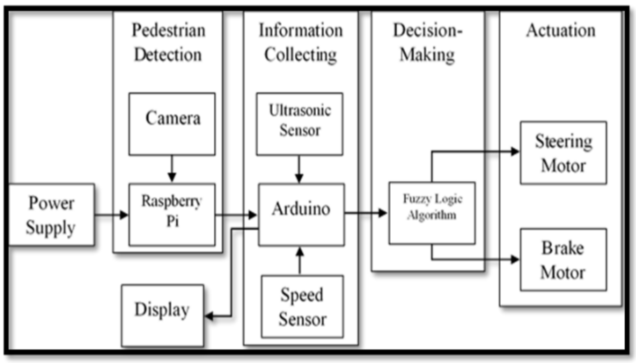

Fig. 1. System block diagram

The block diagram of the overall framework of the system is demonstrated as shown in Fig. 1 The proposed system consists of four main sections include pedestrian detection, information collecting, decision-making and actuation. For the 'power supply' block is a power source which providing electricity to operate the system. In pedestrian detection section, the 'Raspberry Pi' block will use the 'Camera' block for pedestrian detection. Once the 'Raspberry Pi' block detected the occurrence of pedestrians, a signal will send to the 'Arduino' block. Then, in the information collecting section, 'Arduino' block will receive distance information from the 'Ultrasonic Sensor' block and speed information from the 'Speed Sensor' block. Besides that, the 'Arduino' will illustrate the information on the 'Display' block. Next, the 'Arduino' block will run a fuzzy logic algorithm on 'Fuzzy Logic Algorithm' block during the decision-making section. In the decision-making section, the best decision will be determined and transmitted to the respective motor blocks, the 'Steering Motor' block and 'Brake Motor' block. Finally, in the actuation section, the corresponding actions of the respective motor blocks will be taken to avoid the pedestrian collision.

B. Construction Details:

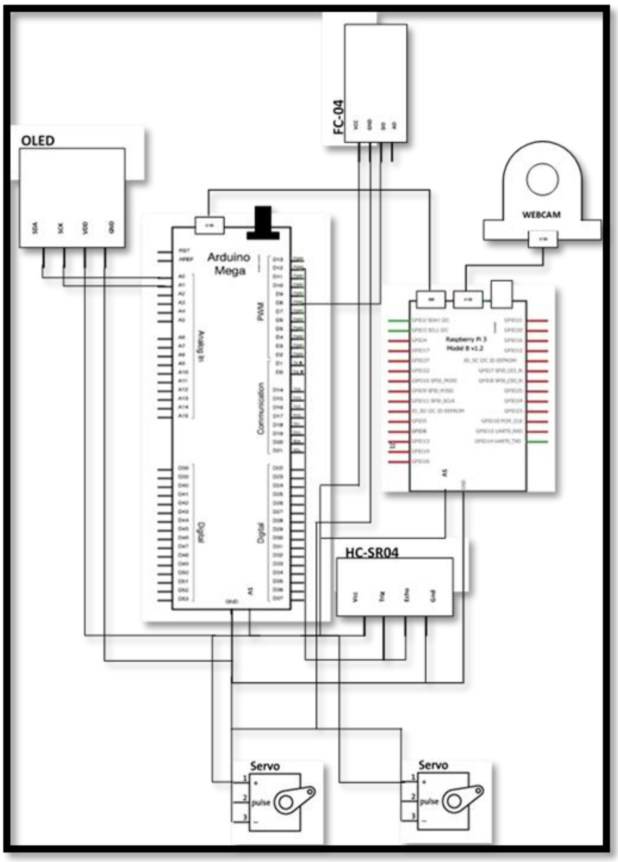

Fig. 2. Schematic wiring diagram

The schematic wiring diagram of the autonomous pedestrian collision avoidance system is demonstrated as shown in Fig. 2 The schematic wiring diagram explains the constructional details of the proposed system. The Raspberry Pi 3 Model B+ is connected to a portable power source. The Logitech C310 HD webcam is connected to the Raspberry Pi 3 Model B+ using USB cable type 2.0 for pedestrian detection.

Next, the Arduino MEGA - ATmega2560 is connected to Raspberry Pi 3 Model B+ using USB cable type A/B. The Arduino MEGA - ATmega2560 is sharing a 5V output and common ground to the sensors, screen display and motors through a breadboard.

There are two digital sensors in the proposed system include the ultrasonic sensor HC-SR04 and the motor encoder RPM speed counter interrupter sensor module FC-03. The operating voltage of both sensors are sharing 5V of power supply and common ground from the Arduino MEGA - ATmega2560 through the breadboard.

The ultrasonic sensor HC-SR04 have 4 data pins include a Voltage Common Collector (VCC) pin, a common ground (GND) pin, a trigger (TRIG) pin and echo (ECHO) pin. The TRIG pin of the ultrasonic sensor is connected to the Arduino's digital pin no.11 while ECHO pin of the ultrasonic sensor is connected to the Arduino's digital pin no.12 using jumper wire. On the other hand, the motor encoder RPM speed counter interrupter sensor module FC-03 also consists of 4 data pins include a VCC pin, GND pin, digital output (DO) pin and analogue output (AO) pin. However, the AO pin is neglected while the DO pin is connected to Arduino's digital pin no.2 using jumper wire.

The monochrome-white OLED display screen also has 4 pins include a Voltage Common Collector (VCC) pin, a common ground (GND) pin, Serial Clock (SCK) pin and Serial Data (SDA) pin. Luckily, the Arduino MEGA - ATmega2560 consists of a serial clock pin and a serial data pin. Hence, both SCK pin and SDA pin of the monochrome-white OLED display screen can be directly connected to the relevant serial clock pin and serial data from Arduino MEGA - ATmega2560.

The servo motor consists of three colour wires, the red wire, the brown wire and the yellow wire. The red wire is the power wire that should be connected to the 5V power supply. The brown wire is the ground wire that should be connected to the common ground pin. The yellow wire is the signal wire which used to receive a command from the microcontroller should be connected on the digital pin. In this system, there are two servo motors, one for the steering control while another one is the brake motor. The signal pins of steering motor and brake motor are respectively connected to the digital pin no.9 and no.10 on the Arduino MEGA - ATmega2560.

C. Cloud Storage and processing

The Longitude, Latitude and body temperature data is further relayed to Node-Red platform which is hosted on IBM server for long term storage and monitoring using Internet connectivity on the microcontroller, typically via a smartphone's Wi-Fi or cellular data connection.

Sensors in the data acquisition part form an Internet of Things (IoT)-based architecture as each individual sensor's data can be accessed through the Internet via the Node-Red server. A storage/processing MySQL database is used for long-term storage and generation of online report. A temporary storage which is commonly referred to as a cloudlet, is used to augment its storage/processing capability whenever the local mobile resources do not fulfil the application's requirements [9].

The cloudlet can be a local processing unit (such as a desktop computer) which is directly accessible by a mobile phone through wireless fidelity (WI-FI) network. Moreover, the cloudlet can be used to transmit the aggregated data to the cloud in case of limitations on the mobile device such as temporary lack of connectivity or energy.

D. Working Principle

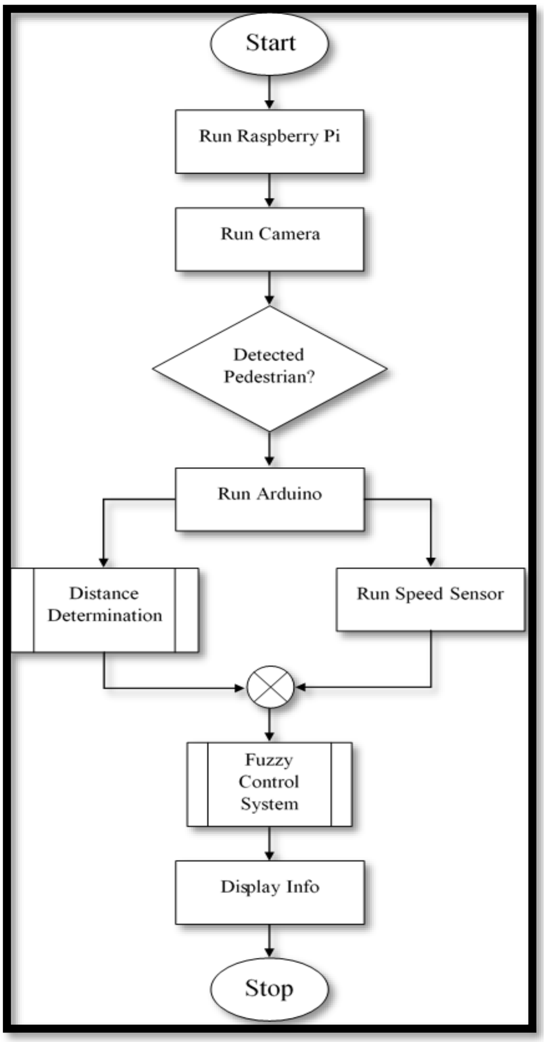

Fig. 3. Flow chart of working principle

The working principle of the entire system is demonstrated as shown in Fig. 3. The proposed system will start with running the Raspberry Pi. The Raspberry Pi with startup with the camera for the purpose of pedestrian detection. Then, if there is any pedestrian is detected, a serial signal will send it to the Arduino board. Once the Arduino board received the serial command from Raspberry Pi, the predefined process of distance determination that stated in Chapter 3 Section 3.3.2 will be executed and the speed sensor will also be activated to receive vehicle's speed information. The predefined process of 'fuzzy control system' will take relevant action to avoid pedestrian collision. Finally, the information of the distance and speed and the action taken by the system will show on the display for noticing the driver.

III. Hardware and System Testing

In this section, the primary form of the prototype of the proposed system is demonstrated as shown in Fig. 4. In the early stage, all the sensors are connected into a breadboard which sharing the 5V power supply from the Arduino. Then, the Arduino is attached with the Raspberry Pi through a USB cable as the Raspberry Pi is commanding the Arduino. A webcam is connected to the Raspberry Pi in order to perform pedestrian detection through computer vision.

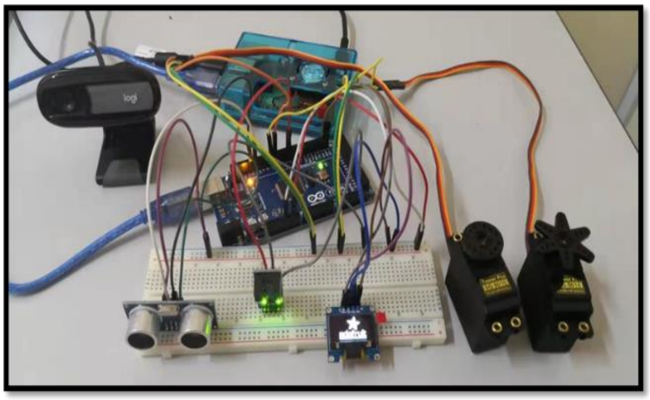

Fig. 4. Circuit of prototype

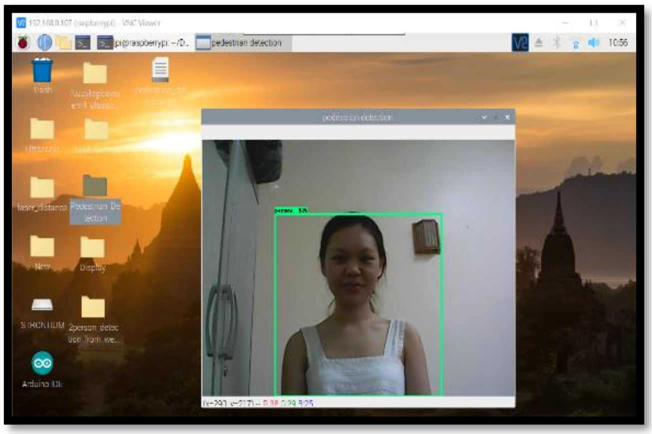

Fig. 5. Simulation Result of Pedestrian Detection

The simulation result of pedestrian detection is demonstrated as shown in Fig. 5. The simulation result shows that the pedestrian detection system is able to detect pedestrian by locating the pedestrian using a bounding box and give a confidence score for the detected pedestrian. The simulation result of the proposed system is demonstrated as shown in Fig. 6. The OLED display screen shows the distance and speed information with the relevant action taken by the proposed system which depending on the predefined fuzzy control system.

A. Simulation and Testing

The accuracy of the pedestrian detection system can be defined by measuring the Average Precision (AP). In order to calculated AP, there are two main terms, the precision and the recall. The precision and recall can be calculated by using the possible classification outcomes, True Negative (TN), True Positive (TP), False Negative (FN) and False Positive (FP) on the following formula [10]:

$$Precision = \frac{TP}{\mathrm{TP} + \mathrm{FP}} \quad (1)$$

$$Recall = \frac{TP}{TP + FN} \quad (2)$$

Ground truth is the exact boundary for the detected pedestrian. The Intersection over Union (IoU) measures the intersection between the ground truth boundary and the prediction boundary. In this test, whenever the IoU value beyond 0.5 the pedestrian detection is considered positive. Then, the proposed system is performed pedestrian detection on 10 sample images from INRIA person dataset and make the ranking for the pedestrian detection based on the confidence value.

TABLE I. CONFIDENCE RANKING

Ranking	*Confidence*	*Positive*
1	0.91	1
2	0.87	1
3	0.85	1
4	0.73	0
5	0.62	1
6	0.62	0
7	0.57	0
8	0.54	1
9	0.42	0
10	0.44	1

According to the confidence ranking table, there are 6 TP and 4 FP. However, there are 3 positive pedestrians are not detected during the test, hence FN=3. Then, the confidence and precision for each ranking are calculated. Next, the values of precision and recall are tabulated as shown in Table II.

TABLE II. VALUES OF PRECISION AND RECALL

Ranking	*Confidence*	*Precision*	*Recall*
1	0.91	1.00	0.11
2	0.87	1.00	0.22
3	0.85	1.00	0.33
4	0.73	0.75	0.33
5	0.62	0.8	0.44
6	0.62	0.67	0.44
7	0.57	0.57	0.44
8	0.54	0.625	0.56
9	0.42	0.56	0.56
10	0.44	0.60	0.67

A precision-recall curve is plotted and demonstrated as shown in Fig. 6. The area under the precision-recall curve is calculated in order to determine the AP. However, the graph is not smooth and hard to be verified hence the zig-zag needs to be smoothed off with the red lines. The Average Precision (AP) can be calculated using the following equation [11]:

$$AP = \int_0^1 p(r)\, dr$$

According to the smoothed precision-recall curve, the average precision of the proposed pedestrian system is determined at around 0.87. However, according to the TensorFlow official research, the Map of the SSDlite MobileNet v2 from COCO is 0.22. The discrepancy between the proposed system and the official research is quite large. However, the reason that caused the huge differences is the training dataset of the official is using COCO dataset which is a 13GB content and it takes all class AP rather than just pedestrian for determined the AP.

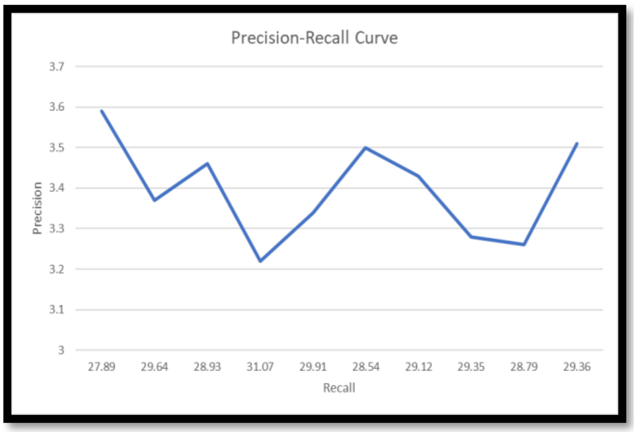

Fig. 6. Precision-Recall curve

B. *Speed Test on Pedestrain Detection*

The speed of the pedestrian detection system can be defined as the processing time taken by the pedestrian detector in order to perform pedestrian detection (including both pre and post-processing). However, the processing time of the pedestrian detector may be affected by various factor such as computer RAM. Therefore, another method to determine the speed of the pedestrian detection system is designed. The speed of the pedestrian detection can be defined by measuring the frames per second (FPS) of the system. The higher the FPS the greater the number of frames that the pedestrian detection system can be handled in a second. However, the FPS cannot determine by naked eye thus programming is applied to the system for FPS counter [12].

The graph of FPS is plotted as shown in Fig.7 whereas the average elapsed time is around 3.40 second and the average approximate FPS is around 29.36. However, the results of FPS are not practical because the FPS testing is not considering any latency. Hence, the FPS of the proposed system is much lower and capped at around 10 FPS. According to the research., pedestrian detection system can operate much faster with an approximate FPS around 60. The discrepancy of the researched value and the measured value is somehow depending on the processor and the camera specification, as the proposed system is just using a 1GB RAM processor and a webcam that capped at 720p@30Hz. Therefore, due to the difference of parameters, the comparison of the proposed system.

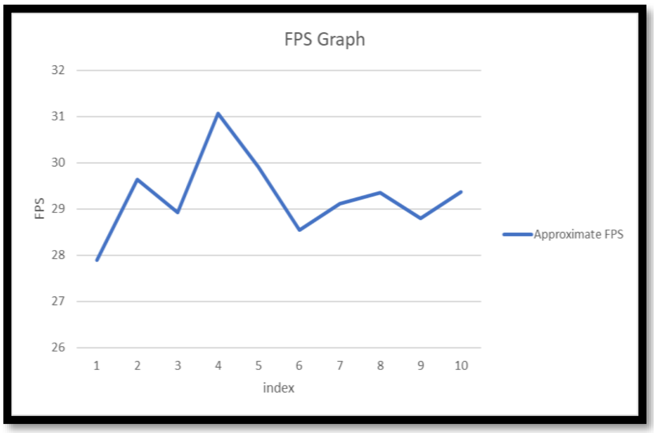

Fig. 7. FPS graph

C. Accuracy Test on Ultrasonic Sensor

The purpose of the ultrasonic sensor is to determine the distance between the vehicle and pedestrian. Hence, the accuracy of the ultrasonic sensor can be defined by verified the distance measurement of the ultrasonic sensor. The accuracy of distance determination is crucial since distance is one of the fuzzy input variables which used to operate the proposed system. In this test, two boxes with varied size will be tested and both are located respectively at 50m, 100cm, 150cm,200cm, 250cm, 300cm, 350cm and 400cm. The approximate dimension of the larger box is 26cm x 42cm x32cm while of the smaller box is 8cm x 8cm x 11cm. Then, the ultrasonic is placed in linearly towards the box. The measurement range of the ultrasonic sensor is from 2cm to 400cm thus the distance measurement limit is set at 4m. The actual value is measured using a measuring tape. The result of distance measurement is tabulated as shown in Table III.

TABLE III. RESULT OF DISTANCE MEASUREMENT

Actual Distance (cm)	*Measured Distance (cm)*	
	Larger Box	*Smaller Box*
50	48.87	47.91
100	101.23	98.02
150	151.18	147.56
200	200.27	198.28
250	250.00	248.37
300	300.15	298.25
350	350.23	348.07
400	399.05	397.23

Based on the above Table III, the distance comparison graph is plotted as shown in Fig. 8. An average accuracy for the larger box is 99.97% while for the smaller box is 98.61%. The average accuracy of ultrasonic on measuring distance of both larger and smaller box is considered very high with less than 2% of error. However, according to the testing results table, the average accuracy on measuring distance of the larger box is significantly 1.36% higher than the smaller box. This outcome claims the size of an object may affect the accuracy of the ultrasonic sensors. Luckily, the proposed system is designed for pedestrian and the average height of a person is around 160 cm.

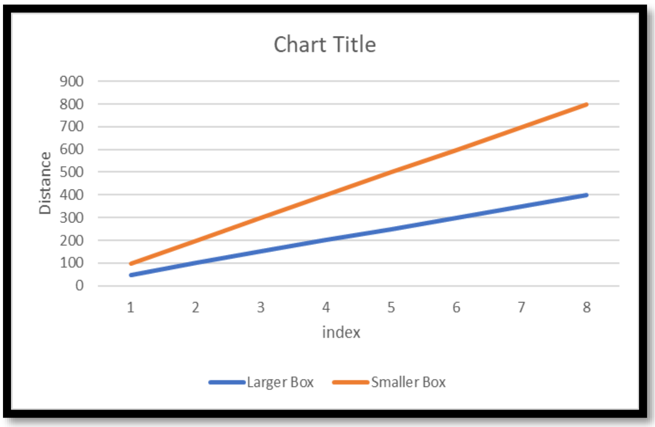

Fig. 8. Distance comparison graph

D. Accuracy Test on Speed Sensor

The purpose of the speed sensor is to determine the speed of the vehicle. Hence, the accuracy of the speed sensor can be defined by verified the speed measurement of the speed sensor. The speed measurement of the actual vehicle is troublesome and somehow the vehicle itself has a speedometer. Therefore, the speed measurement of the speed sensor will be focused on the revolutions per minute (rpm) of a motor. However, the accuracy of speed determination is critical since speed is one of the fuzzy input variables which used to operate the proposed system.

In this test, a motor is attached with an encoder disc and a wheel. The encoder disc is to verify the pulse spectrum for speed measurement. The pulse spectrum for speed measurement is 20 based on the number of notches on the encoder disc. The rpm of the motor will be set at 20rpm, 50rpm, 80rpm, 100rpm, 120rpm, 150rpm, 180rpm and 200rpm. The rpm of the motor can be set by adjusting the potentiometer. Then, the speed sensor will measure the rpm of the motor in order to get the measured value. The actual value of rpm of the motor will be verified by a tachometer. The highest rpm that the motor can reach is around 200 rpm hence the rpm measurement is set up to 200rpm which is shown in the Fig. 9.

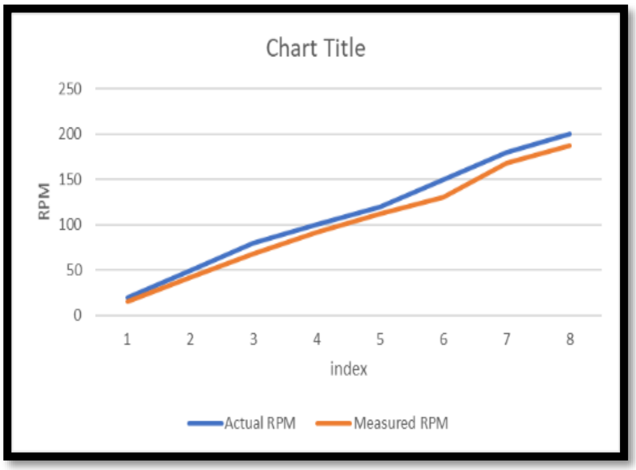

Fig. 9. RPM measurement graph

The average accuracy for rpm testing is 88%. This outcome claims that there are some missing pulses miscounted by the speed sensor. However, the results of the rpm testing are under tolerance since when the rpm is converted to velocity the minor difference can be neglected.

E. Accuracy Test on Fuzzy Control System

The purpose of the fuzzy control system is to perform decision- making for the proposed system in order to avoid pedestrian collision. Hence, the accuracy of the fuzzy logic system can be defined by determining the output value and the actuation. The accuracy of fuzzy control system is important since actuation taken by the vehicle is depended on the proposed fuzzy control system [13]. In this test, 10 set of fuzzy inputs will be applied to the proposed fuzzy control system and the MATLAB fuzzy interference system.

Both systems are using same setting. Then, the output value from both systems will provide a relevant actuation for pedestrian avoidance. Whenever, both actuations are having the same actuation, the statement is considered positive. According to the Fig. 10, although most of the statements are positive. However, the output values of the proposed fuzzy control system and MATLAB FIS are slightly different. The outcome is showing the discrepancy between the defuzzification process of MATLAB and the proposed system.

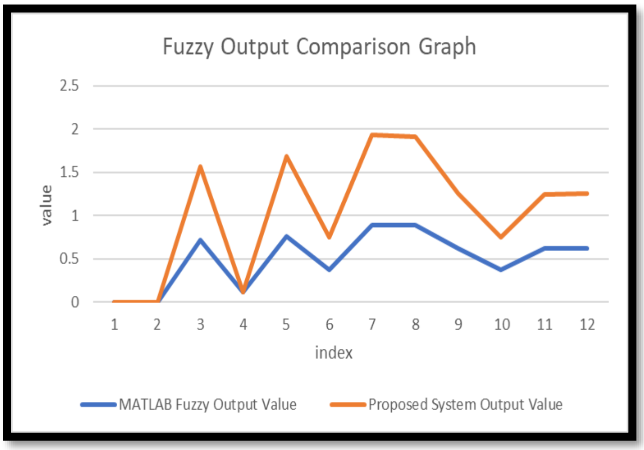

Fig. 10. Fuzzy output comparison graph

IV. Conclusion

A real-time autonomous pedestrian collision avoidance using a fuzzy steering controller has been developed. It has supported for effective automated and controlling to avoid collision between the vehicle and pedestrian. A fuzzy logic system has been incorporated to make decision to avoid collision. A detailed and clear analyze results has proven that the system is more precision and high accuracy can be obtained using this proposed system. The proposed system helps to identifies 87% of accuracy on pedestrian detection and 99.97% of accuracy on determining the distance and 88% of accuracy on rpm determination. The fuzzy logic control system has around 80% of accuracy.

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