Design and Implementation of Fuzzy Logic Controller for A Class of Hexapod Mobile Robot

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***Abstract*—Recently, the development of automation technology relies on the application of artificial intelligence methods such as artificial neural networks, fuzzy logic, genetic algorithms, and so on. Application of such methods improves the system performance and to some extent increases the efficiency of the resources. This paper describes the application of fuzzy logic methods in controlling the speed of a hexapod mobile robot by utilizing Takagi-Sugeno-Kang type of its inference system. A fuzzy logic controller is used to drive a hexapod mobile robot in such a way to avoid an obstacle in the front of it. Such controller was designed to adjust the speed of gait based on two fuzzy inputs, i.e distance between robot and obstacle and its error. The distance variables and its errors comprise of three fuzzy sets with triangular membership function. While, the output of system is the speed variables of robot with three fuzzy sets by their triangle membership function. The experimental results show that the system work well according the objective of the system design. By comparing to the fuzzy logic controller run by simulation using fuzzy logic toolbox under Matlab environment and the experimental results, the speed of robot movement can be adjusted. Robot could move forward with the speed gradually decreases according to the distance between the robot and obstacle in the front of it.**

Keywords*—*fuzzy logic, hexapod mobile robot, Takagi-Sugeno-Kang, obstacle avoidance.

I. Introduction

At present, the development of automation technology relies on the application of artificial intelligence methods such as artificial neural networks, fuzzy logic, genetic algorithms, and so forth. Application of such methods improves the system performance and to some extent increases the efficiency of the resources [1][2][3]. A robot is an automation technology product designed to facilitate human work and even handle difficult work if done by persons. Recently, artificial intelligence methods have also been applied in the development of robots, see [4][5][6][7][8][9][10] for name a few. Those works involve application of artificial neural networks in robotics learning experiment [4] and in tracking control of a wheeled mobile robot [5]. While in [6], Ahn *et al.* addressed the fuzzy logic approach in handling an uncertainty of weight objects for a humanoid robot. Hidayati *et al.* in [7] employed the fuzzy logic controller based on Mamdani inference system to navigate a hexapod robot in a certain room. In addition, Chen *et al.* in [8] designed a fuzzy logic controller which enabled the robot to demonstrate intelligent behaviors in complex environments. The other works revealed the genetic algorithm in determining the link lengths of a 5 DoF underactuated thumb-exoskeleton [9] and solving a nonlinear programming which appeared in optimal control problem of the robot arm [10]. Without intending to exaggerate, the artificial intelligence becomes the main approach for the next generation of the robotics research [11].

This paper describes the application of fuzzy logic methods in controlling the speed of a hexapod mobile robot by utilizing Takagi-Sugeno-Kang type of its inference system. The hexapod robot is a six-legged robot that can walk through the area for a certain task. It is widely known that the legged robots outperform than the wheeled robots because of their ability to explore an uneven terrain. It is possible because the legged robots do not require continuous contact with the road surface [12]. Some related works dealing with fuzzy logic approach in designing the controller for a hexapod mobile robot include the selection of the cutting parameter more precisely for the drilling operation by hexapod robot [8], the realization of autonomous navigation of a hexapod robot during walking [13], the navigation of a hexapod fire extinguisher robot [7], etc. In general, fuzzy logic based controller design is rather effective means to cope the systems which having an imprecision input and/or involving many parameters but wanting to render a precise solution. In addition, fuzzy inference system is constructed from human knowledge in the form of the fuzzy If-Then rules. It made the fuzzy logic based design more natural. However, some works have been devoted to combine several artificial intelligence methods in the framework such as ANFIS [14], CANFISGA [15] , GEFREX [16], and so on.

The rest of the paper is structured as follows. Section 2 describes a framework of the proposed system includes block diagram and schematic diagram respectively. Simulation and experimental results and discussion as well are given in Section 3. Finally, some concluding remarks and further recommendation for future research are summarized in Section 4.

II. System Design

In this work, block diagram of the proposed hexapod robot is depicted in Fig. 1. While, its mechanical structure is shown in Fig. 2. The framework of this robot is inspired by a spider that has six legs to support the body as well as to walk. As shown in Fig. 1, we employ the Arduino Mega 2560 microcontroller to process the information taken from sensors which later used to render the control action according to fuzzy inference system embedded in microcontroller. The Arduino Mega 2560 is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button [17]. Such microcontroller is capable of handling the control mechanism due to its larger space and compactness. It has already been reported the utilization of the Arduino Mega 2560 microcontroller in some applications include stabilization for a class of nonlinear systems [18], path planning of a mobile robot [19], pH sensor and glucose biosensor [20], and so forth. In our work, this microcontroller was exploited to render the robot movements such that they follow a class of the fuzzy logic inference systems so called Takagi-Sugeno-Kang model.

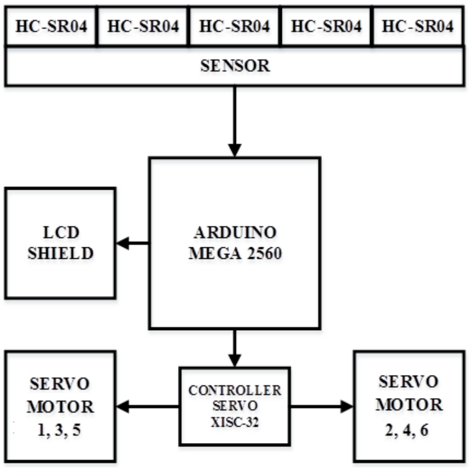

Fig. 1. Block diagram of the proposed hexapod robot

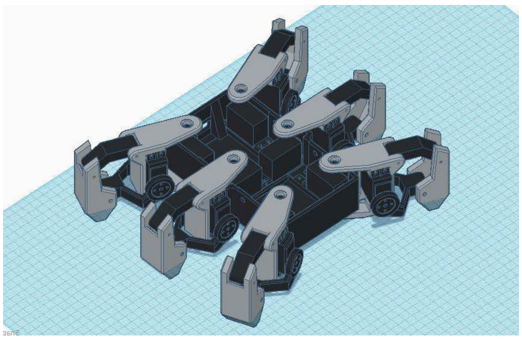

Fig. 2. Mechanical structure of the proposed hexapod robot

Distance between robot and obstacle is provided by five ultrasonic sensors HC-SR04 that installed at the top of robot such that robot could recognize the environment around the robot. Such sensors navigate the robot for walking in a certain track and avoid an obstacle. Meanwhile, the movement of robots is supported by a leg structure consisting of coxa, femur, and tibia as shown in Fig. 3. Coxa or hips have a function to hold the body in a static position (e.g when it stands) and dynamic (e.g during walking or running). Femur is a connector between coxa and tibia. While, tibia has the function of forming a hinge along with a thigh bone called the knee that allows the robot to walk, run and climb stairs.

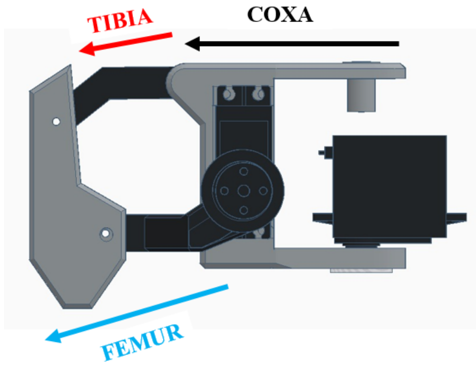

Fig. 3. Leg structure of the hexapod robot

Block diagram of closed loop system which represents our work is shown in Fig. 4.

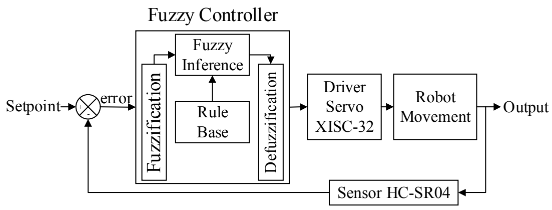

Fig. 4. Block diagram of closed loop system

The objective of recent work is designing the robot movement in such a way to avoid an obstacle in the front of it and render movements effectively. This goal is realized by the application of fuzzy logic methods in controlling the speed of a hexapod mobile robot. A fuzzy logic controller that used to drive a hexapod mobile robot was designed to adjust the speed of gait based on two fuzzy inputs, i.e distance between robot and obstacle and its error. The distance variables and its errors comprise of three fuzzy sets with triangular membership function. While, the output of system is the speed variables of robot with three fuzzy sets by their triangle membership function. In fact, these fuzzy sets represent the delay time which correspond to the duration time of an actuation signals delivered to servomotor. The more delay time the slower robot movement. The distance variables are divided to three fuzzy sets i.e far, medium, and near. The membership functions of three fuzzy sets respectively are depicted in Fig. 5. Noting that distance between robot and obstacle equals 250 cm. While, its error consists of three fuzzy sets including small, medium, and large respectively with their membership function are given in Fig. 6.

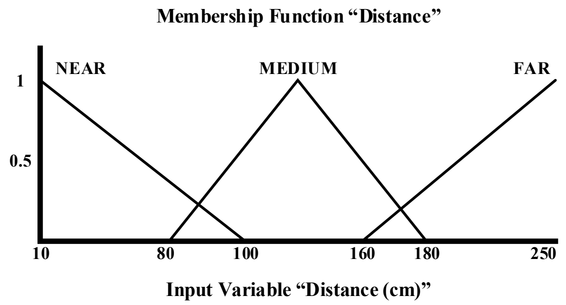

Fig. 5. The membership functions of fuzzy sets of distance variables.

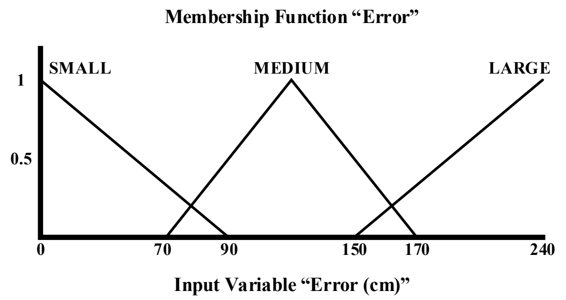

Fig. 6. The membership functions of fuzzy sets of error variables.

In Takagi-Sugeno-Kang model, the output membership functions are either linear or constant. In this work, we define the three of fuzzy singleton for denote the output variables as shown in Fig. 7. The fuzzy sets comprise of fast, medium, and slow respectively.

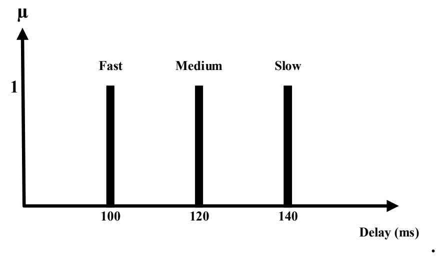

Fig. 7. The membership function of fuzzy sets of delay

A typical rule in the Takagi-Sugeno-Kang model has the form "If Input 1 is x and Input 2 is y, then Output is z". To this end, a rule base to realize the proposed fuzzy logic method in a hexapod mobile robot is listed in TABLE I.

TABLE I. A RULE BASE WHICH USED IN THE INFERENCE SYSTEM

distance / error	near	medium	far
small	slow	medium	fast
medium	medium	medium	fast
large	slow	medium	fast

By using a fuzzy logic toolbox under Matlab environment, we get the simulation results as shown in Fig. 8-11. These results represent four conditions that may appear in the experiment. When the distance between robot and obstacle equals 205 cm and its error is equal to 195 cm, interval time of actuating signal to drive a servomotor equals 100 ms as given in Fig. 8. While, interval time of actuating signal increases that means the speed get lower whenever robot move get closer to obstacle. Such condition is compiled from Fig. 9-11.

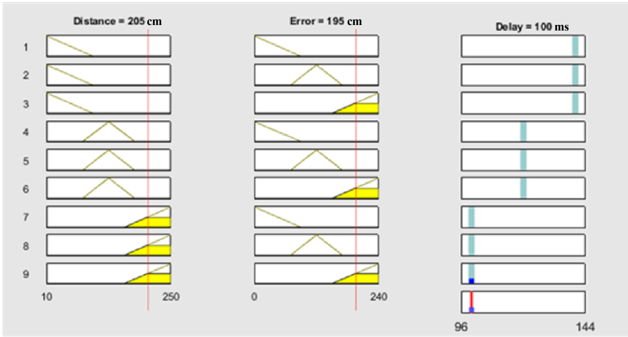

Fig. 8. Simulation result for input variables with the distance value equals 205 cm and its error is equal to 195 cm.

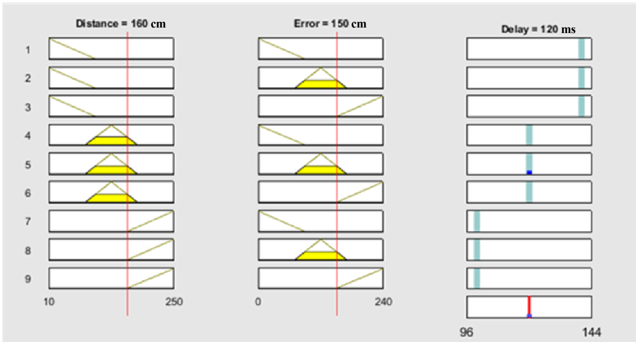

Fig. 9. Simulation result for input variables with the distance value equals 160 cm and its error is equal to 150 cm.

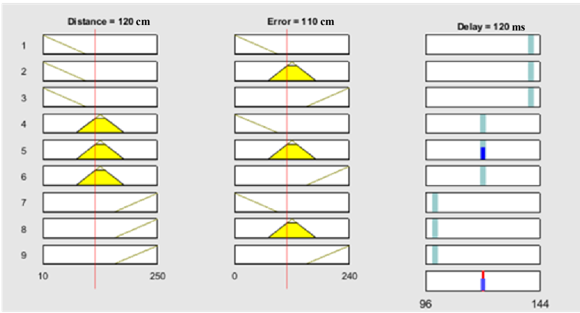

Fig. 10. Simulation result for input variables with the distance value equals 120 cm and its error is equal to 110 cm.

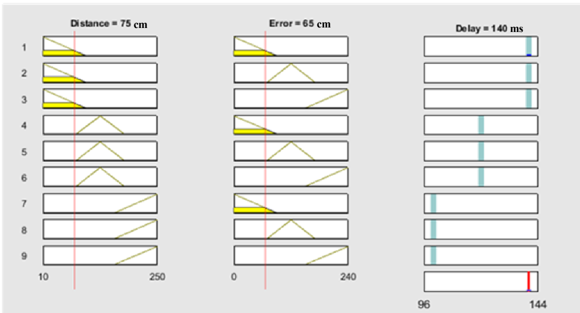

Fig. 11. Simulation result for input variables with the distance value equals 75 cm and its error is equal to 65 cm.

III. RESULTS AND DISCUSSION

Realization of the hexapod mobile robot which used in this work is depicted in Fig. 12. Five ultrasonic sensors are placed at the top of robot to detect the obstacle in the front and rear the robot. From these measurements, the crisp data can be classified into their respective fuzzy sets of input variables. Robot movement is implemented by a gait mechanism which supported by six servomotors installed in its leg.

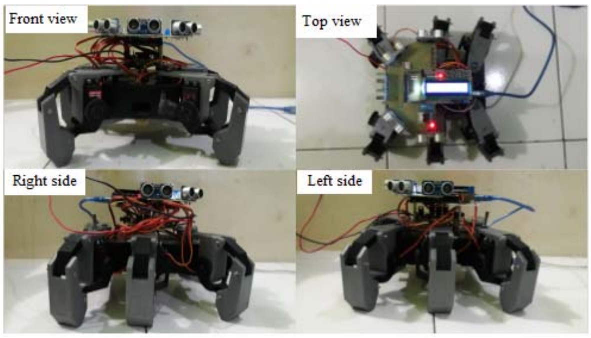

Fig. 12. The hexapod mobile robot used in the experiment.

The experimental test is carried out by putting the robot in a certain position and then observing the adjustment of the speed during walking. The direction of forward motion and the distance that corresponds to the respective fuzzy set are illustrated in Fig. 13.

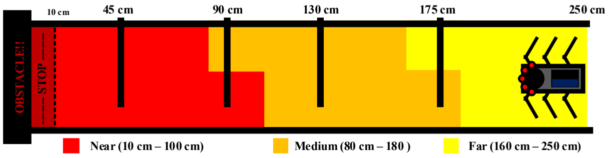

Fig. 13. Illustration of direction of robot movement

The robot is placed at an initial distance of 250 cm from obstacle. It moves forward by adjusting the speed depending on the result of inference system of fuzzy logic method embedded in the microcontroller. Snapshot of the experimental results is shown in Fig. 14-15.

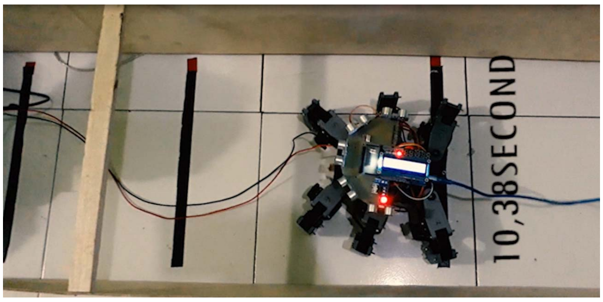

Fig. 14. Travelling time when the robot moves from a distance of 250 cm to a distance of 170 cm from obstacle.

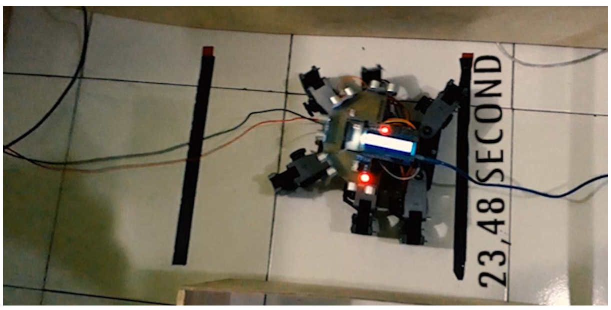

Fig. 15. Travelling time when the robot moves from a distance of 250 cm to a distance of 90 cm from obstacle.

As observed from the experimental results, the travelling time increases when the robot get closer to obstacle. In other word, the speed of robot movement gradually decreases along with the track as depicted graphically in Fig. 16.

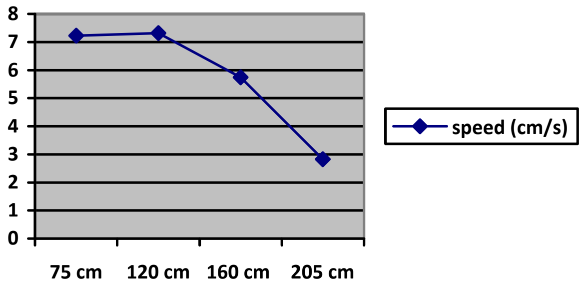

Fig. 16. The speed adjustment of robot during walking

IV. Conclusion

The design and implementation of fuzzy logic controller to adjust the speed of a class of hexapod mobile robot is already presented. We employed the Takagi-Sugeno-Kang model in realization of fuzzy logic method for rendering the control objective. From simulation under Matlab environment and the experimental results as well, the proposed fuzzy logic controller achieved the objective of control design. Robot could move forward with the speed gradually decreases according to the distance between the robot and obstacle in the front of it.

However, further works are needed to improve the performance of the hexapod mobile robot in terms of smoothness in the robot movement, robustness for parameter uncertainty may appear in design and implementation. Application of mix method in intelligent control is also interesting to be implemented in adjusting the speed of the robot during walking and its orientation as stated in [21] [22].

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