UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF A MOBILE ROBOT LOCAL NAVIGATION SYSTEM BASED ON FUZZY-LOGIC CONTROL AND ACTUAL VIRTUAL TARGET SWITCHING

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By

OMID REZA ESMAEILI MOTLAGH

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirement for the Degree of Master of Science

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DEDICATION

I dedicate this dissertation to my parents

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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December 2006

Chairman: Tang Sai Hong, PhD

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Robot local path planning in an unknown and changing environment with uncertainties is one of the most challenging problems in robotics which involves the integration of many different bodies of knowledge. This makes mobile robotics a challenge worldwide which for many years has been investigated by researchers.

Therefore in this thesis, a new fuzzy logic control system is developed for reactive navigation of a behavior-based mobile robot. The motion of a Pioneer 3TM mobile robot was simulated to show the algorithm performance. The robot perceives its environment through an array of eight sonar range finders and self positioning-localization sensors. The robot environment consists of walls and dead end traps from any size and shape, as well as other stationary obstacles and it is assumed to be fully unknown.

Robot behaviors consist of obstacle avoidance, target seeking, speed control, barrier following and local minimum avoidance. While the fuzzy logic body of the algorithm performs the main tasks of obstacle avoidance, target seeking, and speed adjustment, an actual-virtual target switch strategy integrated with the fuzzy logic algorithm enables the robot to show wall following behavior when needed. This combinational approach which uses a new kind of target shift, significantly results in resolving the problem of multiple minimum in local navigation which is an advantage beyond the pure fuzzy logic approach and the common virtual target switch techniques.

In this work, multiple traps may have any type of shape or arrangement from barriers forming simple corners and U-shape dead ends to loops, maze, snail shape, and many others. Under the control of the algorithm, the mobile robot makes logical trajectories toward the target, finds best ways out of dead ends, avoids any types of obstacles, and adjusts its speed efficiently for better obstacle avoidance and according to power considerations and actual limits.

From TRAINER Software and Colbert Program which were used in the simulation work, the system managed to solve all the problems in sample environments and the results were compared with results from other related methods to show the effectiveness and robustness of the proposed approach.

Abstrak tesis yang dikemukakan kepada Senat University Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PEMBANGUNAN SISTEM PEMANDUAN TEMPATAN ROBOT BERGERAK BERASASKAN KAWALAN LOGIK-KABUR DAN PERTUKARAN SASARAN SAHIH-MAYA

Oleh

OMID REZA ESMAEILI MOTLAGH

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Masalah yang paling kerap dihadapi dalam robotik dan melibatkan integrasi dari pelbagai bidang ilmu adalah perancangan laluan tempatan robot di dalam persekitaran yang mempunyai banyak ketidakpastian dan dinamik. Ini menyebabkan robotik bergerak menjadi cabaran global yang dikaji oleh berbagai penyelidik selama ini.

Justeru itu, sebuah system kawalan logik-kabur pemanduan reaktif telah dibangunkan untuk sebuah robot bergerak yang berasaskan kelakuan. Pergerakan sebuah robot bergerak Pioneer 3TM telah disimulasikan untuk menunjukkan keupayaan algoritma. Robot tersebut mengenalpasti persekitarannya melalui suatu susunan lapan deria sonar dan deria penempatan-kedudukan diri. Persekitaran robot tersebut terdiri daripada pelbagai dinding dan perangkap dari segi saiz dan bentuk, dan juga penghalang lain yang tidak diketahui.

Tingkahlaku robot terdiri daripada pengelakan halangan, pencarian sasaran, kawalan kelajuan, penyusulan sekatan dan pengelakan minimum tempatan. Apabila badan logic-kabur dari algoritma menjalankan tugas utama seperti pengelakan halangan, pencarian sasaran dan perubahan kelajuan, suatu strategi pertukaran sasaran sahih-maya yang berintegrasi dengan algoritma logik-kabur membolehkan robot itu menunjukkan kelakuan penyusulan dinding pada masa yang diperlukan. Cara combinasi ini mengunakan peralihan sasaran yang baru dapat memberi keputusan yang sangat baik di dalam penyelesaian masalah pemanduan tempatan berbagai minimum. Cara ini mempunyai kebaikan yang melebihi cara logik-kabur tulen dan teknik pertukaran sasaran maya biasa.

Dalam usaha ini, perlbagai perangkap yang mungkin mempunyai sebarang jenis bentuk atau penyusunan sekatan yang membentukkan sudut biasa dan bentuk U yang mati hujung, gelung, pagar sesat, bentuk siput, dan lain-lain. Dibawah kawalan algoritma, robot bergerak ini membentukkan trajektori logik terhadap sasaran, mencari laluan yang paling sesuai untuk keluar dari mati hujung, mengelakkan perlbagai jenis halangan dan menukarkan kelajuan dengan berkesan untuk mengelakkan halangan sambil mengambilkira kuasa dan had sebenar.

Dari perisian TRAINER dan Program Colbert yang telah digunakan dalam kerja simulasi, sistem tersebut telah berjaya menyelesaikan semua masalah dalam persekitaran sampel dan hasil yang didapati telah dibandingkan dengan hasil dari pengunaan teknik lain untuk menunjukkan keberkesanan dan kekuatan cara yang dicadangkan.

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Finally I would like to thank my parents for their great help, care, and financial support, during my studies. I would not have managed without them. I also thank all my friends who were great assets and helped me throughout the work.

I certify that an Examination Committee met on 27 December 2006 to conduct the final examination of Omid Reza Esmaeili Motlagh on his Master of Science thesis titled "Development of a Mobile Robot Local Navigation System Based on Fuzzy-Logic Control and Actual-Virtual Target Switching" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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Date: 8 FEBRUARY 2007

DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

OMID REZA ESMAEILI MOTLAGH

Date: 9 JANUARY 2007

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CHAPTER 1

INTRODUCTION

1.1 Preface

Autonomous mobile robots are defined as robots capable of intelligent motion and action without requiring either a guide to follow or a tele-operator control, which involves the integration of many different bodies of knowledge. This makes mobile robotics a challenge worldwide. Autonomous robots should be able to perceive the environment and according to a navigation program stored in their memory can navigate by themselves therefore in the other word; an autonomous robot is capable of detecting objects by means of sensors or cameras and of processing this information into movement without a remote control (Kristof, 2005).

Autonomous mobile robots are used in various applications such as in automatic freeway driving (Ken-ichi, 2002), cleaning of hallways (Nagrath, 1997), and exploration of dangerous regions (Tilleme, 1993). All these applications demand robust and adaptable methods for path planning which is defining a route for the mobile robot from an initial start point called robot home to a target where some work need to be done by the robot.

Usually for autonomous navigation, especially where the environment is unknown, like an exploratory mission of an army robot, planning is online or also called local navigation.

1.1.1 Local navigation

Path planning is one of the key issues in mobile robot navigation. Path planning is traditionally divided into two categories, global path planning and local path planning. In global path planning also called deliberative, prior knowledge of the workspace is available but in local path planning there is no prior knowledge available and the environment is assumed to be fully unknown.

Mobile robot local path planning or also called reactive navigation in an unknown and changing environment with uncertainties is one of the most challenging problems in robotics. For real-time autonomous navigation, the robot should be capable of the followings:

(1) Sensing its environment.

(2) Interpreting the sensed information to obtain the knowledge of its position and the environment.

(3) Planning a real-time route from an initial position to a target with obstacle avoidance.

(4) Controlling the robot direction and velocity to reach the target.

There are many approaches to real-time local navigation that deal with one or more related issues and try to tackle the problem in their own way. Some of the online approaches to path planning include wall following method (Andrew, 2002), virtual target approach (Xu, 1999), land mark learning (Krishna, 2001), edge detection (Feng, 1997), artificial potential field methods (Mauro, 2001), vector field histogram methods, graph-based methods, dynamic window approaches (Oliver, 1999), neural network based methods (Billur, 2000 and Thrishantha, 2005), fuzzy logic methods and many others.

1.1.2 Fuzzy logic control (FL Control)

Since the introduction of the fuzzy logic control in 1965 by Lotfi Zadeh of the university of California at Berkeley (Zadeh, 1965), this approach to mobile robot navigation and obstacle avoidance has been investigated by several researchers. Fuzzy systems have the ability to treat uncertain and imprecise information using linguistic rules. Thus, they offer possible implementation of human knowledge and experience, and have an advantage in that they do not require a precise analytical model of the environment. Therefore unique features of the fuzzy logic control has established this approach as the most appealing navigation technique, and still most of robot navigation methods, make use of one or more set of fuzzy logic rule bases as the kernel of their navigation algorithm.

1.1.3 Local minimum situation

Although fuzzy logic technique can significantly simplify navigation problems but there are situations happen in local navigation work space, where a pure fuzzy logic approach fails in taking appropriate action. Of these troublesome situations, obstacles forming a loop shape which is also called dead end trap is the most common problem.

The local minima situation occurs when a robot navigating past obstacles towards a desired target with no prior knowledge of the environment gets trapped in a loop. This happens especially if the environment consists of concave obstacles, mazes, and the like. Figure 1.1 shows how a mobile robot that uses pure fuzzy logic navigator gets trapped in a U-shape dead end. Because the rules that are fired for target attractor and obstacle repulsor modules give output actions that neutralize each other, the robot gets into an infinite loop or a local minimum (Krishna, 2001).

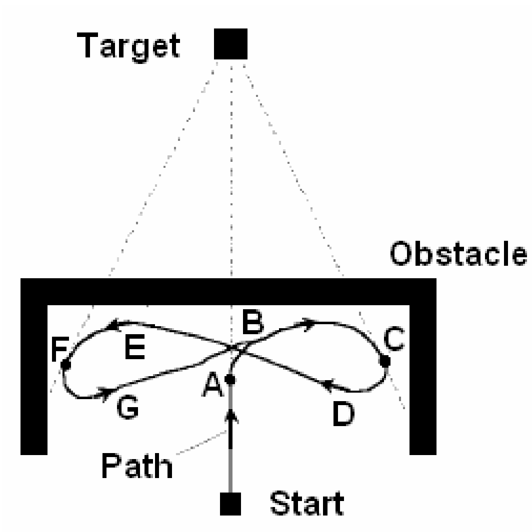

Figure 1.1: Inability of fuzzy logic control system in local minimum problem

Initially the robot moves directly toward the target due to target seeking behavior, because there is no obstacle sensed in front of the robot and this is an ideal shortest path to the target. This continues until point “A” Where the robot detects the obstacle at the direct front, it makes a right turn due to obstacle avoidance behavior that results to wall following until robot reaches the point “C”.

This is because until this point both the target and obstacle are at the left hand side of the robot. But as the robot in passing by point “C”, the target is going to be at right hand side of the robot, while the obstacle is still at the left hand side. Therefore due to both target seeking and obstacle avoidance behaviors the robot wants to go back toward the target (point “D”). The result of this behavior is that the robot wanders indefinitely in the dead end trap. The situation is even worse when mobile robot encounters two or more dead ends in row forming a more complicated situation which is called “multiple minimum” in this thesis.

1.2 Problem statement

There are many previous approaches to minimum avoidance in local navigation which are usually a combination of fuzzy logic with other techniques like “virtual target” and many others. But they all have shortcomings in multiple minimums situation which is the problem to be investigated and resolved in this thesis.

The methods reviewed in chapter 2 were able to tackle the minimum problem but showed lack of robustness when more complicated situations occurred (multiple minimum). Therefore a robust approach to the problem is required.

Among all the methods a combinational method developed by (Xu, 1999) showed better properties in minimum avoidance and the robot made more logical trajectories. Figure 1.2 shows how the robot can get out of the dead end trap while pure fuzzy logic control system shown in Figure 1.1 was not able to exit the same trap. In order to find a way to get out of dead end traps in this method, the real target should be ignored for a while and the robot assumes another virtual target somewhere else in the way that makes the robot temporarily go through wall following behavior instead of continuing the limit cycles and therefore the robot escapes the dead end trap.

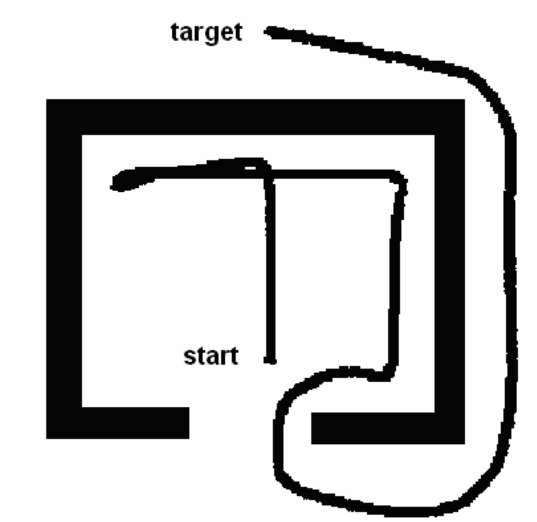

Figure 1.2: Virtual target technique assisting the FL control (Xu, 1999)

The combination of the virtual target technique here with the fuzzy logic body of the algorithm make up a set of 40 rules that meet the navigation requirements. Although this size of the rules set is average in terms of complexity compared to other methods but still it is not the major problem in this method.

The algorithm showed its major weakness when it failed to reach the goal in a concave and recursive U-shape environment shown in Figure 1.3. This is because after going out of the first dead end between “a” and “b”, the robot encounters another local minimum between “c” and “d” when it is still working under the influence of previous virtual sub goal created to guide the robot out of the first minimum trap at the location “a” and “b” (Wang, 2005).

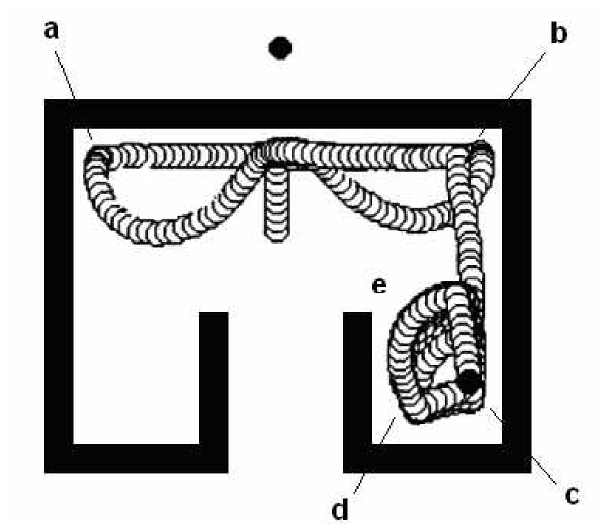

Figure 1.3: Algorithm based on virtual target shift, fails in the second dead end between “d” and “c” (Wang, 2005)

The fact that the robot does not realize it has had two dead end traps in a row, causes failure in exiting the dead end. The method is able to solve the minimum problem but still fails in multiple minimum.

Therefore the research problem in this thesis can be stated as; there is a problem in fuzzy logic local navigation caused by obstacles forming more than one dead end, which causes multiple minimum situations.

1.3 Research objectives

The objectives of this project are as follows:

(1) To develop a fuzzy logic based algorithm for robot local navigation in multiple dead ends. The method will be robust and applicable to any sort of minimum situations.

(2) To compare the algorithm with other previous works.

1.4 Scope of the study

The main contribution of the work is on resolving the problem of multiple minimum in fuzzy logic local navigation, where multiple dead end traps are considered as different possible arrangements of bars, barriers or walls forming any dead end shape from a simple U-shape dead end, to loops, maze, snail shapes and even more complicated shapes.

According to this approach the robot can find its way out from any kind of multiple dead-end, and there is no limit on the shape of the dead ends. Of course width and heights of barriers are important as well as other actual limits such as dimensional size, speed and wheel slippage of the robot.

The robot used to implement the system is a Pioneer 3TM, with an array of eight sonar sensors. The robot is not used physically and only simulation tests are performed by using the simulator software from ActivMedia. The programming language for the simulator is Colbert which is similar to C programming language and is used to convert the algorithm to a comprehensive machine code for the simulator.

The figures (results) shown in chapter 4, are taken from the simulator's window which demonstrate how the robot can efficiently finds its way out from different multiple dead ends and avoid minimum situations.

1.5 Organization of the chapters

The chapters in this thesis are presented and organized as below:

(1) Chapter 1 recalls the scientific environment of this thesis and highlights the research aims, objectives, scopes and limitations of the thesis.

(2) In chapter 2, most related works on minimum problem will be reviewed and their results, improvements and drawbacks will be discussed.