FUZZY LOGIC CONTROL OF AN AUTONOMOUS MOBILE ROBOT

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

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Author : ……………………………………..
Date : ……………………………………….

"I hereby declare that I have read this report and in my opinion this report is sufficient in terms of the scope for the award of Bachelor of Electronic Engineering (Computer Engineering) With Honours."

Signature : …………………………………………

Supervisor's Name: PUAN SHARATUL IZAH SAMSUDIN

Date :

For my beloved family and my fellow friends.

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ABSTRACT

Nowadays, various control techniques have been proposed and are being researched to solve the motion control problems, but, the most reported designs rely on intelligent control approaches such as fuzzy logic and neural networks. In this project, based on the Fuzzy Logic Technique, this project will develop a tracking controller for the dynamic model of a unicycle mobile robot by integrating a kinematics controller and a torque controller. The tracking controller for the dynamic model will use a control law such that the mobile robot kinematics (velocity) reach the given velocity inputs and a fuzzy logic controller provided the required torques for the actual mobile robot. Computer simulations will be done using Matlab software, confirming the performance of the tracking controller and its application to different navigation problems. Since there are two types of method in fuzzy logic control, which are Mamdani and Sugeno. The Mamdani's approach will also differentiate with Sugeno's method in the scope of performance.

ABSTRAK

Pada masa kini, terdapat banyak jenis teknik kawalan yang telah dikenalpasti dan dikaji untuk mengatasi masalah kawalan, tetapi, rekabentuk yang dihasilkan oleh kawalan pintar biasanya berpusat pada Logik Fuzzi dan rangkaian saraf. Berdasarkan tenik logic fuzzy, projek ini akan membangunkan satu model kawalan pelancakan untuk model dinamik robot dengan mengintegrasikan kawalan kinematik dengan kawalan tork. Kawalan pelancakan untuk model dinamik akan menggunakan satu undang-undang kawalan sehingga kinematik pada robot (iaitu kelajuan) menjangkau kelajuan input dan kawalan Logik Fuzzi akan memberikan nilai tork yang sebenar pada robot yang sebenar. Simulasi computer akan digunakan dengan menggunakan Matlab untuk menentukan prestasi pelancakan kawalan dan aplikasi untuk masalah yang lain. Oleh kerana terdapat dua jenis kaedah dalam Logik Fuzzi iaitu Sugeno dan Mamdani, kedua-dua kaedah ini akan dibezakan melalui prestasi kedua-dua kaedah ini.

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CHAPTER I

INTRODUCTION

1.1 Introduction

Mobile robots are mechanical devices capable of moving in an environment with a certain degree of autonomy and posses nonholonomic properties caused by nonintegrable differential constraints while Autonomous robots are robots which can perform desired tasks in unstructured environments without continuous human guidance. Many kinds of robots have some degree of autonomy. Different robots can be autonomous in different ways. A high degree of autonomy is particularly desirable in fields such as space exploration, cleaning floors, mowing lawns, and waste water treatment.

Besides, various control techniques have been proposed and are being researched to solve the motion control problems, but, the most reported designs rely on intelligent control approaches such as fuzzy logic and neural networks. In particular, fuzzy logic has proven to be a convenient tool for handling real world uncertainty and knowledge representation. Fuzzy logic is also a true extension of conventional logic, and fuzzy logic controllers are a true extension of linear control models. Hence anything that was built using conventional design techniques can be built with fuzzy logic, and vice-versa. However, in a number of cases, conventional design methods would have been overly complex and, in many cases, might prove simpler, faster and more efficient. The key to successful use of fuzzy logic is clever combination with conventional techniques. Also, a fuzzy system is time-invariant and deterministic. Therefore any verification and stability analysis method can be used with fuzzy logic too.

Therefore, in this project, based on the Fuzzy Logic Technique, this project will develop a tracking controller for the dynamic model of a unicycle mobile robot by integrating a kinematics controller and a torque controller. The tracking controller for the dynamic model will use a control law such that the mobile robot kinematics (velocity) reach the given velocity inputs and a fuzzy logic controller provided the required torques for the actual mobile robot. Computer simulations will be done using Matlab software, confirming the performance of the tracking controller and its application to different navigation problems. The Mamdani's approach will also be applied and differentiate with Sugeno's method.

1.2 Objectives

In this project, one of the objectives is to develop a tracking controller for the dynamic model of a unicycle mobile robot by integrating a kinematics controller and a torque controller. Besides, its purpose is to simulate and differentiate between Mamdani's method and Sugeno's method in fuzzy logic control system.

1.3 Problem Statement

When advanced autonomous robots navigate in indoor environments, they have to be endowed with the ability to move through corridors, to follow walls, to turn corners and to enter open areas of the rooms. In attempts to formulate approaches that can handle real world uncertainty, researchers are frequently faced in developing systems that are difficult to control.

Nowadays, there are many researchers have carried out a lot solution and design to improve the autonomous unicycle mobile robots. However, most of the research only focused on kinematics models of mobile robot. Those robots have the controlled velocity inputs, but it is not focused to the controlled problem of nonholonomic dynamic system, where forces and torques are the true input.

Therefore, this project will be done to develop a tracking controller for the dynamic model of a unicycle mobile robot by integrating a kinematics controller and a torque controller, in order to solve this problem. Since there is two methods of fuzzy logic control systems, which is Mamdani's and Sugeno's method, this project will also compare the performance of both methods. Matlab software will be used to analysis this project in order to confirm the performance of the tracking navigation problems and its application to different navigation problems.

1.4 Scopes of the Project

A tracking controller for the dynamic model of a unicycle mobile robot based on the Fuzzy Logic technique will be developed. Besides, computer simulations are done by using Matlab software to confirm the performance of the tracking controller and its application to different navigation problem. Lastly, the comparison between Mamdani's method and Sugeno's method also will be done.

1.5 Methodology

In order to make sure that this project is finished and done systematically, some methodology needs to be applied and well arranged. The project consists of two controllers, which is the tracking controller for the mobile robot and the Fuzzy Logic controller of the mobile robot. The overall flowchart of the methodology that is being used is shown as in Figure 1.1 below:

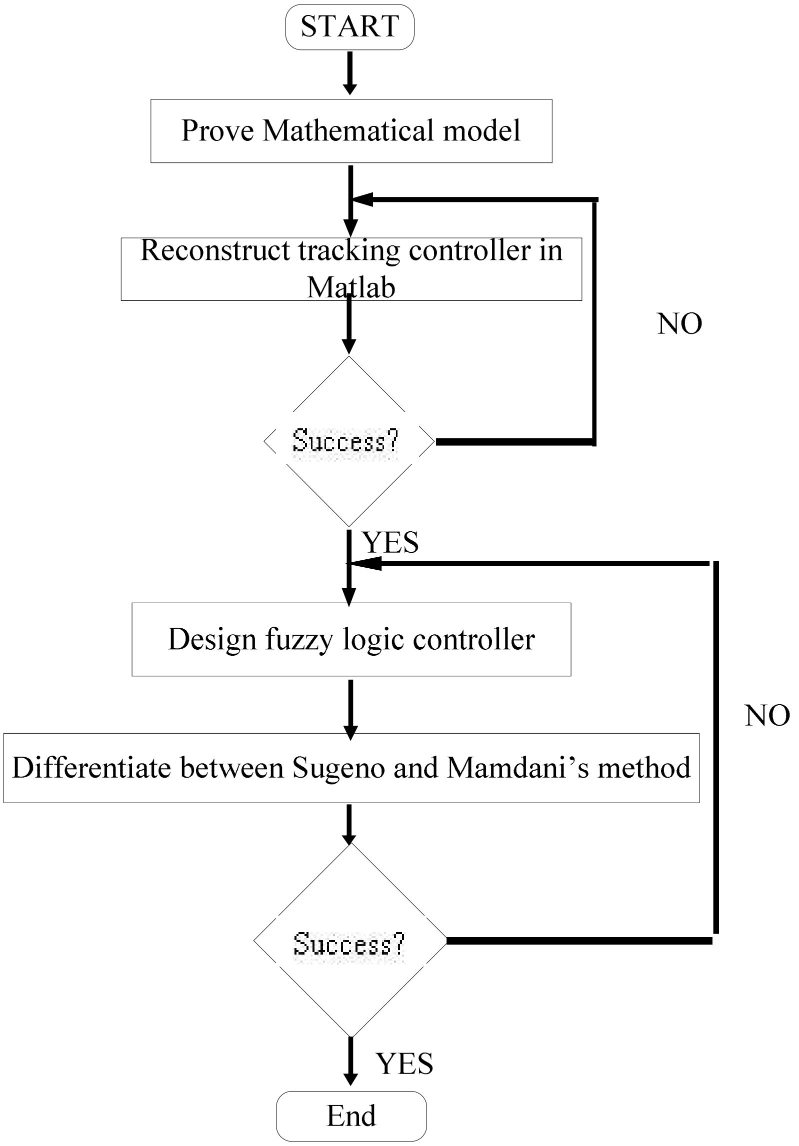

Figure 1.1: Basic flowchart of the project

CHAPTER II

LITERATURE REVIEW

2.1 The Mobile Robot

The term ‘autonomous robot’ has been ascribed to robotic systems to function without human supervision. [3] In this project, we assume that it is a unicycle mobile robot. The robot body is symmetrical around the perpendicular axis and the center of mass is at the geometric center of the body. It has two driving wheels fixed to the axis that passes through C and one passive oriental wheel that is placed in front of the axis and normal to it. The two fixed wheels are controlled independently by motors, and the passive wheel prevents the robot from tipping over as it moves on a plane. In what follows, we assume that the motion of passive wheel can be ignored in the dynamics of the mobile robot.

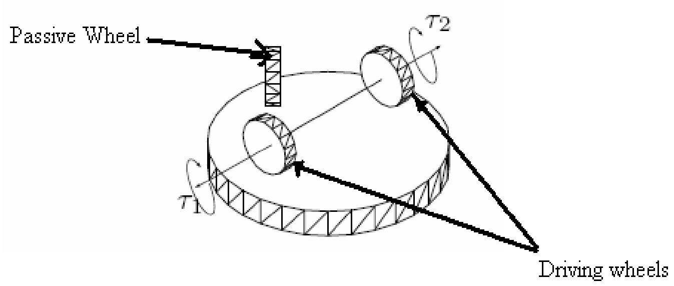

Figure 2.1: The autonomous mobile robot

2.2 Nonholonomic Constraints on Kinematics Model.

Non holonomic robots are most prevalent because of their simple design and ease of control. By their nature, non holonomic mobile robots have fewer degrees of freedom than holonomic mobile robots. These few actuated degrees of freedom in non holonomic mobile robots are often independently controllable or mechanically decoupled, further simplifying the low-level control of the robot. Since they have fewer degrees of freedom, there are certain motions they cannot perform. This creates difficult problems for motion planning and implementation of reactive behaviours. Holonomic however, offer full mobility with the same number of degrees of freedom as the environment. This makes path planning easier because there aren't constraints that need to be integrated. Implementing reactive behaviours is easy because there are no constraints which limit the directions in which the robot can accelerate. [4]

Normally, a unicycle mobile robot is said as nonholonomic because the constraints of the system impose on their kinematics. Besides, the order of the system is second order system, since the robot is nonholonomic. [6]

2.3 Kinematic Equation [6]

Firstly, the Xm – Ym coordinate system is fixed to the unicycle mobile robot with C at the origin as below: [6]

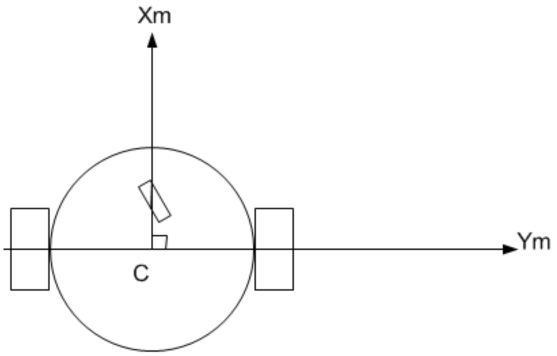

Figure 2.2: Unicycle Mobile Robot with Xm-Ym Coordinate System [6]

Then, the robot is assumed to move in a linear velocity, v which is in the same direction of Xm axis and ω is the angular velocity of it. Figure 2.2 shows the angle, θ is representing the heading direction of the robot.

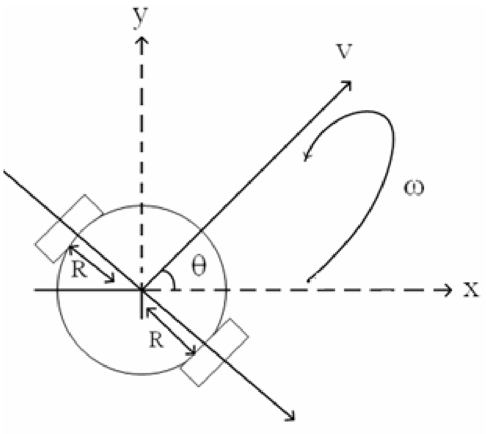

Figure 2.3: Unicycle Robot with Velocity Vector (v, ω) and angle θ

From figure 2.3, we can generate the coordinates by using the trigonometry theorem as below:

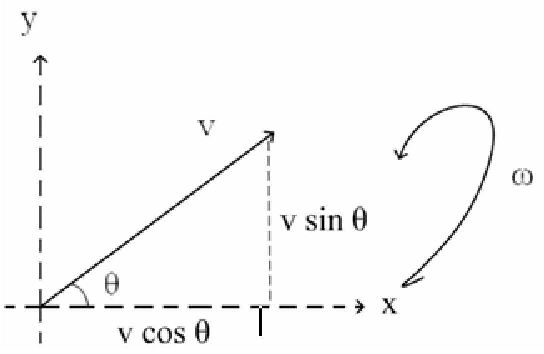

Figure 2.4: Trigonometry Theorem

From Figure 2.4, the polar coordinates of v and θ can be converted to the Cartesian coordinates of x and y by using the trigonometric function as:

$$\dot{x} = \cos \theta$$

$$\dot{y} = \sin \theta$$

The angle, θ

$$\dot{\theta} = \omega$$

We know that $\dot{q} = (\dot{x}, \dot{y}, \dot{\theta})$ for robot position

Therefore,

$$\dot{q} = \begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} v\cos\theta \\ v\sin\theta \end{bmatrix}$$

Factoring…

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

Therefore, the planar motion of mobile robot under nonholonomic constraint of ideal rolling condition is:

$$\dot{q} = \begin{bmatrix} \cos\theta & 0 \\ \sin\theta & 0 \\ 0 & 1 \end{bmatrix} \begin{vmatrix} v \\ \omega \end{vmatrix} \qquad (2.1)$$

2.4 Control of the Kinematics Model [6]

Based on the equation (2.1), the desired trajectory, q_d (t) should satisfy as equations above: [6]

$$q_d(t) = \begin{bmatrix} \cos\theta_d & 0 \\ \sin\theta_d & 0 \\ 0 & 1 \end{bmatrix} \begin{vmatrix} v_d \\ \omega_d \end{vmatrix} \qquad (2.2)$$

The error coordinates can be defined as (2.3):

$$e = T_e (q_d - q) ,$$

$$\begin{vmatrix} e_x \\ e_y \\ e_\theta \end{vmatrix} = \begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{vmatrix} x_d - x \\ y_d - y \\ \theta_d - \theta \end{vmatrix} \qquad (2.3)$$

Based on Leslie Austudillo's control objective, we know that the mobile robot that the mobile robot can be controlled in stable if there is no error between the real-time trajectory, q (t) and the desired trajectory, $q_d(t)$. The controller applies adequate torque must fulfill this condition.

Therefore, the τ (t) is derived as below, into specific $v_c(t)$ that controls the steering system.

$$v_c = f_c\,(e, v_d),$$

$$\begin{vmatrix} v_c \\ \omega_c \end{vmatrix} = \begin{bmatrix} v_d + \cos e_\theta + k_1 e_x \\ w_d + v_d k_2 e_y + v_d k_3 \sin e_\theta \end{bmatrix} \qquad (2.4)$$

2.5 Dynamic Equation [6]

Most of the nonholonomic system is described by the dynamic equations based on the Euler Lagrange formulation. The equation is shown as below:

$$\mathrm{M}\,(q)\,\ddot{q} + \mathrm{C}\,(q, \dot{q})\,\dot{q} + g(q) = \mathrm{B}(q)\,\tau + \mathrm{J}^{\tau}\,(q)\,\lambda \qquad (2.5)$$

From the equation, M (q) is the symmetric positive-define n x n inertia matrix. The M (q) plays important role both in the robot's dynamic model as well as in control design. Besides, the C $(q, \dot{q})$ is the matrix of Cariolis and centripetal forces for robot. In this project, the value of C $(q, \dot{q})$ is assumed as 0, which is will be neglected. In this project the gravitational torques, g (q) is 0 because the trajectory of the mobile base is constrained to the horizontal plane.

The dynamical equations of mobile base can be expressed in matrix form as below:

$$\begin{bmatrix} m & 0 & 0 \\ 0 & m & 0 \\ 0 & 0 & m \end{bmatrix} \begin{bmatrix} \ddot{x} \\ \ddot{y} \\ \ddot{\theta} \end{bmatrix} = \frac{1}{r} \begin{bmatrix} \cos\theta & \cos\theta \\ \sin\theta & \sin\theta \\ R & R \end{bmatrix} \begin{bmatrix} \tau_1 \\ \tau_2 \end{bmatrix} + \begin{bmatrix} -\sin\theta \\ \cos\theta \\ 0 \end{bmatrix} \lambda \qquad (2.6)$$

Where m is the mass of the mobile robot; I is the mass moment of inertial; r is the radius of the wheel; R is the distance of the rear wheel; τ_1 and τ_2 are the torques of the left and right motors; and λ is the Lagrange multipliers of constrained forces.
Hence,

$$C\,(q, \dot{q}) = 0 \qquad (2.7)$$

$$g\,(q) = 0 \qquad (2.8)$$

$$J^{\tau}\,(q) = \begin{bmatrix} -\sin\theta \\ \cos\theta \\ 0 \end{bmatrix} \qquad (2.9)$$

$$M\,(q) = \begin{bmatrix} m & 0 & 0 \\ 0 & m & 0 \\ 0 & 0 & I \end{bmatrix} \qquad (2.10)$$

$$B\,(q)\,\tau = \frac{1}{r} \begin{bmatrix} \cos\theta & \cos\theta \\ \sin\theta & \sin\theta \\ R & -R \end{bmatrix} \qquad (2.11)$$

$$\tau = \begin{bmatrix} \tau_1 \\ \tau_2 \end{bmatrix} \qquad (2.12)$$

Solve by using equation (2.6),

$$\begin{bmatrix} m\ddot{x} \\ m\ddot{y} \\ I\ddot{\theta} \end{bmatrix} = \frac{1}{r} \begin{bmatrix} \tau_1 \cos\theta + \tau_2 \cos\theta \\ \tau_1 \sin\theta + \tau_2 \sin\theta \\ \tau_1 R - \tau_2 R \end{bmatrix} + \begin{bmatrix} -\lambda \sin\theta \\ \lambda \cos\theta \\ 0 \end{bmatrix} \qquad (2.13)$$