UNIVERSITI PUTRA MALAYSIA

OBSTACLE AVOIDANCE OF A MOBILE ROBOT USING FUZZY LOGIC CONTROL

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To everybody who encouraged and helped me to finish this project

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During the past several years fuzzy logic control (FLC) has emerged as one of the most active and fruitful areas for research in the application of intelligent system design. Presently, fuzzy logic has found a variety of applications in various fields ranging from industrial process control to medical diagnosis and securities trading. Most notably, a fuzzy logic system has been applied to control nonlinear, time-varying, ill-defined systems, to control systems whose dynamics are not exactly known, as servomotors position control, and robot arm control, and to manage complex decision-making or diagnostic systems.

This project has the objective of designing a fuzzy logic controller, which will be used to control the navigation process of an autonomous mobile robot in a completely unstructured environment. The navigation algorithm is proposed for static obstacles and with no priori knowledge about the environment. In addition, an on-line path planning is

used while navigation. The controller will have its inputs from the sensors that will be mounted on the robot. The number of sensors used is five where, three of them will be on the front side of the robot, whereas, one on the left side and one on the right side.

The FLC was designed using three different fuzzifiers (triangular, trapezoidal and Gaussian) to represent the sensor readings values so that they can be interpreted by the inference mechanism. Moreover, two different implication methods (Mamdani minimum and Mamdani Product) implications are used in the interpretation of the IF-THEN rules in the rule-base. Depending on the number of fuzzy sets used to represent the sensor readings, the total number of control rules used in the design was 243 at the first stage and then reduced to 108. In other words, if the number of fuzzy sets used to represent each sensor reading is three (far, near, and very near) then the total number of rules is 243 which is (3^5). On the other hand, if the left and right sensors reading values were represented using only two fuzzy sets (far and near) then the total number of rules is 108 i.e. ($3^3 * 2^2$). In addition, two defuzzification strategies (center of gravity and center average) were used to get the output of the FLC in a crisp value.

It was observed that the triangular fuzzifier, center average defuzzification method, and the Mamdani minimum implication method with a total number of 108 rule are the best choices for the design.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia Sebagai memenuhi keperluan ijazah Master Sains

PENGELAKAN HALANGAN ROBOT MOBIL DENGAN MENGGUNAKAN PENGAWALAN LOGIK FUZZY

Oleh

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Dalam masa beberapa tahun kebelakangan ini pengawalan logik fuzzy telah berkembang sebagai salah satu bidang paling aktif dan sangat berkesan dalam pengunaan rekabentuk sistem kecerdasan. Pada masa sekarang, fuzzy telah membolehkan pelbagai kegunaan dalam banyak bidang, iaitu bermula dari pengawalan pemprosesan industri ke pemeriksaan perubatan dan perdagangan keselamatan. Yang paling ditumpukan, satu sistem logik fuzzy telah digunakan untuk pengawalan tidak linear, pengubahan masa, sistem bermasalah, untuk mengawal sistem-sistem dinamik yang tidak begitu dikenali sebagai pengawalan kedudukan servomotor, dan pengawalan tangan robot, dan untuk menangani pembuat keputusan yang kompleks atau sistem-sistem pemeriksaan.

Projek ini mempunyai objektif merekabentuk satu pengawal logik fuzzi, yang akan digunakan untuk mengawal proses pemanduan satu robot mobil autonomous dalam satu alam tidak berstruktur sempurna. Algoritma pemanduan dicadangkan untuk halangan-halangan berstatik dan dengan ketiadaan pengetahuan tentang alam. Lebih-

lebih lagi, satu perancangan jalan on-line digunakan semasa pemanduan. Pengawal ini mempunyai masukan-masukannya dari pengesan-pengesan yang dipasang pada robot. Bilangan pengesan ialah lima, dimana tiga akan digunakan di sebelah depan manakala satu di sebelah kiri dan satu lagi sebelah kanan.

FLC direka dengan menggunakan tiga fuzzifier yang berbeza (segitiga, trapezium dan Gaussian) untuk mewakili nilai-nilai bacaan pengesan supaya mereka dapat diterangkan oleh mekanisma dugaan. Tambahan lagi, dua cara implikasi yang berbeza (Mamdani minima dan Hasil Mamdani) digunakan dalam penerangan cara IF-THEN. Bergantung kepada bilangan set-set fuzzy yang digunakan untuk mewakili bacaan-bacaan pengesan, bilangan peraturan kawalan yang digunakan dalam rekabentuk ialah 243 sebagai peringkat pertama dan kemudian dikurangkan ke 108. Dalam perkataan yang lain, jika bilangan set-set fuzzy yang digunakan untuk mewakili setiap bacaan pengesan ialah tiga (jauh, dekat dan sangat dekat) maka jumlah bilangan peraturan ialah 243 yang mana ialah (3^5). Sementara itu, jika nilai bacaan pengesan kanan dan kiri diwakili hanya dengan dua set fuzzy (jauh dan dekat) maka jumlah bilangan peraturan ialah 108, contohnya ($3^3 * 2^2$). Lebih-lebih lagi, dua strategi pendefuzzian (tengah graviti dan tengah purata) digunakan untuk mendapatkan keluaran FLC dalam nilai tertentu.

Dapat kami perhatikan bahawa fizzifier segitiga, cara pendefuzzian purata tengah dan cara implikasi minima Mamdani dangan jumlah bilangan peraturan 108 adalah pilihan yang terbaik untuk rekabentuk.

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LIST OF SYMBOLS AND ABBREVIATIONS

AMR	Autonomous Mobile Robot
CFR	Calculus of Fuzzy Rules
COG	Center of gravity
FKBC	Fuzzy Knowledge Base Control
FL	Fuzzy Logic
FLC	Fuzzy Logic Controller
fls	Front Left Sensor
FLS	Fuzzy Logic System
fms	Front Medium Sensor
frs	Front Right Sensor
Gauss.	Gaussian
lss	Left Side Sensor
CCD	Charge Couple Device
MF	Membership Function
MIMO	Multi Input Multi Output
MISO	Multi Input Single Output
nl	Negative Large
NN	Neural Networks
ns	Negative Small
pl	Positive Large
ps	Positive Small
rss	Right Side Sensor
Trap	Trapezoidal
Tring	Triangular
VLSI	Very Large Scale Integration
z	Zero
MAPS	Modular Azimuth Position System
INS	Inertial Positioning System
GPS	Global Positioning System
AGV	Automated Guided Vehicle

CHAPTER I

INTRODUCTION

Prologue

To have a clear picture of fuzzy algorithms and its distinction it is necessary to study fuzzy logic and its related topics such as fuzzy sets, fuzzy control and fuzzy systems. Logic is the study of methods and principles of reasoning, where reasoning means obtaining new propositions from existing propositions. In classical logic, the propositions are required to be either true or false, that is, the truth value of a proposition is either 0 or 1. Fuzzy logic can be thought of as a convenient way to map an input space to an output space. Fuzzy logic can also be defined as an extension of multivalued logic. More widely, fuzzy logic is almost synonymous with the theory of fuzzy sets, a theory which relates two classes of objects with unsharp boundaries in which membership is a matter of degree. Among the most successful applications of the fuzzy set theory has been the area of fuzzy logic control. This means that fuzzy control has become one of the most important alternatives in control area especially when it is hard if not impossible to apply conventional approaches, such as the area of mobile robot navigation.

A fuzzy set is a generalization of a classical set by allowing the membership function to take any values in the interval [0,1]. In other words, the membership function of a classical set can only take two values (zero and one), whereas the membership function of a fuzzy set is a continuous function with range [0,1]. Fuzzy sets are one of the fuzzy concepts that have a direct relation with fuzzy logic systems. A fuzzy logic systems are defined to be knowledge-based or rule-based systems.

The main part of the project is to design a fuzzy logic controller, which is the main component of a fuzzy control system. More attention has been given to this part since the author has implemented a complete design process. The four elements, which compose the fuzzy controller, are discussed in detail. The designed controller will be used to control the navigation process of an autonomous mobile robot (AMR) in a completely unstructured environment.

Importance of the Project

There are several reasons behind using fuzzy logic control in controlling real time systems with uncertain, ambiguous or insufficient information about the system model and/or variables. Some of the reasons that attract researchers to study fuzzy logic systems and control are listed below:

- Fuzzy logic facilitates design systems that mimic human reasoning.
- Fuzzy logic systems accept data input from sensors then make decisions based on that input.
- Fuzzy logic is firmly grounded in mathematical theory. Combining multi-valued logic, probability theory and artificial intelligence.
- In general, fuzzy logic is best applied to non-linear, time varying, ill-defined systems that are too complex for conventional control systems to apply.

Using fuzzy logic to control AMR gives it the big challenge and real benefit. The AMRs are used in many areas, such as industrial, medical, and education. Below is a list of some of the areas in which mobile robots are used:

- Carry stuff to and from stores in hospitals and factories,
- Moving towards noise,
- Moving towards objects with high heat temperature or high light intensity,
- Collect things.

For these applications the mobile robot should detect the presence or absence of obstacles that may be encountered in the way of movement and therefore to avoid them.

Objective of the thesis

The main objective of this thesis is to design and simulate a fuzzy logic controller. The FLC will be used to control the navigation process of AMR in a completely unstructured environment. The robot will move from a current position to a desired destination. Using the five sensors that are mounted on its body, the robot will detect the presence or absence of obstacles in the way of movement. The reading of these sensors are the inputs of the FLC. Through the output of the FLC (orientation) the AMR will avoid any obstacle that may be encountered in the way while in motion.

The FLC was designed using three different fuzzifiers (triangular, trapezoidal and Gaussian) to represent the sensor reading values so that they can be interpreted by the inference mechanism. Moreover, two different implication methods (Mamdani minimum and Mamdani Product implications) are used in the interpretation of the IF-THEN rules in the rule-base. The number of control rules used in the design was 243 rules as a first stage of the design, then reduced to 108 rules depending on the number of fuzzy sets used to represent the sensors readings. In addition, two defuzzification strategies (center of gravity and center average) will be used to get the output of the FLC in a crisp value. The results of all these methods is obtained and discussed and the most appropriate one was chosen.

Thesis Layout

This thesis is organized into five chapters. Chapter I gives an introduction to the author's work and his objective of designing and constructing a fuzzy logic controller that will be used for the navigation process of an autonomous mobile robot in a completely unstructured environment.

Chapter II contains a literature review of mobile robot navigation, robot sensing, fuzzy logic and fuzzy logic control systems. The mobile robot navigation problem is defined. Its various methods are described together with a previous work in this area. Sensors, their classes, their role in robotics, and a description about some of them have also been described. In addition, the basic definition of fuzzy logic, use of fuzzy logic, and a comparison of a fuzzy logic control and the conventional methods is presented.

Fuzzy sets definition and properties, and operations performed on it is also presented. Moreover, membership function definition, parameters, and types is discussed. In addition, a description of fuzzy control, reasons and benefits of its usage is presented. A classification of fuzzy logic systems (FLS) and the creation of a fuzzy control system procedure is discussed in detail.

Chapter III contains the basic architecture of the designed FLC. The AMR description is also presented. In addition, the design procedure of the FLC is presented in detail. The flowchart of the software program is given. In this chapter, the types of membership functions used to represent the inputs and the output of the FLC, the rule-base construction, the different implications used, and the defuzzification strategies implemented are discussed.

Chapter IV contains the results obtained from testing of the FLC with a number of sets of input data using different fuzzification, implication, and defuzzification methods. Tables of the resultant output using the software program are presented. The behavior of the AMR for successive sets of data is presented. A number of surface views, which simulate the general behavior of the FLC obtained using the MATLAB fuzzy logic toolbox, are presented and discussed.

Chapter V presents a general conclusion about the work and recommendations for future work. In addition, the possible improvements are also presented.

CHAPTER II

LITERATURE REVIEW

Introduction

A good engineering approach should be capable of making use of all the available information effectively. For many practical problems, however, an important portion of information comes from human experts which is usually not precise and is represented by fuzzy terms like small, large, not very new, and so on. In addition, in controlling complex systems such as mobile robot navigation, we are faced with the problem of inadequate modeling of the systems, a large quantity of uncertain sensory measurements that are difficult to interpret accurately, and lacking efficient computations of control actions to achieve a desired performance of the systems. This means that, effective control of mobile robots and their associated sensors demands the synthesis and satisfaction of several complex constraints and objectives in real-time, particularly in unstructured, unknown, or dynamic environments such as those typically encountered by outdoor mobile robots. The publication of Professor Zadeh (Zadeh,1965) on fuzzy sets has spurred a great interest in the development of fuzzy logic controllers as an alternative to existing advanced model-based controllers for controlling such complex systems. Fuzzy sets were first advocated by Professor L.A. Zadeh in 1965. Besides a few specialists, the world did not pay much attention to fuzzy sets for the first 10 years, but recently there has been a rapid growth in the number of research work and papers devoted to them (Terano et al., 1992). This rapid progress in the recent years was motivated by the practical success of fuzzy control in consumer products and industrial process control. In addition, researchers are trying to explain why the practical results are good, systematize the existing approaches, and develop more powerful ones. Therefore, the whole picture of fuzzy systems and fuzzy control theory becomes clearer.

Mobile Robot Guidance Navigation

Overview

Two major areas of research for mobile robots or autonomous vehicles are navigation and guidance (Griswold and Eem, 1990). The goal of autonomous mobile robotics is to build physical systems that can move purposefully and without human intervention in unmodified environments i.e., in real world environments that have not been specifically engineered for the robot (Saffiotti, 1997). The use of mobile autonomous agents is becoming increasingly popular for a variety of applications. Recently such systems have been used in integrated manufacturing, surveillance, and map generation for environmental clean-up (Pirjanian and Christensen, 1995). However, despite the impressive advances in the field of autonomous robotics in recent years, a number of problems remain. Most of the difficulties originate in the nature of real-world environments. The main challenge of today's autonomous robotics is to build robust control programs that reliably perform complex tasks in spite of the environmental uncertainties.