SOLVING TRACKING AND REGULATION OF A MOBILE ROBOT

MOHD FEKRI BIN AB HALIM

This report is submitted in partial fulfillment of the requirements for the award of
Bachelor of Electronic Engineering (Industrial Electronics) With Honours

Faculty of Electronic and Computer Engineering
Universiti Teknikal Malaysia Melaka

November 2008

UNIVERSTI TEKNIKAL MALAYSIA MELAKA
FAKULTI KEJURUTERAAN ELEKTRONIK DAN KEJURUTERAAN KOMPUTER

BORANG PENGESAHAN STATUS LAPORAN
PROJEK SARJANA MUDA II

Tajuk Projek : SOLVING TRACKING AND REGULATION PROBLEM OF A MOBILE ROBOT

Sesi Pengajian : 2008/2009

Saya .... MOHD FEKRI B AB HALIM ....
(HURUF BESAR)

mengaku membenarkan Laporan Projek Sarjana Muda ini disimpan di Perpustakaan dengan syarat-syarat kegunaan seperti berikut:

1. Laporan adalah hakmilik Universiti Teknikal Malaysia Melaka.

2. Perpustakaan dibenarkan membuat salinan untuk tujuan pengajian sahaja.

3. Perpustakaan dibenarkan membuat salinan laporan ini sebagai bahan pertukaran antara institusi pengajian tinggi.

4. Sila tandakan (√) :

☐ **SULIT*** (Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972)

☐ **TERHAD*** (Mengandungi maklumat terhad yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)

☑ **TIDAK TERHAD**

Disahkan oleh:

_____
(TANDATANGAN PENULIS)

Alamat Tetap: NO. 72 KG. CHABANG 3 BATU, 16370 SELASA BACHOK KELANTAN

Tarikh: 29 APRIL 2009

_____
(COP DAN TANDATANGAN PENYELIA)

NOOR ASYIKIN BT SULAIMAN
Pensyarah
Fakulti Kejuruteraan Elektronik Dan Kejuruteraan Komputer
Universiti Teknikal Malaysia Melaka (UTeM)
Karung Berkunci No 1752
Pejabat Pos Durian Tunggal
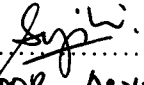76109 Durian Tunggal, Melaka

Tarikh: 29/4/09

"I hereby declare that this report is the result of my own work except for quotes a cited in the references. "

Signature   : ....

Author   : MOHD FERM B. AB HALIM

Date   : 09 APRIL 2009

"I hereby declare that I have read this report and in my opinion this report is sufficient in term of scope and quality for award of Bachelor Degree of Electronic Engineering (Industrial Electronic) with Honours. "

Signature   : ....

Supervisor name : NOOR ASYIKIN SULAIMAN

Date   : 29/4/09

DEDICATION

For my beloved family and friends

ACKNOWLEDGEMENTS

Firstly, I would like to express my gratitude to my supervisor, Ms/Madam Noor Asyikin binti Sulaiman for her endless encouragement, support, and guidance throughout this project.

Secondly I would like to express my heartfelt appreciation to all my fellow friends for his/her sharing the opinions and helps during completes on this project.

Last but not lest, deepest thank you and appreciation to my lovely family and my girlfriend, whose have been there to encourage me. Without them all, I would not walk through the hard time during this period.

ASTRACT

This project is to develop a stable controller that can solve both tracking and regulation of a mobile robot by using kinematics mathematical model. For tracking trajectory the linear and angular velocities are not converging to zero and maintain at constant speed, while for regulation trajectory linear and angular velocities are converging to zero. To solve this problem a single controller will be developed to solve both trajectory problems. This project starts by studying on tracking and regulation problem, then proceed by deriving the mathematical model for the controller. This project continues by transforming the mathematical model into MATLAB/SIMULINK to become a controller. Then start simulated and compare with the actual result with desired output response. The tracking control problem with saturation constraint for a class of unicycle-modeled mobile robots is formulated and solved using the back-stepping technique. With the proposed control laws, the robot can globally follow any path specified by a straight line, a circle or a path approaching the origin using a single controller. As demonstrated, the circular and parallel parking control problem is solved using the proposed controller. Computer simulations are presented using MATLAB/SIMULINK.

ABSTRAK

Projek ini adalah untuk membangunkan seorang pengawal yang stabil yang dapat menyelesaikan kedua-dua masalah penjejakan dan peraturan satu kepergerakan robot dengan menggunakan kinematik model matematik. Untuk masalah penjejakan halaju yang lurus dan bersudut tidak harus bertemu kepada sifar dan dikekalkan pada kelajuan malar dan untuk masalah peraturan kemestian halaju-halaju lurus dan bersudut bertemu kepada sifar. Untuk menyelesaikan masalah ini satu pengawal akan dimajukan untuk mengawal halaju lurus dan bersudut untuk pergerakan robot. Projek ini bermula dengan membuat kajian tengtang penjejakan dan peraturan masalah, kemudian meneruskan dengan pemilihan model matematik untuk pengawal. Projek ini diteruskan dengan menukarkan matematik model ke dalam bentuk MATLAB / SIMULINK menjadikannya satu pengawal. Kemudiannya, simulasi dan perbandingan antara hasil sebenar dengan respons pengeluaran yang dikehendaki. Masalah kawalan penjejakan dengan kekangan ketepuan robot-robot lincah dirumuskan dan menyelesaikan menggunakan teknik melangkah. Dengan mengunakan undang-undang kawalan, robot boleh mengikuti semua jenis jalan sama ada satu garis lurus, sebuah bulatan atau satu tindakan menghampiri asal menggunakan satu kawalan. Seperti yang ditunjukkan, tempat letak kereta bulat dan selari masalah kawalan diselesaikan menggunakan kawalan yang dihasilkan. Simulasi komputer dipersembahkan menggunakan MATLAB / SIMULINK.

TABLE OF CONTENTS

III   **MOTION CONTROL OF MOBILE ROBOT**

IV   **CONTROL LAWS OF A NON-HOLONOMIC WHEELED MOBILE ROBOT**

V   **SIMULATION RESULTS AND ANALYSIS**

LIST OF FIGURES

CHAPTER I

INTRODUCTION

1.1   Project Introduction

In recent years there has been an increasing amount of research on the subject of mobile robotics. Mobile robots are increasingly used in industry, in service robotics, for domestic needs (vacuum cleaners, lawn mowers, pets), in access the dangerous areas (space, army, nuclear-waste cleaning) and also for entertainment (robotic wars, robot soccer). Several controllers were proposed for mobile robots with non-holonomic constraints, where the two main approaches to controlling mobile robots are posture stabilization and trajectory tracking. The aim of posture stabilization is to stabilize the robot to a reference point, while the aim of trajectory tracking is to have the robot follow a reference trajectory.

For mobile robots trajectory tracking is easier to achieve than posture stabilization. This comes from the assumption that the wheel makes perfect contact with the ground, resulting in non-holonomic constraints, which means that not all the velocities are possible at a certain moment. An extensive review of non-holonomic control problems can be found in [1]. According to Brockett's condition [2] non-holonomic systems cannot be asymptotically stabilized around equilibrium using smooth

time-invariant feedback. Completely non-holonomic, drift less system are controllable in a nonlinear sense; therefore, asymptotic stabilization can be obtained using time-varying, discontinuous or hybrid control laws. An exponentially stable, discontinuous feedback controller was proposed by [3] and the point stabilization of mobile robots via state-space exact-feedback linearization using proposed coordinates was studied in [4]. Trajectory tracking is more natural for mobile robots.

Usually, the reference trajectory is obtained by using a reference robot; therefore, all the kinematics constraints are implicitly considered by the reference trajectory. The control inputs are mostly obtained by a combination of feed-forward inputs, calculated from reference trajectory, and feedback control law. Lyapunov stable time-varying state-tracking control laws were pioneered, where the system's equations are linearized with respect to the reference trajectory, and by defining the desired parameters of the characteristic polynomial the controller parameters are calculated. The stabilization to the reference trajectory requires a nonzero motion condition.

Ina trajectory-tracking state-feedback controller is combined with an observer that is used to estimate an unknown orientation error. Some of the solutions to the controller design solve both the trajectory-tracking and posture-stabilization (regulation) control problems, where the stabilization problem is usually converted to an equivalent tracking problem. In [5] a saturation feedback controller where saturation constraints of the velocity inputs are incorporated into the controller design is introduced. In the field of mobile robotics predictive approaches to path tracking also seem to be very promising because the reference trajectory is known beforehand. Most model-based predictive controllers use a linear model of mobile robot kinematics to predict future system outputs. In [6] a generalized predictive control is chosen to control a mobile robot, where a quadratic cost function penalizing the tracking errors and control effort is minimized. In [7] a model-predictive control based on a linear, time-varying description of the system is used.

The control law is again solved by an optimization of a cost function. The nonlinear predictive controller scheme for a path-tracking problem is proposed in [8]. Here, a multi-layer neural network is employed to model the nonlinear kinematics behavior of a mobile robot. However, the optimum solution of the control vector is still obtained by minimizing a cost function. This thesis deals with a differentially driven mobile robot and trajectory-tracking control on a reference trajectory that is a smooth twice-differentiable function of time.

The model predictive control law is based on a linearized error model obtained around the reference trajectory. The main idea of the control law is to minimize the difference between the future trajectory-following errors of the robot and the reference robot with defined, desired dynamics. The proposed control law is analytically derived; therefore, it is computationally effective and can be easily used in fast real-time implementations. The main advantages over predictive control are an error model based prediction and an explicitly obtained analytical control law.

Mobile robots with a steering wheel (unicycle) or two independent drive wheels are examples with substantial engineering interest. Most wheeled mobile robots can be classified as non-holonomic mechanical systems. Controlling such systems is, however, deceptively simple. The challenge presented by these problems comes from the fact that a motion of a wheeled mobile robot in a plane possesses three degrees of freedom (DOF)(x,y,and θ); while it has to be controlled using only two control inputs under the non-holonomic constraint. The methods used in recent years to solve mobile robot control problems can be classified into three categories.

The first category is the sensor-based control approach to navigation problems. The emphasis is on interactive motion planning in dynamic environments [9]. Because the working environment for mobile robots is unstructured and may change with time, the robot must use its on-board sensors to cope with the dynamic environment. Most reported designs following this approach rely on intelligent control schemes, such as fuzzy logic control [10] and neural-network learning control [11]. Obstacle motion

estimation and environment configuration prediction using sensory information are important for proper motion planning [12]. However, since a mobile robot responds to its surroundings in a reactive or reflexive way; the executed trajectory may not be globally optimized.

In the second category, the navigation problem is decomposed into a path planning phase and a path execution phase. A collision-free path is generated and executed based on a prior map of the environment. The executed path is planned using certain optimization algorithms based on a minimal time, minimal distance or minimal energy performance index. Methods for avoiding both static and moving obstacles have been reported in the literature [13]. In these methods, a collision-free path is planned according to the environment map space-time relations. The mobile robot must follow the planned path employing a path-following controller.

The third category follows the motion control approach, in which a desired trajectory must be tracked accurately. Among these, tracking controller designs employing a simplified linear model have been reported [14], [15]. Song and Li [16] developed an LQR controller based on a linearized state-space model. In their presentation, the tracking errors can be eliminated and the mobile robot can follow the specified trajectories. In the linear model approach, however, the controller works only when the linear velocity is not zero. Under such circumstances, it would be difficult to control the mobile robot to track the specified trajectory and in the mean time stop with the specified pose. Consequently a more generalized approach is desirable. Nonlinear system theory has been employed to solve this problem [17], [18]. Two main research directions employing nonlinear control design can be distinguished. The first, initiated by Bloch et al. [3], [19], used discontinuous feedback, whereas the second research direction used time-varying continuous feedback, which was first investigated by Samson [20]. Pomet [21] then proposed several smooth feedback control laws. However, though these solve the regulation problem, they were found to yield slow asymptotic convergence.

Using Barbalat's lemma or the backstepping method, control schemes have been proposed for mobile robots to globally follow special paths such as circles and straight lines. Similar results were obtained by Fliess et al. [22] using time reparametrization and the motion-planning properties of differentially flat systems. Despite this apparent advance, there exist several key restrictions on these applications:

In some studies on tracking problems [3], [4],, only certain special cases (e.g., straight lines or circles) are solved, where the tracked linear velocity or angular velocity must not converge to zero. These restrictions limit the range of applications and, more importantly, make it impossible for a single controller to treat the regulation problem and the tracking problem simultaneously.

1.2 Objectives of the project

The objective of this project is to develop a stable tracking and regulation controllers system. At the end, of this project, the controller for non-holonomic mobile robot is able to solve both tracking and regulation problems. The method used on this controller is based on kinematics model. Then, the simulation will be performed using MATLAB/SIMULINK.

1.3 Scopes of the project

This project was carried out within the following frame of work:
(i)   The non-holonomic mobile robot considered in this project is a tricycle-type mobile robot.
(ii)   This project considered only kinematics model.
(iii)   It is consider that the dynamics part of the mobile robot is neglected such as gravitational force, acceleration, mass, torque and
(iv)   All simulation works are to be conducted using MATLAB/SIMULINK software.

1.4   Methodology

Generally, the method used to accomplish this project is described in Figure 1.1. The first step is to study on tracking and regulation of non-holonomic wheeled mobile robot system. Next step is study on mathematical modeling of the robot based on kinematics equation. Then, the controllers are developed by transforming the mathematical equation into controller block, and then simulation is performed using MATLAB/SIMULINK. Last but not least, the actual output response is compared with the desired output response.
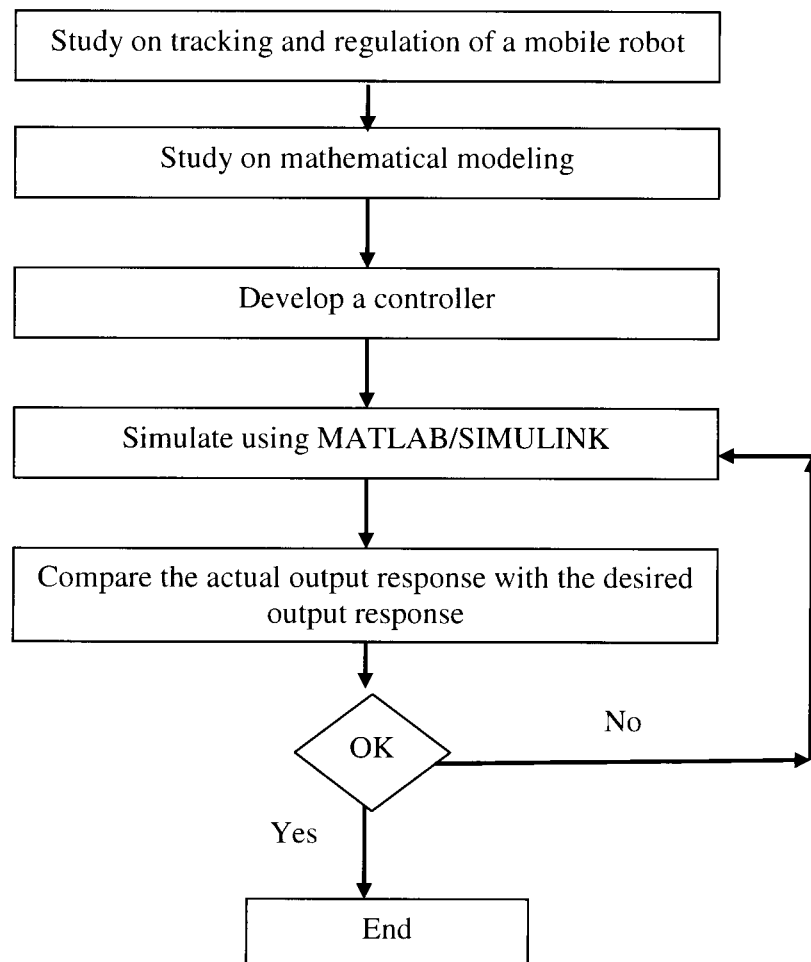

Figure 1.1: Methodology of the project.

1.5   Thesis outline

This thesis consists of six chapters. Chapter I tell about some background of the project, the objectives, the scope of studies and the methodologies. Chapter II contains the literature review on non-holonomic system and also on a number of control techniques applied to the mobile robot that were proposed by some researchers. Chapter III entails the kinematics modeling of the non-holonomic wheeled mobile robot system. Chapter IV follows by developing controller based on mathematical model discussed on Chapter III. Simulation results, analysis and discussion of the performance of the proposed controller are presented in Chapter V. The work is then concluded in Chapter VI with some suggestions and future works.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

This chapter will discuss on wheeled mobile robot, non-holonomic system and also on a number of control techniques applied to the mobile robot that were proposed by some researchers.

2.2 Mobile robot

Dealing with cooperative multi-robot systems, the most important requirement is the motion coordination among the robots that means, the robots have to keep a suitable relative configuration during the whole mission. Motion control is strictly related to the typology of the robots and to their kinematical and dynamical characteristics; in fact, wheeled robots (holonomic/non-holonomic), have different kinematical/dynamical characteristics and may give rise to different control problems.

2.3 Wheeled mobile robots

The wheel has been by far the most popular locomotion mechanism in mobile robotics and in man-made vehicles. It can achieve good efficiencies and need a relatively simple mechanical implementation. Usually, wheeled robots do not have balance problems (three wheels are sufficient to guarantee stable balance), thus, the research in the field focuses on the problems of traction and stability, maneuverability and control, that is, guaranteeing that the robot is able to move on all the desired terrains and that the robot wheels configuration enables sufficient control to the velocity of the robot. While designing a wheeled mobile robot, the main aspects concern the kind of wheels, their configuration and their actuation systems (eventual steering mechanisms). These parameters define the mobility characteristic of the robot. E.g., some robots result omni-directional, that is, they can instantaneously move in any direction along the plane not considering their orientation around the vertical axis.

However, these kinds of vehicles are uncommon because they need particular wheels (like spherical wheels or Swedish wheels) or mechanical structures. Other kinds of wheeled robots have a car-like structure, that is, they have four wheels (two of them on a steering mechanism) that permit a translation in the frontal direction of the vehicle and a rotation around a point that depends on the wheels steering angle. It is easy to understand that these kinds of vehicles are not omni-directional; in fact, supposing that the wheels do not slide on the floor, a car-like robot can not translate in its lateral direction. The most popular kind of mobile robot is the two-wheel differential-drive robot, that is, a robot with two wheels actuated by two independent motors with a coincident rotation axis. However, because the mobile robots need three ground contact points for the balance, for differential-drive robot, one or two additional passive castor wheels (i.e., free wheels rotating around a vertical axis) or slider points may be used for stability.

2.4   Kinematics Based Controllers

The kinematics controllers are developed based on a kinematics model of the robotic vehicle. This type of modeling usually leads to the use of the linear and angular velocities of the robots as control inputs. Although this approach is simpler than considering a dynamic model of the robot, the accuracy of the results may be compromised in real applications since several factors (such as the mass or the friction forces), are not being considered in the development of the controller. However, this has been shown to be a valid approach in several reported results. Here we state some of the latest such results. The work in [10] presents a kinematics model of a unicycle mobile robot and a controller that solves the regulation and tracking problems at the same time. In that paper the reference trajectory is assumed to be feasible (satisfies the robot's model), the controller uses the linear and angular speeds as control inputs and considers the input saturation in its development.

In [11] the authors develop a tracking control law (extended also for the regulation problem) for a mobile robot. The robot model is identical to the one described in [12] and the desired trajectory is also assumed to satisfy the robot's kinematics model. The difference is that [10] presents a controller that takes into account bounded kinematics model disturbances. Another result of interest is the one presented in [2] where the authors again use a kinematics model of the same robot as in [10] and [11]. In this case however, the controller is developed without any assumptions about the reference trajectory. The approach here is to design an estimator for the velocities that best approximate the movement of the target, even if it is not feasible by the robot. After these velocities are approximately calculated, the control inputs, which are the linear and angular velocities, are controlled to match the desired velocities given by the estimator.

In [16] the authors develop a procedure that can use any smooth existing kinematics controller to obtain a dynamic control law using a back-stepping technique. The controller they develop solves the problems of trajectory tracking, path following and point stabilization. In addition, the authors use Neural Networks to approximate the dynamics of the robot, making the system robust to bounded, un-modeled dynamic disturbances. The authors also present simulation results to show the performance of their controller. In these simulations they explicitly show the differences in performance between a kinematics controller, a dynamic controller without a neural network, and a dynamic controller implemented using neural networks.

In [17], the authors propose a sliding mode controller based on a dynamic model of a non-holonomic mobile robot. The controller, developed in polar coordinates, solves the tracking problem assuming that the reference trajectories are feasible. However, the authors make other assumptions in the development of the controller (angular variables of the robot must lie in trajectories can not cross universal frame origin, and the body and the universal frame can never be perpendicular to each other) that makes it unsuitable in some situations. A similar result can be found in [18], where Chwa proposes a sliding mode controller with a similar procedure to the previous work. The controller in this case solves the tracking and the position problems with the same assumption of feasible reference trajectories. The difference here is that the author avoids the previously mentioned assumptions by combining three controllers, two that act on the positioning (one for negative and one for nonnegative surge speed) and one that controls the heading of the plant.

In [19] the authors present experimental results performed on a two-wheeled mobile robot, while in [6] only simulation results are shown. Another interesting result is reported in [13], where the authors develop an adaptive kinematics and dynamic controller for the trajectory tracking problem, using a back-stepping technique. This controller solves the tracking problem and adds robustness to structured uncertainties of