DESIGN AND DEVELOPMENT OF AUTONOMOUS OMNI-DIRECTIONAL MOBILE ROBOT WITH MECANUM WHEEL

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by

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APPROVAL AND DECLARATION SHEET

This thesis titled Design and Development of Autonomous Omni-Directional Mobile Robot with Mecanum Wheel was prepared and submitted by Jefri Efendi Bin Mohd Salih (Matrix Number: 0430610020) and has been found satisfactory in terms of scope, quality and presentation as partial fulfillment of the requirement for the award of degree of Master of Science in Mechatronic Engineering in University Malaysia Perlis (UniMAP).

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For my wife, Ropidah and my sweet little girls, Rania and Najla…

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MEREKABENTUK DAN MEMBANGUNKAN ROBOT BERGERAK BERARAH OMNI DENGAN RODA MECANUM

ABSTRAK

Kepelbagaian rekabentuk robot bergerak telah dibangunkan kebelakangan ini dalam usaha memperbaiki keupayan pergerakannya dan aplikasi praktikal. Robot berarah omni mempunyai kelebihan berbanding robot lain yang terbatas kerana keupayaannya bergerak dalam persekitaran yang sesak. Objektif utama penyelidikan ini adalah merekabentuk, membangun dan mengimplimentasikan robot berarah omni yang dilengkapi roda *mecanum* untuk bergerak secara berpanduan. Dengan menggunakan roda *mecanum*, robot memeberikan tiga darjah kebebasan dalam pergerakan. Keutamaan juga diberikan dalam membangunkan model kinematik dan dinamik untuk analisis keupayaan platfom robot yang telah dibangunkan. Litar kawalan motor dan litar kawalan robot telah direkabentuk dan kesemua komponen fizikal dan perisian telah diintergrasikan bagi menghasilkan sistem robot bergerak yang sempurna. Algoritma kawalan pergerakan menggunakan perisian *BasicStamp Editor* telah dibangunkan untuk menguji keupayaan sistem. Ujikaji telah dijalankan untuk menganalisa ciri-ciri pergerakan dalam paksi X dan paksi Y serta keupayaan pemanduan kebezaan. Dengan mengantaramukakan penderia *ultrasonic* dan *infrared* pada litar kawalan robot, navigasi berpanduan telah dibangunkan dan diuji. Berdasarkan ujikaji, keupayaan navigasi berpanduan berada pada tahap yang memuaskan.

DESIGN AND DEVELOPMENT OF AUTONOMOUS OMNI-DIRECTIONAL MOBILE ROBOT WITH MECANUM WHEEL

ABSTRACT

A variety of designs of mobile robot have been developed in recent years in order to improve their omni-directional maneuver and practical applications. Omni-directional mobile robot has vast advantages over conventional design likes differential drive in term of mobility in congested environments. The main purpose of this research is to design, develop and implement an omni-directional mobile robot with custom made mecanum wheel for autonomous navigation. Using these mecanum wheels, the mobile robot is provided with three degree of freedom (DOF) mobility. Attention also paid for the development of kinematics and dynamics model to analyze the mobile platform motion performances. Motor driver and robot controller were also developed. Motion control algorithm using BasicStamp Editor software was developed to test the capabilities of the system's mobility performance. Experiments were performed to analyze the motion characteristic of the mobile robot motion in Y axis, X axis and differential drive capabilities. Using ultrasonic and line follower sensors, basic autonomous navigation had been develop and tested. Based on the experiment conducted, the autonomous navigation gave satisfactory result. The developed mobile robot will provide a test bed for advanced path planning and navigation projects in the future.

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LIST OF SYMBOLS, ABBREVIATIONS & NOMENCLATURE

$\dot{\theta}_{1,2,3,4}$	Wheels angular velocities in rad/s or RPM
θ	Theta, wheel roller angle
Ø	Mobile robot orientation in rad
$\dot{\theta}$	Mobile robot orientation in world global frame
Φ	Phi, rotational velocity
π	Pi (equal to 3.142 rad)
a	Acceleration in $m.s^{-2}$
A	ampere
ADC	Analogue-to-Digital Converter
AGV	Autonomous Guidance Vehicle
b	Drag coefficient in Ns/m (equal to 501.1 Ns/m)
bx	Drag factor in x-axis
by	Drag factor in y-axis
BS2	Parallax Basic Stamp 2 microcontroller module
CPU	Central processing unit
d	Distance between wheels in x axis
D	Torque available from a single motor in Nm
DC	Direct Current
DOF	Degrees of Freedom
FMS	Flexible Manufacturing System
IC	Integrated Circuit
IR	Infra Red
I/O	Input and Output port
kg	kilogram
kΩ	resistance value kilo Ohm
m	Mass in kg
m_r	Mass of the robot chassis in kg
MHz	megahertz

mA	miliampere
mm	millimeters
mV	milivolt
PC	Personal computer
PCB	Printed Circuit Board
PID	Proportional Integral Derivative
PWM	Pulse Width Modulation
r	Radius of the wheel
RISC	Reduced instruction set computer
s	Distance between wheels in y axis
SMT	Surface Mount Technology
$T_{1,2,3,4}$	Traction force of a single wheel
T_{ix} / T_{iy}	x/y vector of the traction force in Newton
V	voltage
$V_{1,2,3,4}$	Wheels linear velocities in m/s
Vin	Input voltage for motor driver
V_{dc}	volt in DC
V_{dd}	Voltage supply to robot controller
V_{out}	Output voltage to motor driver
Vss	Ground pin for robot controller
V_x	Translational velocities in x axis
$\dot{V}x$	Accelerations in x axis
V_y	Translational velocities in y axis
$\dot{V}y$	Accelerations in y axis

CHAPTER 1

INTRODUCTION

Omni-direction is used to describe the ability of a system to move instantaneously in any direction from any configuration. Omni-directional robotics platform has vast advantages compared to conventional designs in term of mobility in congested environments. Such capabilities have the potential to solve a number of challenges in industry and society. They are capable of easily performing the task in environments congested with static and dynamic obstacles and narrow aisles commonly found in factory production floor, office, warehouse and hospitals facilities. Many designs of omni-directional or near omni-directional have been proposed and generally can be divided into two approach i.e. conventional wheel designs and special wheel designs.

1.1 Background of Research

Current research into omni-directional vehicle movement takes a number of forms. The design concepts for this project form part of the research involved with the use of wheels that roll with two degrees of freedom (DOF). This research is about to design and development of an omni-directional mobile robot using four custom-made mecanum wheels.

Mecanum wheel was designed and invented in Sweden in 1973 by Bengt Ilon, an engineer with Swedish company Mecanum AB (Diegel et al 2002). Mecanum wheel is based on the principle of a central wheel with a number of rollers placed at an angle around the periphery of the wheel. The angled peripheral roller translates a portion of the force in the rotational direction of the wheel to force normal to the wheel directional. Depending on each individual wheel direction and speed, the resulting combination of all these forces produces a total force vector in any desired direction thus allowing the platform to move freely in direction of resulting force vector, without changing the direction of the wheel. Figure 1.1 shows a traditional mecanum wheel design by Ilon with the peripheral roller with 45° degree slope held in place from the outside.

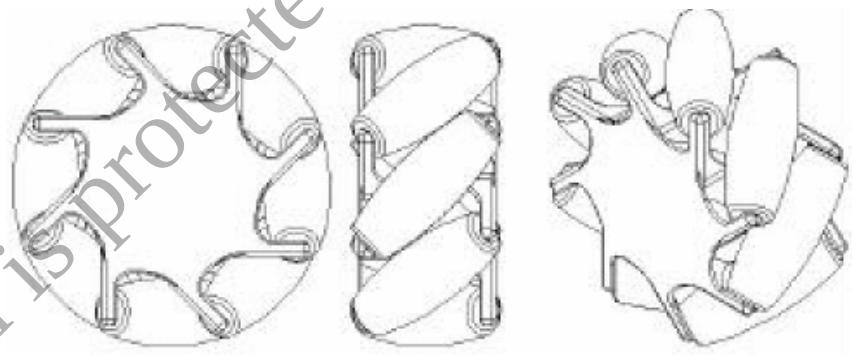

Figure 1.1: Mecanum wheel based on Ilon's concept (Diegel et al 2002)

Using four of mecanum wheels provides omni-directional movement for a vehicle without needing a conventional steering system. Slipping is a common problem in the Mecanum wheel as it has only one roller with a single point of ground contact at any one time. Due to the dynamics of the mecanum wheel, it can create force vectors in both the x and y-direction while only being driven in the y-direction. Positioning four mecanum wheels, one

at each corner of the chassis (two mirrored pairs), allows net forces to be formed in the x, y and rotational direction.

Navigation and obstacle avoidance are very important issues for the successful use of an autonomous mobile robot. When computing the configuration sequence, we allow the robot to move from one position to another. When the environment of the robot is obstacle free, the problem is less complex to handle. But as the environment becomes complex, motion planning needs much more treatments to allow the robot to move between its current and final configurations without any collision within the surrounding environment. With the omni-directional capabilities provided by mecanum wheel the navigation process become less complicated and easy to control due to high mobility but the wheel slip factor had become major issue in order to achieve satisfactory motion control and planning.

1.2 Motivation of Research

The research problems considered in this thesis stem from a complexity of mecanum wheel design and the motion control difficulty due to the fact that there are four wheels to control three different degrees of freedom (DOF). In this case the system is said to be over determined and it is possible to create conflicts in the actuation during mobile robot movement. As a result of the constraints associated with the mecanum wheel some form of robot controller is required to produce satisfactory motion. With the wheel slip factor is the major issue in mobile robot kinematics and dynamics, designing omni-directional mobile robot become more challenging compared to normal mobile robot design like differential drive mobile robot.

The vast advantages of mecanum wheel in vehicle and mobile robot propulsion had attracted many robotics research laboratories in universities, NASA and high tech firm around the world. The omni-directional motion produced by mecanum wheel had been commercialized for military ground support equipment, warehouse transportation and even wheel chair for disabled. Mecanum wheel also had some disadvantages where it's consumed more power to control all four wheels. It's also not suitable for outdoor application when uneven and soft work surface likes mud and sand eliminated the omni-directional capability (Dickerson and Lapin 1991).

Many practical applications for mecanum wheel platform develop using control pendant or joystick and control manually and directly by human. So the development for autonomous navigation is crucial in the future where many applications like mecanum wheel AGV can be applied and the basic study and performance can be evaluated in this research. Hopefully in the future, the use of mecanum wheel Automated Guided Vehicle (AGV) can be integrated into current Flexible Manufacturing System (FMS) in UniMAP robotic laboratories.

1.3 Research Objectives

There are four main objectives to be achieved in this research. The objectives are as follows:

i. To design and develop a less complex mecanum wheels that can be easily fabricated and assembled but perform exactly the same as original designs.
ii. To develop mobile robot controller that consist four channels motor driver and interfacing for control software development.

iii. To develop basic mathematical modeling for mecanum wheel mobile robot using Matlab and Simulink to simulate the wheel slip factor in robot motion.

iv. To evaluate the mecanum wheel mobile robot motion characteristics in order to interface the system with sensor array to perform autonomous navigation using obstacle avoidance technique and line follower for practical applications such as AGV in FMS system in UniMAP robotics lab.

1.4 Scope of Research

There are several concerns in defining the scope of this project. The following scopes were considered for this research:

i. The mecanum wheel mobile robot consists of both hardware and software development for omni-directional motion characteristics and autonomous navigation.

ii. Development of mechanical design for wheel and mobile robot platform and electronics design for motor driver and robot controller for input and output interfacing.

iii. Data from mobile robot modeling and motion characteristics are crucial for development of autonomous navigation control algorithm, where wheel slip is the major factor for satisfactory autonomous navigation.

iv. Initial control program for basic motion and variable speed control are the key to perform any control algorithm for developed mobile robot study.

1.5 Dissertation Layout

This thesis is divided into six chapters. The first chapter includes the introduction, background of research, application, motivation, objective and scope of research. It will briefly discuss the main idea and the aim of the project. It will also cover the scopes of the project that reflect the feasibility of this study. The research can be separated into two major parts. Part 1 is the development of mobile robot system hardware including mecanum wheel, robot chassis, motor controller and robot controller. Also included in Part 1 is control software development for motion control and sensor interface. Part 2 concerns about the mobile robot characteristics, motion study, modeling and development of autonomous navigation using obstacle avoidance and line follower applications. The overview, literature review, system development, and system testing are explained separately in the respective chapters. Both part finally combined together for the autonomous navigation capability development based on motion characteristic study.

Chapters 2 discuss the definition of autonomous mobile robot, omni directional mobile robot and the literature review of mecanum wheel mobile robot. This chapter helps in understanding the mobile robot system and developing the proposed system.

The development of hardware aspect of the mobile robot will be discussed in Chapter 3. This chapter will highlight the development of mechanical and electronic aspect of the mobile robot. Some kinematics and modeling analysis are also discussed.

Chapters 4 discuss the motion characteristics for the developed system. The data produces in basic mobility are very useful to determine the motion performance and

limitation of the mobile robot design in this research. The results are presented in tables and graphs with respective discussions.

The development of autonomous navigation for obstacle avoidance and line follower methods are discussed in Chapter 5. This chapter is important for evaluation of the system being developed in term of input and output interfacing and motion control both in fixed speed and variable speed control to achieve satisfactory navigations.

Finally, conclusion and recommendations for future works are proposed in Chapter 6. Conclusion based on result obtained through experiment in Chapter 4 and 5 will be made. Some research contributions and recommendations for future improvement are suggested as well.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

This chapter will discuss and review available literature on autonomous mobile robot platform on holonomic or omni-directional systems. Mobile robot platform can be divided into three categories either legged, wheel or combination of these two. Various types of wheel are found in the literature, some wheels are called fixed wheel, center orientable, off-center orientable and omni-directional wheel.

2.1 Autonomous Mobile Robot

Autonomous mobile robots are mobile robot which can perform desired tasks in unstructured environments without continuous human guidance. Many kinds of robots have some degree of autonomous. Different mobile robots can be autonomous in different ways. A high degree of autonomy is particularly desirable in fields such as space exploration. Other more mundane uses benefit from having some level of autonomy, like cleaning floors, mowing lawns, and waste water treatment.

Some modern mobile robot operates within the strict confines of their direct environment. Even though not every DOF exists in their surrounding environment, the work place of the factory or manufacturing floor can provide challenges and can often be unpredictable or even chaotic. The exact orientation and position of the next object of work and in the more advanced factories even the type of object and the required task must be determined. This can vary unpredictably at least from the robot's point of view.

One important area of robotics research is to enable the robot to cope with its environment whether this is on land, underwater, in the air, underground, or in space. A fully autonomous robot has the ability to:

i. Gain information about the environment.
ii. Work for an extended period without human intervention.
iii. Move either all or part of itself throughout its operating environment with human assistance.
iv. Avoid situations that are harmful to people, property, or itself.

An autonomous robot may also learn or gain new capabilities like adjusting strategies for accomplishing its tasks or adapting to changing surroundings.

2.2 Omni-Directional Mobile Robot

Omni directional vehicles have been studied and developed extensively over the last decade in a number of robotics laboratories around the world. Such vehicles are characterized by the ability to move sideways and spin on the spot. This extra maneuverability enables