Simulation and Analysis of Point-to-Point Differential Drive Mobile Robot

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ABSTRACT

A differential drive robot and Path motion point to point are studied and implemented in this thesis. The model by the Dudek model on Instantaneous Centre of Curvature is also discussed. The simulation of the mathematical model of the mobile robot was carried out in Simulink by using the Differential Drive Forward Kinematics and Differential Drive Inverse Kinematics blocks to convert between body velocities and wheel velocities. And use the Differential Drive Simulation block to simulate the pose given wheel speeds as inputs. Point to point motion was performed to test the robustness of the controller (0.0) as starting point and (4.4) as final destination and the results were used to optimize better performance.

ABSTRAK

Kesimpulannya, robot pemacu pembezaan dan Path motion point to point dikaji dan dilaksanakan dalam tesis ini. Model oleh model Dudek pada Pusat Lengkung Segera juga dibincangkan. Simulasi model matematik robot mudah alih telah dijalankan dalam Simulink dengan menggunakan blok Differential Drive Forward Kinematics dan Differential Drive Inverse Kinematics untuk menukar antara halaju badan dan halaju roda. Dan gunakan blok Simulasi Pemacu Berbeza untuk mensimulasikan pose yang diberikan kelajuan roda sebagai input. gerakan titik ke titik dilakukan untuk menguji kekukuhan pengawal (0.0) sebagai titik permulaan dan (4.4) sebagai destinasi akhir dan hasilnya digunakan untuk mengoptimumkan prestasi yang lebih baik.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Contrary to popular belief, robots are relatively old, with the first robot recorded in history by Leonardo's mechanical knight dated 1495[1].The first significant robotic wave began in the late 1960s in industrial environments, as automatic robots gradually replaced manual labor on assembly lines.

For several years, the presence of robots in industry has grown, but there is still a big market gap for other types, owing to technological limitations and high pricing. Recent advancements have significantly enhanced processor computing capability while also lowering costs. This opens the door for inexpensive, precise, and strong robots to become a reality in the future years, when human imagination has hitherto held them back.

A robot is a self-contained machine that can execute a certain duty. Since their inception, robots in the industry have served the objective of making tasks easier and more flexible, reducing task execution time as well as the people required to complete such operations. Industrial robots require a defined workspace, and as a result, they cannot do tasks in other locations. The demand for mobile robots arose from the requirement to reallocate those robots to other locations where they must be employed to divert humans away from risky and/or repetitive activities, thereby assisting plant workers. A mobile robot is one that can move around over a given terrain regardless of the type of locomotion that is uses. Mobile robots can be classified into aerial, terrestrial or aquatic. Terrestrial mobile robots are classified according to the type of movement or locomotion they have[2].

Differential drive Mobile wheeled robots are the mobile robots most used. The drives can be a distinctive drive of the wheeled moving robot. Two fixed power wheels mounted on the left and right side of the robot platform are the differential drives. The two wheels are driven autonomously. For balance and stability, one or more passive rivet wheels are used. The robot moves straight or reverse if its wheels rotate at the same speed. If one wheel runs faster than the other, the robot follows a curved path along the arch. If the two wheels rotate in the same direction at the same speed, the robot turns around the middle of both paths.

1.2 Problem Statement

There are several key issues with Mobile Robots that the robotics and control communities are attempting to resolve. A Mobile Robot must go from a starting place to destination while adhering to velocity and position limits. Point-to-point stabilization is a problem in nature when the robot needs to begin from the initial point and reach a destination[3]. The conduct of the robot between the initial and the final point and the robot's final orientation is not specifically controlled in this kind of problem. The stabilization of point after point can be dealt with in the subclass of problems in tracking or posture regulation, depending on the objective of tracing a path or reaching a point of reference.

1.3 Aim and Objectives

The primary objective of the project is to simulate differential drive mobile robot and check the point to point performance in term of accuracy.

The following aims are set out in this research:

1- To derive mathematical modelling of differential drive mobile robot
2- To simulate the differential drive mobile robot and path motion of point to point by using MATLAB Simulink.
3- To analyze the differential drive mobile robot and path motion of point to point simulation.

1.4 Scope of Study

1- This research will focus on the simulation of the differential drive mobile robot and path motion of point to point.
2- The simulation of this research will be using MATLAB Simulink.
3- The starting point of path motion will be (0.0) and the final destination will be (4.4)
4- The differential drive mobile robot movement simulation is circle.

1.5 Outline of the report

This thesis has been organized in different chapters. In the introduction, chapter 1, background of study is discussed, then the problem is introduced and it is explained how the work in this thesis after that the objectives and scope of the research been explicated.

Chapter 2 it is discoursed about relevant studies for locomotion of differential drive mobile robot, stability, maneuverability and controllability also discussed about the kinematic and inverse for the differential wheel literature studies also been reviewed.

Chapter 3 is present the mathematical modeling of differential drive mobile robot and concept of instantaneous center of curvature also samples of the kinematic equation, additionally, the principle of the point-to-point motion.

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In chapter 4 the experiment setup showed point to point simulation and the differential drive simulation in circle movement.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

In this chapter related work to the project was discussed and focused on locomotion of differential drive mobile robot, stability, maneuverability and controllability also discussed about the kinematic for the differential wheel and inverse kinematic for the differential wheel.

2.2 Locomotion of Differential Drive Mobile Robots

A mobile robot requires unlimited movement of locomotive mechanisms. However, there are many moving ways, and therefore a robot's locomotive approach is an important factor in mobile robot design. The most popular locomotive mechanism is the wheel in mobile robotics and manufactured vehicles. It can be efficient and must be performed relatively simply. The main functions when designing a mobile robot on wheels relate to the type, design, and control systems of the wheels (eventual steering mechanisms)[4].

The robot's mobility feature is set by these parameters. Some robots are omnidirectional therefore, without regard to their position on the vertical axis, they can instantly move in any direction along the plane. However, mobile robots of this kind are rare, since rollers or mechanical structures are required. Other wheel like robot types have 4 wheels, which allow the front line to be transferred to the car and to rotate around the points according to the steering angle of the wheels. It is possible to rotate the robots on the wheels. It is easy to understand that these robots are not all way a robot that looks like a car is not able to slip laterally, if in fact the robot does not slide on the floor.

It is the most popular mobile robot of its kind a two-wheel robot operated by two separate motors on a coinciding rotational axis[5]. But as mobile robots must be stable, one or two additional passive rotor wheels or slider points can be used to balance the robot with three ground contact points. There is many possible wheel configurations when you consider possible techniques for mobile locomotion because four main wheel types are available [6]:

1- Standard wheel: two degrees of freedom rotation around the wheel axle and the contact point
2- Caster wheel: two degrees of freedom rotation around an offset steering joint
3- Swedish wheel: three degrees of freedom rotation around the wheel axle around the rollers and around the contact point
4- Ball or spherical wheel: realization technically difficult

There are two types of wheels in the differential robot, the standard wheel and the rotor roll, each with its primary axis of rotation, which makes it extremely oriental. As shown in Figure 2.1

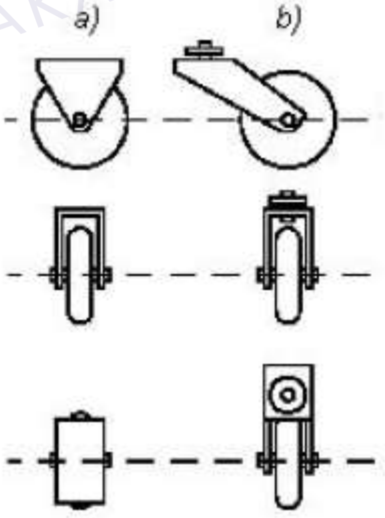

Figure 2.1: Two basic wheel (a) standard wheel (b) castor wheel [6]

To move in a different direction, the wheel must first be guided along a vertical axis. The main difference between the two wheels is that the standard steering wheel does not cause side effects, since the Centre of rotation is the point of contact with the ground and the rivet wheel is rotating around the offset axle, forcing the robot chassis to steer[7]. In wheel configuration, the number of changes to mobile robots is quite high. However, these choices govern three basic features of a robot: stability, maneuverability, and control.

2.2.1 Stability

To guarantee a stable balance, stability needs a minimum number of wheels two, provided the Centre of gravity is included within the triangles of ground contact points for the wheels. However, if the Centre of mass is underneath the wheel axle, two wheeled differential robots can achieve stability [8].

2.2.2 Maneuverability

Robot is a combination of available mobility based on the film sliding limits of the standard wheels, and the freedom offered by standard steering and shifting wheels. This is shown in Figure 2.2.

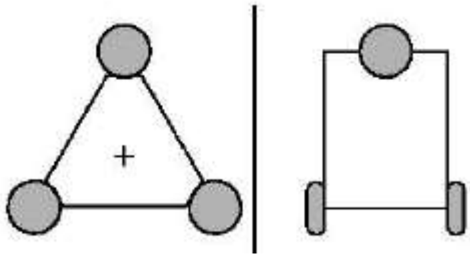

Figure 2.2: the degree of manoeuvrability of the mobile robot [9]

Some robots are omnidirectional which means that they can move at any time, regardless of the direction of the robot around its vertical axis, in any direction on the ground level (x, y). The degree of maneuverability M — omnipresent in Figure 2.2 the degree to which the bile robot moves. The mobile steering robot is equal to three because the mobility m/degree alloy's is equal to three and the steering capacity is equal to zero. In mobile robot differential driving, the maneuverability degree is two because the mobility degrees is two and the steering capacity degree is zero [9].

2.2.3 Controllability

Because the controllability problem for mobile robot systems is subject to cinematic restrictions on speed and application to collision-free trajectory planning, there is often an inverse link between control and maneuverability. The two motors on the two rolls must be driven along the same speed profile with a moving differential drive, which is difficult in view of differences in the environment between rollers, motors and rollers. In comparison with less maneuverable models, it is more difficult and often less precise to control an omnidirectional robot in a specific direction of journey [10].

2.3 Kinematic for Differential Wheel Mobile Robot

Due to hard, smooth flooring in existing industrial environments, mobile robots are more efficient than legged or treaded robots on hard as well as smooth surfaces and are capable to achieve widespread application in the industry. In the applications as described, several mobility configurations can be found. Dispersion drive and synchronic or auto-like drive and omnidirectional steering robots are the most frequently used single-body robots. Apart from the relevance in applications, many researchers also took an interest in the problem of the autonomous motion planning and control of mobile roster[11].

In recent years, the motion control of mobile robots on wheels has attracted considerable attention. Particularly interesting is the nonholonomic behavior of robotic systems, which points out that a low number of actuators can fully control the mechanism. In particular, the rolling constraints on wheel movement provide typical exemplars of nonholonomic mechanisms. Several mobile controllers with nonholonomic constraints, with posture stabilization and trajectory tracking, being the two main approaches to controlling mobile robots have been proposed [12].

The modelling process can be inspired by Muri and Neuman's wheeled mobile robot "A robot capable of locomoting on the surface only by the action of wheels mounted on the robot and in touch with the surface. A wheel mount is a device that provides relative movement between its mount and the surface on which a single contact point is intended." The vehicle's cinematic design must however be free (mobility) so that the vehicle can adapt without slip to changes in surface and roller rolls. Instead of conventional wheels, mobility is enhanced by omnidirectional wheels [13]. The need for an ideal rolling system without slipping sideways on wheels impairs the motion of mobile robot wheels with non-holonomic (non-integrative) constraints. Alexander and Maddocks based on constraint, developed the relationship between the robot's rigid body motion and the steering and driving rates of wheels as "rolling without sliding." The slip due to misalignment of the wheels is examined here to minimize a no smooth, convex dissipation function derived from Coulomb's friction law.

In the design of a robot there must be considered three related but various cinematic aspects. The mobility, control, and positioning of these can be listed. The first, mobility, addresses the possible motions that the robot can use in any direction to reach its destination. The second aspect, control, concerns the selection of cinematic variables: widespread speeds or co-ordinates. Finally, the third aspect, positioning, refers to the location system used to estimate the robot's actual position and direction through a reduction in the region of uncertainty of the robot, based on the sensors needed for an independent operation[3].

Shih et al.[14] Show that the moving robot with a wheel cannot move exactly along a straight line, although the movie problems are perfectly corrected, with the result that the motor controller is restricted with acceleration. The kinematic model of a parallel wheeled mobile robot does not meet Brockett's requirement to stabilize feedback, which implies that no invariant time is smooth or permanent. In several papers, the stabilization and control for non-holonomic systems with dynamic equations were considered.

2.4 Inverse Kinematics for Differential Wheel Mobile Robot

The objective coordinates are known in this case, but the intervening angles are unknown. The issue is figuring out how to account for those perspectives. When the ultimate goal is accomplished, these are the mathematically solved coordinates for the locations of the linked pieces. However, these may not be the most effective or time-saving methods for achieving the aim. The Euler angles described in Dynamics are studied by Lagrange Euler and Newton Euler formulations, which is one technique to perform the inverse solution[15].

There are a number of well-known and widely used inverse kinematics methods[16]. To address the problem, these use a variety of numerical approaches, particularly those utilizing the Jacobian. None of these inversion methods are complete or guaranteed to work right out of the gate. In this paper, an inverse kinematics approach was proposed that was guaranteed to return a configuration that could be reached from the start. While this approach was framed as solely an inverse kinematics algorithm, it was essentially a path planner because the data acquired from the process could be utilized to find a path from start to finish. The method used in this thesis is compared to the method used in[13].

2.5 Simulation Technique

Since the early twentieth century, simulation has been recognized as an important study tool for robotic systems and simulation methods are now a powerful tool supporting the design, planning, analysis, and judgments in several fields of research and development. Simulink is a Matlab add on that allows users to create a continuous causal design graphically without having to write code. It was first introduced in 1990[17] Simulink has progressed in a number of directions, including the addition of new blocks, built-in algebraic loop solution, and physical modeling of toolboxes.Simscape is a physical modeling toolbox developed by Math works for use with Simulink, and it has been available from Matlab suite version R2007A . It offers a foundation library with fundamental electrical, hydraulic, mechanical, and thermal system components. There are other more specialized physical modeling toolboxes that are now considered part of the Simscape product family. One of the advantages of this mechanical modeling software is that it provides a single simulation environment for the development of reliable mechanical and controller models. Converting these models into compact, efficient C code for embedded controller implementations allows them to be reused [18].

CHAPTER 3

METHODOLOGY

3.1 Overview

In this chapter will briefly mentioned some of the mathematical modeling of differential drive mobile robot and concept of instantaneous center of curvature also samples of the kinematic equation, meanwhile the principle of the point-to-point motion.

3.2 Mathematical Model

The wheeled robot with two controllable wheels right and life are a differential robot as shown in Figure 3.1. The robot needs a Linear Velocity V and Angle Velocity ω to maneuver each differential drive robot in a plane. The path of the robot can be planned by controlling the speed and orientation.

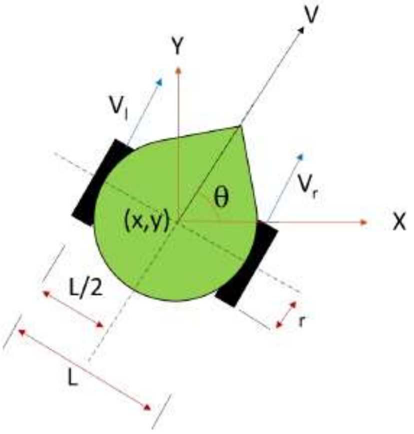

Figure 3.1: Differential Drive Mobile robot. [6]

The differential robot drive layout is shown in Figure 3.1 where Vr is the right wheel, Vl is the left wheels' velocity, L is the distance between the wheels' centres, the robot's directional angle about the system of the reference co-ordinates and R is a wheel's radius. The speed of the robot is the average speed and is determined by.

$$V = \frac{Vr+Vl}{2} \tag{3.1}$$

3.3 Kinematic Equation of a Mobile Robot

Kinematics is the branch of classic mechanics which, without consideration of the masses of objects, or the forces which might cause motion, describes the movement of a point (center of an object). The kinematic equations are utilized to transform motion in a rectangular(x, y), system from Polar Coordinates(x, y), linear velocities (V) and orientation (θ) inputs required for a moving robot. The rate of change of robot position in x-direction is x daily, and in y-direction y daily is given as follows:

$$x = V\cos(\theta) \tag{3.2}$$

$$y = V\sin(\theta) \tag{3.3}$$

And the angle velocity of the robot is given by.

$$w = \frac{(Vr-Vl)}{L} \tag{3.4}$$

By substituting the liner velocity V from equation 3.1, in equation 3.2 and 3.3.

$$x = \frac{(Vr+Vl\,)}{2}\cos(\,\theta) \tag{3.5}$$

$$y = \frac{(Vr+Vl)}{2}\sin(\,\theta) \tag{3.6}$$

The velocity V of the robot in a fixed reference coordinate system is therefore as given.

$$V = \sqrt{x^2 + y^2} \tag{3.7}$$

From equations 3.5 and 3.6

$$V = \sqrt{(\frac{Vr+Vl}{2})^{\,2}\;\; cos^2(\theta) + \left(\frac{Vr+Vl}{2}\right)^{2}\;\; sin^2(\theta)} \tag{3.8}$$

The individual velocities (Vr)r and(Vl), can be calculated using the equations.

$$Vr = (V - \frac{L}{2}\;w) \tag{3.9}$$

$$Vl = (V - \frac{L}{2}\;w) \tag{3.10}$$

3.4 Concept Instantaneous Center of Curvature

A circle was another simple form used to test the robot's differential drive. The work of Dudek and Jenkin on ICC (Instantaneous Center of Curvature) was used to assist the robot in constructing circles. Figure 3.2 shows a robot model based on Dudek and Jenkin's work[19], which focuses on ICC (Instantaneous Center of Curvature). The center around which the robot moves to form a circle, or the point around which the robot spins, is known as the ICC.

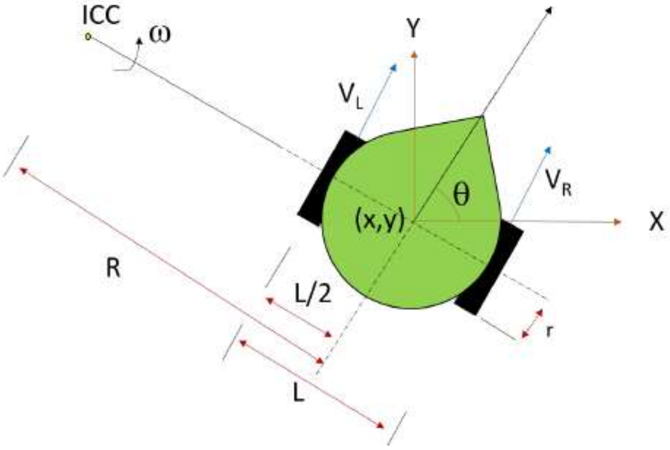

Figure 3.2: Instantaneous Center of Curvature [17]

Because it exists at that specific moment in time, this point varies with the robot's mobility and is referred to as an instantaneous point. Demonstrates the ICC concept. As illustrated in the diagram, R is the distance between ICC and the robot's center. When the robot is moving in a straight line, R will be infinite, and these parameters will be defined when the robot is moving on a curved path, i.e. when the left and right wheels are moving at different speeds. Equations 3.11 and 3.12 describe how to calculate Vr and Vl in terms of angular velocity and radius.
There are four cases explaining the relation between velocities and direction.

1- If Vr = Vl robot will move straight in linear direction. R is infinite and will be zero.

2- If Vr = -Vl robot will rotate in the same place along its axis about its center Point.

3- If Vl = 0, robot will turn around left wheel.
4- If Vr = 0, robot will turn around right wheel.

Kinematic equations for the mobile robot as per the ICC concept are

$$Vr = w(R + \frac{L}{2}) \qquad 3.11$$

$$Vl = w(R - \frac{L}{2}) \qquad 3.12$$

$$w = \frac{Vr - Vr}{L} \qquad 3.13$$

Using equations (3.13) (3.11) (3.12) the individual wheel velocities to the robot, based on the required radius and angular velocity, were calculated. By controlling the angle of the robot, any arc or semi-circle can also be drawn, in the reference plane.

3.5 Point To Point Motion

To begin the maneuverability test of the mobile robot, the first task is moving the robot from point to point (P2P).There are two factors which are required for motion of the robot: direction and driving velocity. In addition, the distance between the robot and the destination point is required as shown in Figure 3.3 where (x1, y1) is the starting point, (x2, y2) is the destination point and θ is the inclination of the destination point with respect to starting point.

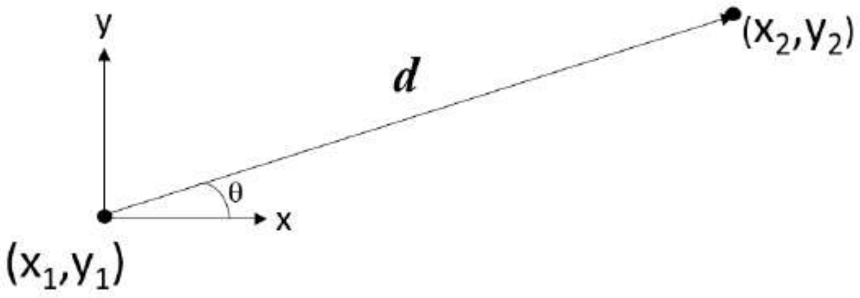

Figure 3.3: point to point motion [7]

To perform a P2P task, the robot needs a constant velocity and the desired direction (θ) pointing towards the destination point. The direction is calculated as

$$\theta = \text{atan2d}((y2 - y1)(x2 - x1)) \quad 3.14$$

The distance to the destination point is calculated using the distance formula

$$d = \sqrt{(x2 - x1)^2 + (y2 - y1)^2} \quad 3.15$$

In practical situation, it is difficult to reach the destination point with zero error, the robot would not reach the exact destination in general. To avoid overshoot, the speed of the robot is reduced as it reaches its goal.

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