# DEVELOPMENT AN INTELLIGENT CONTROLLER OF AN AUTONOMOUS MOBILE ROBOT

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**UNIVERSTI TEKNIKAL MALAYSIA MELAKA**
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For my lovely family, and those who I love and care

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# ABSTRACT

This project is proposed to develop a tracking controller for the dynamic model of unicycle mobile robot by integrating a kinematics controller and a torque controller based on Fuzzy Logic Technique. The main objectives are to prove the mathematical model which represents the tracking controller of the mobile robot by using the control law and design an intelligent controller for a unicycle mobile robot. This project is divided into two parts. The first part is to develop and prove the mathematical model of a unicycle mobile robot in the form of equations by using Matlab. Then, controllability and stability of the kinematic model is shown from the errors whether the mobile robot velocities reach the given velocity inputs, and a fuzzy logic controller such that provided the required torques for the actual mobile robot. Meanwhile, the second part is to develop the tracking controller by using fuzzy logic controller. Computer simulations are presented confirming the performance of the tracking controller and its application to different navigation problems.

# ABSTRAK

Projek ini dicadangkan adalah bagi membangunkan satu pengawal penjejakan untuk model dinamik bagi satu ekasikal robot dengan menyepadukan satu pengawal kinematik dan satu pengawal "*torque*" berdasarkan Logik Fuzzi. Objektif utama projek ini adalah membuktikan persamman kinematik dan dinamik yang digunakan sebagai model matematik bagi robot dengan menggunkan hukum. Satu pengawal cerdik juga akan dibina untuk robot tersebut. Projek ini dibahagikan kepada dua bahagian. Bahagian pertama adalah membangunkan dan membuktikan model matematik dengan menggunakan persamaan yang dibuktikan dalam program Matlab. Kemudian, kebolehkawalan dan kestabilan kinematik dan dinamik model dibuktikan daripada keputusan yang diingini iaitu halaju robot akan menjadi sama dengan halaju yang diberi. Bahagian kedua adalah bagi membangunkan penjejakan pengawal dengan menggunakan Pengawalan Logik Fuzzi. Simulasi komputer digunakan untuk mengesah prestasi pengawal penjejakan tersebut.

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| NO | TITLE | | PAGE |
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| FIS | - | Fuzzy Inference System | |
| TS | - | Takagi Sugeno | |
| GUI | - | Graphic User Interface | |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background Study

Autonomous mobile robots are robots which can perform desired task in free environments without any continuous guidance from human. These kinds of control problems are always gain attraction to researchers of control community. This is because autonomous mobile robots are widely used in industrial, military, household, space and science laboratory. Hence, performance, safety and reliability of the autonomous mobile robots are needed to be improved further.

When dealing with mobile robots or more specifically in unicycle mobile robots, the ideal rolling condition of the robot is needed to be considered. It is meant that the wheel of the robot is rolled without any slipping occurs and the sideways component of wheel velocity assumed to be set to zero so that the sideways slip could be eliminated [1], [10], [12], [13], [14], [16], [17], [18], [19]. Ideal rolling conditions is imposed to the nonholonomic constraints on the wheel and consequently on the vehicle motion [7], [12], [13], [14], [16], [17], [19]. A nonholonomic system can be said that a system in which a return to the original internal configuration does not guarantee return to the original system position.

In the past decades, a lot of study and methods had been carried out for the motion control problem of nonholonomic mobile robots which is based on their input and output dynamics [12]. Many types of control problems such as path following, trajectory tracking and point stabilization have been solved by using different types of methods. Lyapunov function was use by Kanayama [16] to solve the stability of tracking control for nonholonomic vehicles. Back-stepping technique was applied by Jiang and Pomet to the adaptive control of nonholonomic systems with unknown parameters [20]. In addition, many researchers use Fuzzy Logic Control and Neural Network approaches to design their nonholonomic mobile robots.

This project will develop a regulator as well as tracking controller for the dynamic model of unicycle mobile robot by integrating a kinematics controller and a torque controller based on Fuzzy Logic Technique. The tracking controller is present by using a control law such that the mobile robot velocities reach the given velocity inputs, and a fuzzy logic controller such that provided the required torques for the actual mobile robot. Computer simulations are presented confirming the performance of the tracking controller and its application to different navigation problems. Here, Simulink, Matlab is used to run simulation and the output is being observed to ensure that the unicycle mobile robot can be controlled appropriately.

## 1.2 Problem Statement

Many researchers from control community have carried out a lot of solution and design to improve the properties of autonomous unicycle mobile robots. However, most of the approaches have only focused on kinematics models of model robots, which its input is controlled by velocity, while paid less attention to the control problem of the nonholonomic dynamic system, where forces and torques are the true input.

When a mobile robot moving from a place to another, there might have some errors occur. For example, the mobile robot reaches a desire location with a longer distance or the path it goes has bent to right or left. This is due to the environment condition and the rolling effect of the robot’s wheel. Hence, the rolling effect must be concerned whether it is ideal or not.

There are many types of autonomous mobile robot with different degree of autonomy. Different robot can be autonomous in different ways. Many types of equations and approaches had used by many researchers on their research of autonomous mobile robot. Each of the equations and approaches which are used by them may be referred from other sources only and without any proving on the equation to show the controllability and observable.

## 1.3 Objectives

- To prove the mathematical models of unicycle mobile robot
- To develop tracking controller for unicycle mobile robot
- To design an intelligent controller for unicycle mobile robot by using Fuzzy Logic Control

## 1.4 Scopes

This project will be focused on unicycle mobile robot and the application of Matlab.

1. Prove the mathematical model for:
    a. Error
    b. Robot position

    of an autonomous mobile robot
2. Development of tracking controller structure by using Matlab / Simulink
3. Design an intelligent controller by using the Fuzzy Logic Controller

## 1.5 Methodology

There are 5 steps in developing the intelligent controller of the autonomous mobile robot. First, the mathematical models of the kinematic system are proved and verified by comparing the equations which were used by the researches that did the similar projects. Then the mathematical equations are used to build a model by using

Matlab. From the Matlab's result, the controllability of the model is confirmed. After that, a tracking controller will be developed based on the mathematic model that has been built previously. Designing the fuzzy logic controller is then followed when developing the tracking controller is succeeded.

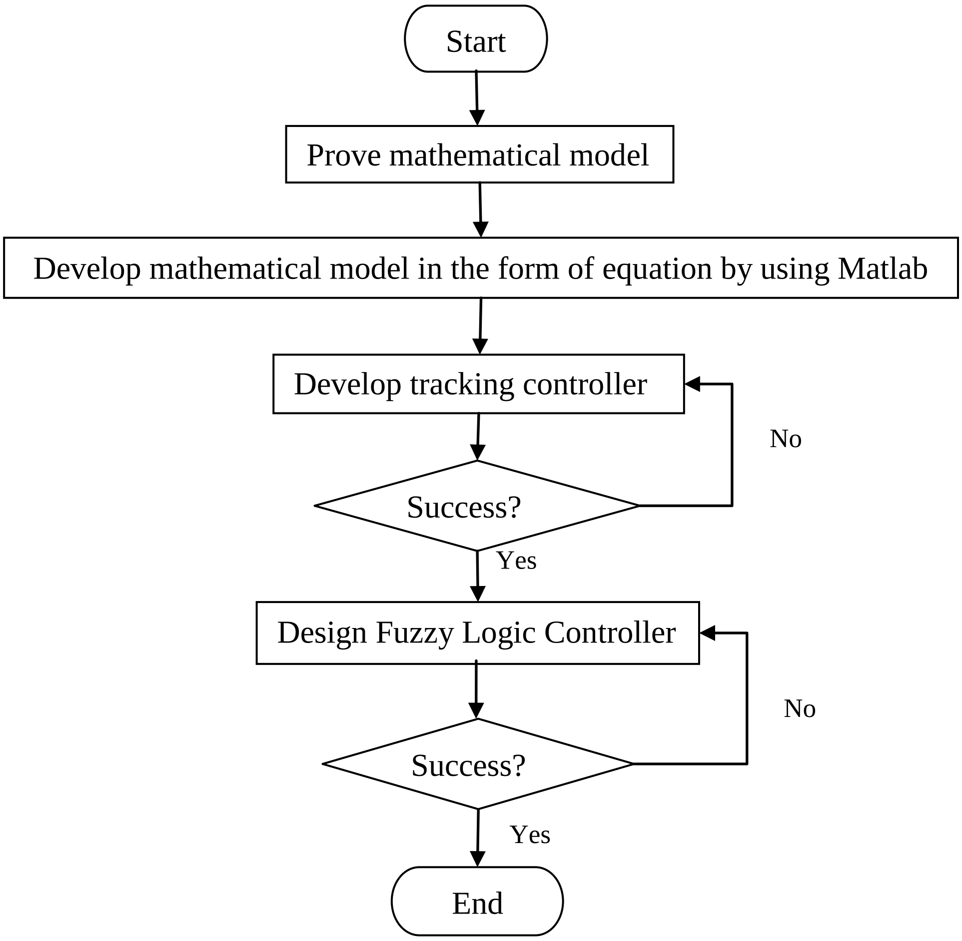


Figure 1.1 Project's flow chart

## 1.6 Report Structure

There will be five chapters in this project. Chapter One is briefed about the introduction of the project on autonomous mobile robot with nonholonomic constraints and the flow of the designs and the structure of this project.

In Chapter Two, literature review will be discussed related to the history and general knowledge on mobile robot. Some theories and methods applied in this project will be explained. Some case studies including the perspective and techniques used in previous researches are discussed. After that, it will discuss the fuzzy logic technique and the comparison between Mamdani and Sugeno's method on dealing a system. Finally, it also reviews some characteristic and function of Simulink which will be used later.

Chapter Three will discuss about the methodology used to prove and obtain the data and the flows to complete the project.

Chapter Four shows the result and discussion of the project. The equations used by the previous researches will prove and apply in this project. The block diagrams for the model in Simulink will also show in this chapter. The different between the finding and the expected result is compared and discussion will be made.

Chapter Five will discuss on the analysis related in this project. The analyses will use the test and error method. The best result in these tests will be used as an overall result in this project.

Lastly in chapter Six, a conclusion is generated. It covered the project progress, results, and suggestion that can be done for further improvement.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 The Mobile Robot

The term unicycle is often used in robotics and control theory which mean a generalized cart or car moving in a two-dimensional world. The first unicycle robot was built at Stanford University on 1986 [21] and was characterized as an unstable system and non minimum phase behavior in lateral and longitudinal axis system. This type of robot is not practically used due to the properties of it. Many experiments were carried out when unicycle mobile robot was first invented. Unfortunately, most of researchers failed due to its characteristic and some other reasons such as time constraints, unsuitable used of sensors, etc. Nevertheless, only the inverted pendulum problem for the longitudinal control of the unicycle mobile robot was successfully implemented [21].

These theoretical vehicles are typically shown as having two parallel driven wheels, one mounted on each side of their centre, and (presumably) some sort of offset castor to maintain balance. A physically realizable unicycle, in this sense, it is a nonholonomic system. Which means that it supposes will return to the original internal (wheel) configuration but it does not guarantee return to the original system (unicycle) position. In other words, the system outcome is path-dependent. It is also known as nonholonomic because of the uncontrollable rolling dynamic and inequality constrains on velocity or kinematics. However, this type of nonholonomic robots had giving out a lot of opportunity to the researchers from the control community to study the cases of unicycle robots.

Different types of experiments and researches had been done. For example: Jung-Ming Yang and Jong-Hwan Kim [13] had proposed a novel control algorithm to achieve trajectory tracking of a mobile robot with nonholonomic constraints. They used the computer-torque method for feedback-linearization of the dynamic equation and a theory of sliding mode for robust control. From their study, it was found that a mobile robot with two control inputs to asymptotically stabilize to a desired trajectory consisting of three posture variables.

Danwei Wang and Guangyan Xu [12] had analyzed the stability of the full state tracking problem of nonholonomic wheeled mobile robots under control laws based on the input-output dynamics. From the research, it was shown that the tracking error internal dynamics and zero dynamics play an important role in the full state tracking stability of such mobiles robots.

The model considered in this project is a unicycle mobile robot, it is symmetrical around the perpendicular axis and the center of mass is at the geometric center of the body. It consists of two driving wheels which are attached to the same axis and a passive wheel that is placed in front of the axis and normal to it. The passive wheel prevents the robot from tipping over as it moves on a plane. Therefore, the motion of passive wheel can be ignored in the dynamics of the mobile robot.

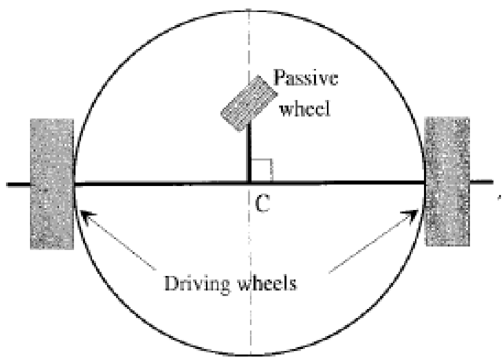


Figure 2.1 Unicycle Mobile Robot [13]

## 2.2 Nonholonomic Constraints on Kinematics Model

A nonholonomic system is a system in which a return to the original internal configuration does not guarantee return to the original system position. This type of system has restricted the motion of a system. Normally, a unicycle mobile robot is said as nonholonomic because the constraints of the system impose on their kinematics.

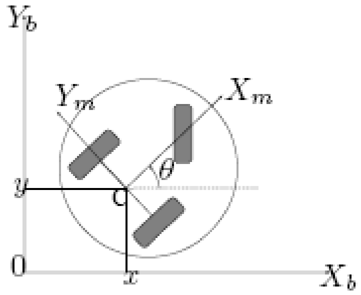


Figure 2.2 Coordinate of Mobile Robot [13]

Figure 2.2 shows the coordinate of the mobile robot. The planar motion of mobile robots under the nonholonomic constraint of ideal rolling condition is described as the equation of motion follows [10], [13], [14], [15], [17], [18], [19], [22], [23]:

$$\dot{q} = \begin{bmatrix} cos\theta & 0 \\ sin\theta & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} \upsilon \\ \omega \end{bmatrix} \tag{1}$$

Where $q = [x, y, \theta]^T$ is the vector of generalized coordinates which describes the robot position; $(\upsilon, \omega)^T$ is the vector of velocities, υ and ω are the linear and angular velocities respectively.

The dynamic model of the mobile robot is based on the Lagrange-d'Alembert Principle [17], [18], [19], [23]:

$$M(q)\ddot{q} + C(q, \dot{q})\dot{q} + g(q) = B(q)\tau + J^T(q)\lambda \tag{2}$$