PATH PLANNING FOR CONSTANT SPEED ROBOT

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A project report submitted in partial fulfillment of the
requirements for a award of the degree of
Master of Engineering (Electrical-Mechatronics and Automatic Control)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

NOVEMBER 2006

DEDICATION

Dedicated to my loving mum, SITI PATIMAH, my loving wife, NORZARINA and my adorable kids SARAH and ADAM

ACKNOWLEDGEMENT

بسم الله الرحمن الرحيم

First and foremost, الحمـــد لله , thank to Allah, I praise God for the blessings endowed upon me and provide me perseverance and patience to complete the work entrusted to me.

My deep sense of gratitude is expressed here to Dr. Shahrum Shah Abdullah, for his valuable supervision, guidance and enlightening discussions throughout the period of my work and preparation for this thesis.

I am indebted to my mum, Siti Patimah Saleh, my wife, Norzarina Samua, my kids, Sarah and Adam without whose help, encouragement and patience I would never have gotten this thesis completed and who made it all worthwhile.

I would also like to thank my wonderful parents-in-law, Norhayati and Samua, who also gave me a great deal of support and encouragement. Special thanks are due to Andi Andrian Shah who willing to share his knowledge on mobile robot without which this work would have taken a lot longer or have been a lot shorter. Finally, thank you to all the other people who have supported me during the course of this work. To all my friends who provided help, suggestions and good accompany in the long nights spent in my office.

PUBLICATION

The following paper, based on the work described in this thesis, has been submitted for publishing:

1. Ahmad Takiyuddin Abdullah and Shahrum Shah Abdullah. "PATH PLANNING FOR CONSTANT SPEED ROBOT", 1st International Conference on Control, Instrumentation & Mechatronics CIM'07. (Verbally accepted for oral presentation)

ABSTRACT

The purpose of this thesis is initially to present an implementation of a guidance algorithm based on the geometrical analysis for the adoption of path planning problem. A mobile robot (named toward its unique characteristic in this project as constant speed robot) moving at a constant speed and having a constant swerving ability is used in the analysis. The guidance algorithm is formed based on an initial direction and distance of the target location without considering the time taken by the robot to reach the desired destination. At the moment, the guidance algorithm managed to assist the robot to reach the desired destination, within a certain small error tolerance. The development of the path planning algorithm is initially presented by the geometrical analysis and it is then analyzed by simulation using Matlab. The simulation analysis is performed to prove the effectiveness and robustness of the guidance algorithm for the mobile robot. The performance of the guidance algorithm will be compared with an existing guidance algorithm based on kinematics geometry introduced by Lin [5] and with an alternative guidance strategy employing geometrical analysis and Matlab's simulation.

ABSTRAK

Tesis ini pada permulaannya bertujuan untuk mempersembahkan perlaksanaan algoritma berpanduan berasaskan analisis geometri untuk di adaptasikan di dalam permasalahan laluan terancang. Robot bergerak (dinamakan robot halaju malar mengikut sifat uniknya) bergerak dengan halaju malar dan mempunyai keupayaan belokan malar digunakan di dalam analisis ini. Algoritma berpanduan dibentuk berasaskan arah dan jarak awal lokasi sasaran tanpa mempertimbangkan masa yang diambil oleh robot untuk sampai ke tempat yang diinginkan. Sehingga apa yang dilaksanakan, algoritma berpanduan berjaya membantu robot untuk sampai ke destinasi yang diinginkan dengan toleransi salah yang kecil. Algoritma laluan terancang pada awalnya dipertingkatkan dengan analisis geometri dan kemudian dianalisis menggunakan Matlab. Analisis simulasi dilakukan untuk membuktikan keberkesanan dan kemantapan penggunaan algoritma berpanduan ke atas robot bergerak. Prestasi algoritma berpanduan akan dibandingkan dengan geometri kinematik yang diperkenalkan oleh Lin [5] dan alternatif startegi berpanduan dengan menggunakan analisis geometri dan simulasi Matlab.

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LIST OF ABBREVIATIONS

DOF	Degree of Freedom
AGV	Automatic Guided Vehicle
LOS	Line-of-sight
FCS	Future Combat System
DMA	Defense Mapping Agency

CHAPTER 1

INTRODUCTION

1.1 Introduction

According to Gallistel, [1] path planning is the process of determining and maintaining a course or trajectory of a mobile robot to a goal location. In a more elaborate definition, Levitt and Lawton [2] describes path planning as the process of answering the following three questions: (a) "Where am I?", (b) "Where are other places with respect to me?"; (c) "How do I get to other places from here?".

Path planning is a well-studied problem having an extensive history. It has been analyzed in the context of operations research, engineering, computer science as well as other fields. The mathematical equations have been studied intensively and many algorithms have been developed, typically using graph representations to determine a path in a known environment.

A plan cannot be generated by a planner and blindly executed by the robot without additional feedback. This would be courting error of the desired destination. Consequently, many approaches have been taken to try and cope with the uncertainty and non-monotonicity inherent in the problem.

There are a lot of mobile robot tasks such as path planning, obstacle avoidance, object detection, landmark recognition, position evaluation and etc. The interdisciplinary science that is closely related to the work of mobile robots include mathematics, Physics, control-theory, cybernetics, computer science, artificial intelligence, biology, psychology, sociology, philosophy and artificial life. The way in which control is applied and the exchange of information between the different tasks module constitute principal differences in the mobile robot systems are the most interested areas for the research. Some current state-of-the-art of the mobile robots in application or research is shown in **Figure 1.1**.

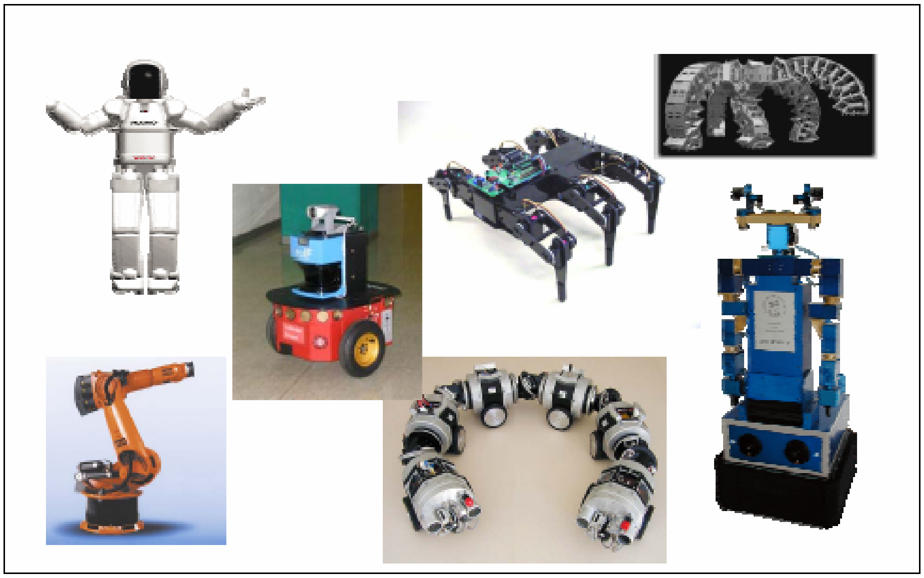

Figure 1.1: Some state-of-the-art of the mobile robots

The path planning for a mobile robot (a constant speed robot in this case) begins with the mathematical representation, followed by the guidance algorithm. Most mobile robot systems built to date still have had narrow focus of interaction with their environment. There are road-following vehicles, hall-following robots, guide-dog robots, etc. Little effort has been placed, however, on the development of a more general purpose robot capable of functioning well in both indoor and outdoor environment.

Mobile robotics in many respects is decidedly different from conventional robotics. It is worth describing some of the characteristics that distinguish it from the more conventional robot arms and manipulators. Some of the materials in the next explanation are adopted from Thorpe [3] and Andresen et. al. [4]. These characteristics include:

i) Environmental uncertainty
ii) Limited degrees of freedom
iii) Non-repetitive paths
iv) Incomplete model
v) On-line, continuous path planning
vi) Cumulative error
vii) Inherent inaccuracy

1.1.1 Environmental Uncertainty

The environmental uncertainty is simply explained as things are not always where they are expected to be, even when they are modeled. The situation is not only described that the robot's position is uncertain, but the location of objects will also have to be treated with skepticism. In addition, objects may have moved since their last observation or even be in a motion relative to the real application or the robot itself. This has to take note as a contrast to the robot manipulator which is highly in structured environment.

1.1.2 Limited Degree of Freedom

The number of degree of freedom (DOF) for the mobile robot is significantly less than those of robot manipulator. Assuming no translational motion is allowed in the vertical (up and down) direction (generally a necessity due to available locomotion systems – this would change if applied to legged, flying and submarine robots), this shown that the system has 2 DOFs of translation and 1 DOF of rotation. This is half of the 6 DOFs which is commonly found in the robot arm and wrist, a decided decrease in avoiding complexity.

1.1.3 Non-repetitive Paths

The path executed by an autonomous mobile robot is unlikely to be the same twice. Although the general route may be the same, changing conditions combined with positional errors usually will require the actual path taken to differ from the high level specifications each time it is traversed. If this were not so, as in some manufacturing situations, a stripe or wire following automatic guided vehicle (AGV) would be the robot of choice instead of an autonomous vehicle.

1.1.4 Incomplete Model

Any model by definition is incomplete; otherwise it would not be a model. Internal world representations for mobile robots are perhaps more incomplete than most, due to the larger and more unstructured world in which it operates when compared to industrial robots. Space-versus-time computational tradeoffs must be made in order to meet the real constraint of path planning, replanning and obstacle avoidance. Excess representational baggage is a luxury that generally cannot be afforded. It is difficult to find how any representation can be maintained, updated and accessed by algorithms that must process the data in real time with the existing hardware and yet is complete enough for accurate positioning of the robot, semantic interpretation of high level commands and objective statements, supporting multi-modal sensors, coping with uncertainty, handling goal recognition and choosing alternate path planning strategies dependent upon external factors.

Representational incompleteness can also be encountered when the robot is required to traverse areas in which it has never been before. The representation may have to be built dynamically from only partially correct possibly contradictory sensor data.

1.1.5 On-line, Continuous Path Planning

The robot must not close its ‘eyes’ for long while moving. Constant monitoring for collision avoidance is essential. In order to obtain enhanced performance, path planning should be maintained during robot motion, just in case unexpected event arises that would affect a path change. These might include such things as an unanticipated barrier (necessitating a detour) or the absence of a modeled obstacle (opening up a better path). This dynamic replanning must be conducted in real time.

1.1.6 Cumulative Error

Errors if left uncorrected will tend to increase. This is a typical condition of any type of dead reckoning system. A path cannot be computed and the robot sent off to execute it without frequently verifying and correcting the robot’s internal model of its position. Merely avoiding obstacles along the way is insufficient to guarantee that a robot will reach its goal or even recognize when it reaches it. Consequently information must be maintained in a representation that enables this type of updating to be performed.

1.1.7 Inherent Inaccuracy

The sensors relied upon by a mobile robots can easily yield the imprecise and inaccurate data. Even if the devices are highly accurate, (e.g. shaft encoders), the correspondence of the changes in the sensors to the changes in the robot’s environment may be poor (e.g. due to wheel slippage). Feedback in the traditional sense of control theory is not immediately applicable and can only be used as a guide to establish expectations for higher level processing.

1.2 Objective

The main objective of this project is to realize the movement of a mobile robot towards the desired destination in a simulation form. In order to accomplish the project, the following sub-objectives are necessary to be achieved before hand.

i) To implement and possibly improve the existing mathematical model of path planning for constant speed robot.
ii) To develop simulations for the movement of a constant speed object representing a constant speed robot.
iii) To implement existing guidance algorithm allowing the constant speed robot to reach the desired destination from its initial position

1.3 Scope of Work

The scope of work is to clearly define the specific field of the research and ensure that the entire content of this thesis is confined to the scope. It is begun with the implementation or possibly an improved implementation of existing mathematical model on a mobile robot for the following specifications:

i) Constant speed at all times with velocity of $v(t)$
ii) Swerving ability of $\alpha(t)$

The next step is to model a simulation to represent the mobile robot according to specifications. Then the mobile robot is visualized in a simulation to move from its initial position to the desired destination. Finally, the validation of the approach effectiveness is carried out in between the targeted and simulation destination. The scope of work can be described in terms of flowchart as shown in **Figure 1.2**.

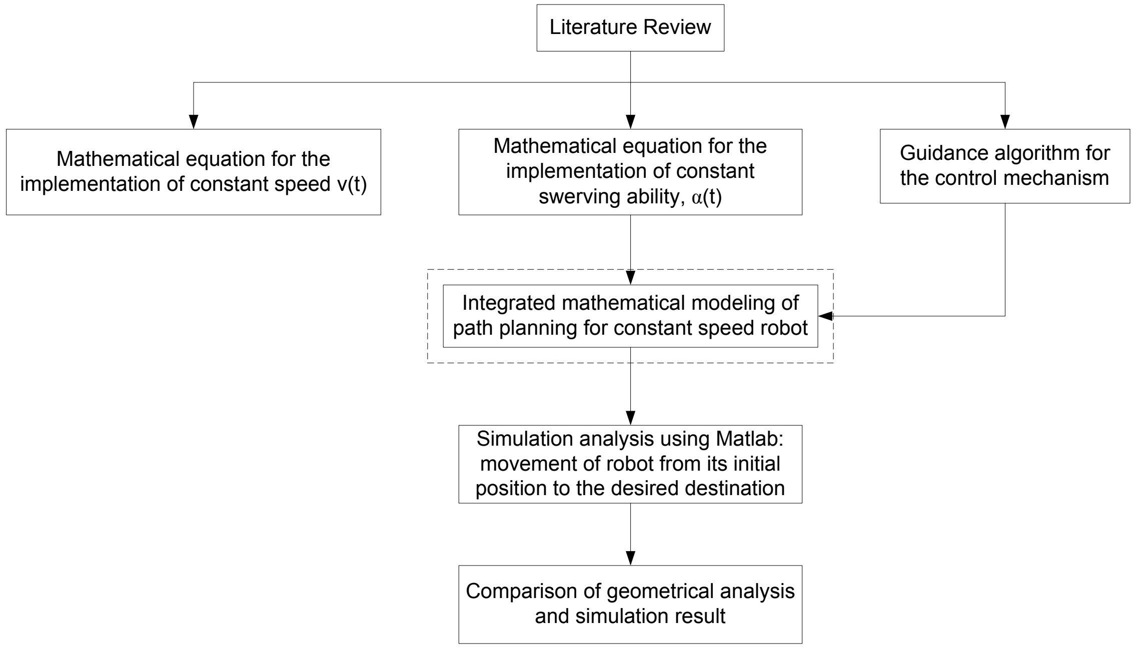

Figure 1.2: Flowchart represents the scope of work

1.4 Outline of the Thesis

The thesis presents the implementation of the existing mathematical model and guidance algorithm of path planning for the constant speed robot.

Chapter 2 is the literature review which introduces the overview of the existing robot research. The explanation begins with the related existing work which is found to be related to this project. This chapter then describes the existing control system implementation in the mobile robot and current interest in the robot research.

Chapter 3 provides the methodology that is used through out the work of this project. It covers the technical explanation of this project and the implemented technique of mathematical equations and guidance algorithm for both plotting and simulation.

Chapter 4 deals with the results of the geometrical analysis and Matlab's simulation. The multi-conditions of the execution for Matlab's simulation will also be presented in this topic.

Chapter 5 presents the conclusions of the project as well as some constructive suggestions for further development and the contribution of this project. The project outcome is concluded in this chapter. As for future developments, some suggestions are highlighted with the basis of the limitation of the effective mathematical equations and simulation analysis executed in this project.

Table 5.1: The project criticality toward the parameters

Criticality	**Parameters**
HIGH	Initial target angle (must be in first quadrant)
	Swerving constant (must be in first quadrant)
MEDIUM	Velocity constant
	Swerving constant in first quadrant
LOW	Initial position grid
	Initial direction (degree)
	Initial target distance, d(cm)
	Initial target angle in first quadrant

The initial work of plotting and Matlab's simulation have proved that the system is reliable and further works in varying the multi-condition parameters has strengthen the prove of its application. The varying of multi-condition parameters has also revealed the weakness that needs future improvement.

5.3 Future Development

The future development of this mobile robot is suggested to be chronologically executed as follows:

i) Implement the control system introduced by Hong. The work on mathematical equations was shown in subchapter 2.3.1.

ii) Implement the control system by using artificial intelligence techniques

The objective of these recommendations is to have the guidance algorithm of path planning that can reach the exact desired destination.

REFERENCES

1. Gallistel, C.R., "The Organization of Learning". 1990: MIT Press/Bradford Books.
2. Levitt, T.S. and D.T. Lawton, "Qualitative Navigation". AI Journal, August 1990. Vol. 44 (3): p. 305-361.
3. Thorpe, C., "Path Relaxation: Path Planning for a Mobile Robot". CMU Robotics Institute Technical Report CMU-RI-TR-84-5, April 1984.
4. Andresen, F.P., et al., "Visual Algorithms for Autonomous Navigation". Proc. IEEE Int. Conference on Robotics and Automation, St. Louis, Mo., 1985: p. pp. 856-861.
5. Lin, C.F.,"Modern Navigation, Guidance and Control Processing". 1991: Prentice Hall.
6. JohnL, "Military Aviation Webring: GLOSSARY/Abbreviations". Retrieved October, 15 2006 from http://www.vodoo.cz/hornet/glossary.html, 1998.
7. Shamos, I. and D. Hoey, "Closest Point Problems". 16th Annual Symposium on the Foundations of Computer Science, October, 1975: p. pp. 151-162.
8. Miller, D., "A Spatial Representation Systems for Mobile Robots". CH2152-7/85, IEEE, 1985: p. pp. 122-127.
9. Kirkpatrick, D., "Efficient Computation of Continuous Skeletons". Proceedings of the 20th Symposium on Foundations of Computer Science, 1979: p. pp. 18-27.
10. Iyengar, S., et al., "Learned Navigation Paths for a Robot in Unexplored Terrain". IEEE 2nd Conference on Artificial Intelligent Application, December 1985: p. pp. 148-155.
11. Brooks, R., "Planning Collision-free for Pick-and-Place Operations". The Int. Jour. of Robotics Research, 1983. vol. 2, no. 4: p. p.p 19-37.
12. Brooks, R., "Solving the Find-Path Problem by Good Representation of Free Space". IEEE Sys, Man and Cyber., 1983. SMC-13, no.3: p. pp 190-193.
13. Kuan, D.T., J. Zamiska, and R. Brooks, "Natural Decomposition of Free Space for Path Planning". Int. Conf. Robotics and Automation, St Louis Mo., 1985: p. pp. 168-173.

14. Lazano-Perez, T., "Automatic Planning of Manipulator Transfer Movements in Robot Motion: Planning and Control", ed. Brady et. al., 1982: p. pp. 499-535.

15. Moravec, H., "Robot Rover Visual Navigation". 1981: UMI Press.

16. Chatila, R. and J.P. Laumond, "Position Referencing and Consistent World Modeling for Mobile Robots". Proc. IEEE Int. Conference on Robotics and Automation, St. Louis, Mo., 1985. vol. 4, no. 1: p. pp. 59-66.

17. Giralt, G., "Mobile Robots:Artificial Intelligence and Robotics", ed. Brady, Gerhart, and Davidson, Springer-Verlag, NATO ASI series, 1984: p. pp. 365-394.

18. Crowley, J., "Navigation for an Intelligent Mobile Robot". CMU Robotics Institute Technical Report CMU-RI-TR-84-18, 1984.

19 http://education.yahoo.com/reference/dictionary/entry/adit,"Yahoo Dictionary". Retrieved November, 15 2006.

20. Brooks, R., "Visual Map Making for a Mobile Robot". Proc. IEEE Int. Conference on Robotics and Automation, St. Louis, Mo., 1985: p. pp 824-829.

21. Krogh, B. and C. Thorpe, "Integrated Path Planning and Dynamic Steering Control for Autonomous Vehicle". IEEE Conf. on Robotics and Automation, 1986: p. pp 1664-1669.

22. Krogh, B., "A Generalized Potential Field Approach to Obstacle Avoidance Control". SME-RI Technical Paper MS84-484, 1984.

23. Mitchell, J. and D. Keirsey, "Planning Strategic Paths Through Variable Terrain Data". Applications of artificial Intelligence, SPIE, 1984. vol. 485: p. pp. 172-179.

24. Moravec, H. and A. Elfes, "High Resolution Maps from Wide Angle Sonar". CH2152-7/85, IEEE, 1985: p. pp. 116-121.

25. Parodi, A.M., "Multi-Goal Real-time Global Path Planning for an Autonomous Land Vehicle using a High-speed Graph Search Processor". Proc. IEEE Int. Conference on Robotics and Automation, St. Louis, Mo., 1985: p. pp. 161-167.

26. Tachi, S. and K. Komoriya, "Guide Dog Robot". Robotics Research, 2nd Int. Symposium, ed. Hanafusa and Inoue, 1985: p. pp. 333-340.

27. Stentz, A. and S. Shafer, "Module Programmer's Guide to Local Map Builder for ALVan". CMU Computer Science Department, July 1985.

28. Keirsey, D., et al., "Multilevel Path Planning for Autonomous Vehicles". Applications of Artificial Intelligence, SPIE, 1984. vol. 485: p. pp. 133-137.

29. Hong, J. , et al.,"Image-based homing". Feb. 1992. volume 12(Issue 1): p. Page(s):38- 45.

30. Nise, N.S., "Control Systems Engineering". 3rd ed. 2000: John Wiley & Sons, Inc. pp 169-170.