IMPLEMENTATION OF TAKAGI SUGENO METHOD AS FUZZY LOGIC CONTROL WITH MULTIPLE SENSORS ON FIRE FIGHTER ROBOT PROTOTYPE NAVIGATION

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To my beloved parents, thank you.

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ABSTRACT

Autonomous mobile robot will become an interest by many researchers. Due to needs of an effective navigational system for the robot, many approach was purposed to control the reliability of the system in order to achieve an optimum control system respond. Nowadays, AI was used as one of the approached to enhance the decision making by the robot itself without depending on the user. In this development, multiple sensors were implemented to increase the detection accuracy of the prototype during navigate on constantly changing environment. By using multiple sensors (ultrasonic sensor) it means that, it will have more input information so, in order to manage all of this data information, intelligent control strategy was required to achieve an optimum output in term of efficiency and accuracy. On this development, previous prototype was upgraded into more intelligent system. Fuzzy Logic was introduced to this development by using a Takagi Sugeno inference method. In this project Fuzzy control was designed with aid of computing software (MATLAB) and by using a Arduino MEGA controller Fuzzy logic control was apply to realize the real-time simulation for the robot navigation. The fire detection unit by using IR sensor module was purposed to make sure it can scan the IR wave generated by the flame. Differential steering method was selected for semi-autonomous robot driving system and it was powered by 2 DC motor for the robot navigation. All the function of the robot is tested in order to evaluate the capability of the system on the robot by referred to the project scope. On this development, the effectiveness of the system was vary with the number of Fuzzy Rule. The effectiveness of the Fuzzy control was observed by the time taken for the prototype completed the route and the time respond for the prototype to avoid obstacle during the navigation inside the test rig.

ABSTRAK

Robot mudah alih autonomi telah menjadi minat ramai penyelidik. Oleh kerana keperluan sistem navigasi yang berkesan untuk robot, banyak pendekatan bagi mengawal kebolehpercayaan sistem untuk mencapai tindak balas sistem kawalan yang optimum. Pada masa kini, AI digunakan sebagai salah satu pendekatan untuk meningkatkan pembuatan keputusan oleh robot itu sendiri tanpa bergantung kepada pengguna. Dalam perkembangan ini, berbilang penderia telah dilaksanakan untuk meningkatkan ketepatan pengesanan prototaip semasa menavigasi pada persekitaran yang sentiasa berubah. Dengan menggunakan pelbagai sensor (penderia ultrasonik) bermakna, ia akan mempunyai lebih banyak maklumat input jadi, untuk menguruskan semua maklumat data ini, strategi kawalan pintar diperlukan untuk mencapai output yang optimum dari segi kecekapan dan ketepatan. Mengenai perkembangan ini, prototaip sebelumnya telah dinaik taraf kepada sistem yang lebih pintar. Fuzzy Logic telah diperkenalkan kepada perkembangan ini dengan menggunakan kaedah inferens Takagi Sugeno. Dalam projek ini Kawalan Fuzzy telah direka bentuk dengan bantuan perisian pengkomputeran (MATLAB) dan dengan menggunakan pengawal Arduino MEGA Kawalan logik kabur digunakan untuk merealisasikan simulasi masa nyata untuk navigasi robot. Unit pengesan kebakaran menggunakan modul sensor IR bertujuan untuk memastikan ia dapat mengimbas gelombang IR yang dihasilkan oleh nyalaan. Kaedah stereng pembezaan telah dipilih untuk sistem pemanduan robot separa autonomi dan ia dikuasakan oleh 2 motor DC untuk navigasi robot. Semua fungsi robot diuji bagi menilai keupayaan sistem pada robot dengan merujuk kepada skop projek. Mengenai perkembangan ini, keberkesanan sistem adalah berbeza dengan bilangan Peraturan Fuzzy. Keberkesanan kawalan Fuzzy diperhatikan melalui masa yang diambil untuk prototaip melengkapkan laluan dan masa bertindak balas untuk prototaip untuk mengelakkan halangan semasa navigasi di dalam pelantar ujian.

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LIST OF SYMBOLS AND ABBREVIATIONS

AI	-	Artificial Intelligent
CPU	-	Control Processing Unit
TTS	-	Time to Ship
EV	-	Electric Vehicle
IR	-	Infra-red
SMPS	-	Switch Mode Power Supply
AC	-	Alternate Current
DC	-	Direct Current
MM	-	Millimetre
CM	-	Centimetre unit of length
AGV	-	Automated Guided Vehicle
USB	-	Universal Serial Bus
PWM	-	Pulse Width Modulation
ICSP	-	In-Circuit Serial Programming
rpm	-	Revolution per minute
eFLL	-	Embedded Fuzzy Logic Library
PCB	-	Printed Circuit Board
AVR	-	Alf and Vegard's RISC processor
hex	-	Arduino file format
GUI	-	Graphic User Interface
FLS	-	Fuzzy Logic System
MF	-	Membership Function
OA	-	Obstacle Avoiding
MF	-	Membership Function
TS	-	Takagi Sugeno
fis	-	Fuzzy Logic Toolbox file format

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Artificial intelligence has become a popular trend now especially in developing a new mechanism that have an ability to solve problem and making a decision without depending on the user itself. With intelligent system, a man-made mechanism like robot and machine can organise their flow of thinking at the same time can minimize the constraint in order to achieve efficiency and accuracy.

In this project the previous Firefighting robot was upgrade into more intelligent system. On the first phase, the upgrade was focuses on a navigation system that will be used a new algorithm for the obstacle detection. The idea of this project was to implement a computational intelligence technology to enhance a decision making of the robot.

1.2 Background of Study

Nowadays, a robotic technology will be becoming an interesting topic to be discuss. Robot with the autonomous function will help human in order to decrease a workload. For a many years after, human had been discovered and develop a new technology in order to reduce the limitation on human can reach, especially in a critical condition. By a Robotic Technology human were capable to do a hazardous work that may can cause an injury to them.

Other than that, due to the high demand on the industry, robotic technology has improved drastically due to productivity efficiency. Efficiency can be improved by implementing Artificial Intelligence (AI) in term of navigation system and mapping, perceiving, displaying, and arguing knowledge, planning, and lastly interaction and learning [1]. Much of the past work define the adaption of AI in robotic system will gain the productivity and the ability to operate in complex environment for long period of time [1].

1.3 Problem Statement

On the previous project, classical method is used to control the obstacle avoidance system by using standard algorithm by programming sequence or dynamic programming method. On a first generation of the prototype, it equips with one module of distance sensor where the ultra-sonic sensor will update the distance according to the algorithm set in the microcontroller via programming.

By using standard algorithm with only one ultra-sonic sensor the prototype seem struggle to execute each operation when try to avoid the obstacle. Sometime, the prototype gives a slow response when detecting the obstacle. This action will affect the movement of the prototype while avoiding the obstacle, while the protype try to find a correct path to move forward.

With only one ultra-sonic sensor, controlling process might be slow due to limited input. In order to maximize the efficiency of the prototype, new algorithm has been introduced to the control process especially in the avoidance detection.

Computational intelligence was introduced to be choose as a new algorithm for this prototype to enhance the intelligent behaviour in the system so that the system can adapt a complex and constantly changing environment [2].

Other than that, there is need some improvement on the detection unit to increase the accuracy of the detection by using a multiple sensor because more input can be processes during the controlling process [3].Fuzzy logic was introduced as a new algorithm for this prototype. With Fuzzy Logic it will develop decision algorithm for the firefighting robot prototype when deciding to avoid the obstacle depending on the input from ultra-sonic sensor.

With Fuzzy Logic it will create an intelligent control system for the robot navigation in determining the obstacle ahead [4]. Controlling process with of Fuzzy Logic with multiple distance sensor will give an accurate decision because it will give an optimum computing value to enhance the obstacle avoidance system reliability. According to the research by Shihming Chen et.al the result it shows that the implementation of Fuzzy Logic has increase the control stability and obstacle avoidance system efficiency for their unmanned underwater vehicle [5].

1.4 Objectives

The main objective of this project is to intelligent control on a prototype of firefighter robot for barrier avoidance control. These are the sub objective of the project:

1. To implement Fuzzy Logic control system on barrier avoidance control using Takagi Sugeno inference.
2. To design an autonomous prototype robot that can correcting paths and fire sensing using multiple Ultrasonic sensors and flame sensor module.
3. To analyse the performance and effectiveness of the protype over the number of rules

1.5 Scope of project

In order to fulfil the stated objectives, the scope of this project will be divided into 3 scopes.

1. **Barrier avoidance.**
   - Robot will avoid barriers if there have any obstacles that occur during the process of detecting fire.
   - Implement a Fuzzy Logic control to avoid barriers using Takagi Sugeno inference method.
2. **Detection of fire.**
   - In order to utilize a function of a firefighter robot, flame detector feature was added to perform the fire sensing.
   - The robot must be able to detect a fire towards by using the flame sensor and give the feedback about the absent of fire.
3. **Number of Fuzzy rules over the performance.**
   - 6,9 and 21 rules were tested in controlling the prototype navigation.
   - The performance of the prototype was analysed by considered the time taken of the protype completed the route of dedicated path.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The aim of a literature review is to show the research done related to the scope of project. This work contains in many formats, including online sources. The ideas of the project are taken from sections of a report, dissertation, or thesis. The ideas taken related to the research are guided by the objectives of the project and will be used as a framework for further work to provide better understanding and project improvement.

2.2 Intelligent Robotic Technology

In a recent year, there are many types of robots that can perform the specific task. According to the Luigi Pagliarini and Henrik Hautop Lund on their journal state that in very next decade robotics will become vital components in a number of applications and robots paired with AI will be able to perform complex actions that are capable of learning from humans, driving the intelligent automation phenomenon [6].

The application of robot was a brilliant idea to reduce the human workload and can bring more advantages due to the human limitation. In this Fire Fighting robot project it was not feasible to appoint a person to patrol for accidental fire where a robot can do the patrolling [7]. So, a robot was made to patrol for fire detection and early warning in domestic, industrial, and environmental cases.

In mobile robot application sensor was the vital component in navigating the position and give feedback on unpredicted surrounding. Tao Zheng et al, introduced a mobile robot with implementation of LIDAR sensor and the intelligent approach

was apply in order to manage the LIDAR detection to form a 2D map of the indoor to estimate the robot navigation.

Neural network was used to train the optimize segmented point detected by the LIDAR to estimate the map line for the room. [8]. Other than mobile robot, humanoid robot was the most popular among the implementation of intelligent technology nowadays. The conscious of the robot was determined by the intelligent approach to look alike a human interaction.

By using Genetic Algorithm an optimization of the robot output can be tuned by using the pre-sample data from the intermediate advancing angle for the humanoid robot movement and obstacle avoidance. The pre-sample data was feed to the Genetic Algorithmic controller which generates the final sample as the desired final output to avoid the obstacles present in a complex environment and reach the destination successfully [9].

2.3 Fuzzy Logic

Professor Zadeh introduced the concept of fuzzy logic in 1965. It was a logical procedure that states the values of a pair of variables can be derived by comparing the binary complex into a single function . With the use of linguistic variables, values can be obtained with special functions. For instance, the membership function can be extended to provide a fuzzy set [10].

In robotic technology various study of output evaluation have been carried out on a various application and one of purposes was used in mobile robot application especially in navigation process to make sure the mobile robot can navigate the direction by itself. Due to this necessity, the robot must have enough information from their surroundings to move freely when coped with the unknown changing environment according to the situation.

Intelligent techniques such as Fuzzy Logic, Optimization methods and Neural networks (NN) were purposed to adapt the surrounding and gather the information from the sensors. For Fuzzy logic, it comes with several method such as Takagi Sugeno and Mamdani fuzzy controller that can be implement in managing all of these information [11].

2.3.1 Takagi Sugeno Method

Takagi Sugeno method was purposed by Takagi and Sugeno inn 1985. This method performed by fuzzy rule that have an if-then statement combined with fuzzy logic, fuzzy set, and fuzzy inference. Fuzzy rule was important in controlling the output consequences based on the linking inputs variable [12]. Based on research by Prases K., Takagi Sugeno was the best option for fuzzy logic control because it has the advantage on handling the real-time navigation for path planning robots in unknown terrains [13].

This research was supported by another research that conduct a test capability on Pioneer P3-DX robot in V-REP simulation engine using different type of inference method between Takagi Sugeno and Mamdani. The result from the research shows, Takagi Sugeno give a faster response time during the path travelled test. In term of efficiency Takagi Sugeno be able to produce a constant output without delay because no defuzzification process involve and for Mamdani the efficiency was drop due to the delay during defuzzification process on changing the output fuzzy set into one single output [14].

2.3.2 Mamdani Method

Mamdani was one of the most popular approaches widely used in various type of application such as risk evaluation, forecasting and problem-solving technique. Same with T-S method it relies on fuzzy rule who have been set to produce an output. The different was Mamdani use defuzzification process to evaluate the output rather than using weighted average of the rules to produce output in Takagi Sugeno method [15]. Mamdani method was used to convert a crisp numerical value into fuzzy set and membership function was assigned to map the fuzzy set.

This process (fuzzification) allowed the input variable mapped into various type of membership function. On a membership function fuzzy operator was applied to portrays the consequences on each membership function. Fuzzy rule was applied by implication method and the final process of fuzzy system loop was defuzzification that combined the fuzzy set to obtain a single scalar quantity as an output .

2.4 Fuzzy Logic Control

There are three main fuzzy inference systems which is Mamdani, Sugeno, and Tsukamoto type. Ngangbam Herojit Singh paper [16] its introduce a Fuzzy logic interference (Mamdani) system to control the 2 input (Ultrasonic sensor) and 2 outputs (DC Motor). On the output its control direction of the motor whether go to right and left by using Kinematic model to interpret the orientation of the robot during obstacle avoiding and move to the targeted path.

There are 2 main components to be consider in development of mobile robot, which is the ability of obstacle avoidance and energy saving or less time for the robot to reach the destination. With fuzzy logic technique, optimal path can be archive with less computing time during obstacle avoidance test. In this paper, its claim that fuzzy logic was the best techniques can be use on navigation control compared to other approach. In the future, fusion algorithm with Fuzzy-Genetic was developed to tune the membership function on fuzzy input [16].

Priyam Parikh *et al*. presented a fusion technique of between Fuzzy and PID control for archive a constant RPM in Automated Guided Vehicle (AGV) by using fuzzy logic and Ziegler-Nichols Algorithm to tune the PID parameter. In this paper, system response of the prototype was compared between PID with fuzzy logic control and PID without fuzzy logic control by referring their system response. From this project, it concludes that, with these control strategies be able to reduce settling time, steady state error and overshooting [17].

B. B. V. L. Deepak *et al.* purposed research on application Takagi Sugeno method into their free trajectory robot by controlling the steering angle so that the mobile robot can avoiding obstacle within dynamic environment. On this paper, they used bell shape membership function to map the input consequences in fuzzification process. From the conducted experiment, the robot be able to generate an optimal collision free along the path. For the fine-tuned collision system they suggest, to apply more number of fuzzy rule and membership function to increase the effectivity of collision free system [18].

2.5 Fuzzy Logic on Various application

Implementation of fuzzy logic technology for the development of sophisticated control systems has become one of the most rapidly growing successful technologies. This is mainly because fuzzy logic resembles human decision making with an ability to generate precise solutions from approximate information.

In 2018, Aggrey Shitsukane *et.al* has introduce a fusion model of obstacle avoidance robot by implement a fuzzy logic control with multiple sensors to enhance the accuracy of a detection. On this project, Fuzzy logic was used as the algorithm for two-wheel robot to navigate into the environment. On this project their team developed 2 variants of robot, which is with 3 proximity sensor and 8 proximity sensors.

The simulation was performed by using MATLAB and V-REP software in designing and carry out the result. Fuzzy control logic was divided into 4 part which is Fuzzification, Inference engine, Rule base and Defuzzification. From the simulation result it show that, 8 sensor variant model shows the effectiveness in navigation was improved. Other than that, it discovered that, Fuzzy logic was an effective way to be apply on the robot by using a logic rule without intensive mathematical methods [19].

On 2019, Nada Massod.M has introduced a case study that investigate a several methodologies of Fuzzy, Neural and Fuzzy-Neural logic functionality on mobile robot either in static or dynamic environment. On this research, different kind of mobile robot algorithm has been study on the capability of mimic human behaviour to make decision by using a technique of computational intelligent in mobile robot application. Some of the techniques has been identified in this research, such as Fuzzy logic-based algorithm, Neural Network Logic and Neuro-Fuzzy controller.

By using these techniques productivity of any system can be optimized [20]. Computational intelligence can be anything beyond our imagination. Imagine that, by using CI the evaluation of risk can be solve by using a fuzzy logic. In 2020, Bing Wu et al. has designed an intelligent decision-making system for navigation strategy in the inland traffic separation scheme by using fuzzy logic. The purpose model can support a decision-making system for safe navigation and autonomous navigation on inland traffic-management route-system (TSS) waterway for ship navigation during change lane when overtaking or to return after overtaking [21].

Chun-Hsiung Lee *et al*,on his paper, introduced a method of controlling a line flowing robot by using fuzzy logic in controlling obstacle avoidance at the same time

the robot be able to reach the destination when taking the complicated path. The aim of this study was to demonstrate fuzzy theory in control system and seek the optimal fuzzy proportion parameter value through the line-following obstacle avoidance of robots [22].This robot adopts a function oriented modularized design and modularize programming on the control module. Control module consists of 5 modules was design as Figure 2.1.

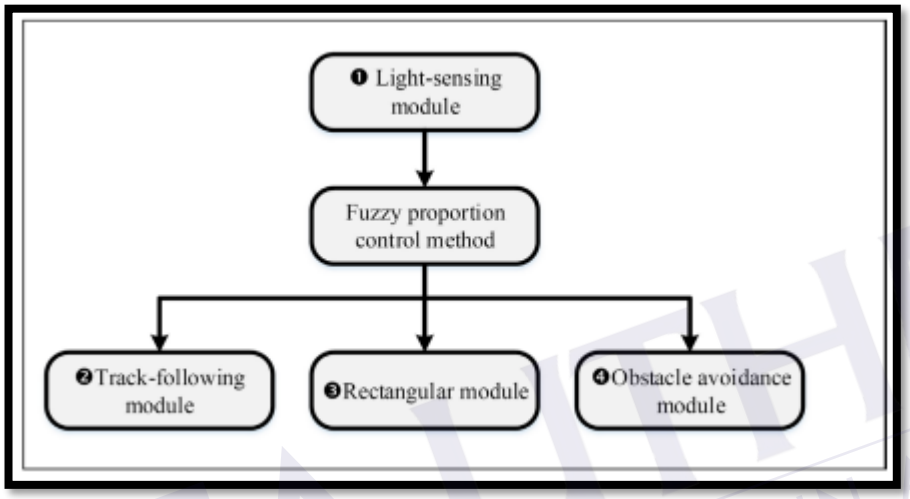

Figure 2.1 The 5 Modules of the Fuzzy Proportion Control Methods for the Line-following Obstacle Avoidance of Wheeled Robots [22]

In this paper they also identify some limitation occur in this project which is failed to evaluate the horizontal black line because the robot was running to fast especially at small turn. Other than that, lacked voltage supply to the obstacle avoidance system so that, the system cannot detect the object towards properly and crush the obstacle. The voltage problem seems a serious problem in designing dynamic moving porotype because of the main component was electric motor that used most of the voltage supply. Lou Frenzel has introduced of application on High Voltage solution on EV. The paper identified that, higher voltage increases the efficiency and power delivery to the car[23] .

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