MODELLING AND CONTROL OF A NONHOLONOMIC MOBILE ROBOT

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ABSTRACT

Mobile robots are becoming more common in today's fast growing environment. Its extensive study and research have become a major part in the mobile robot's rapid development. An effective method of development is via modelling tools and computerized simulations. In this project, kinematic and dynamic models of a nonholonomic two-wheeled mobile robot were simulated with its behaviour defined by a controller. The robot defined in this project has two actuated wheels while any other contact with the surface travelled is assumed to be frictionless. This project identifies two robot controllers, which are the proportional-integral-derivative (PID) control and pole placement methods. These control methods are implemented via the MATLAB/Simulink software into the kinematic and dynamic models of the robot. Controllers were chosen according to its robot model that conforms to the standard robot designed in this project. The tracking control method of each controller was also studied to ensure stability of the model. In the simulation, the robot is given several predetermined paths. The robot does not know these paths and it has to be able to adapt and react to different paths. The controller is considered successful when it can follow the predetermined path accordingly and effectively. Through the simulations, these controllers are studied and compared.

ABSTRAK

Robot bergerak kini menjadi perkara lazim di dalam persekitaran moden yang semakin rancak. Pengajian dan penyelidikan oleh pelbagai pihak membolehkan [area] robot bergerak ini dibangunkan dengan pesat. Salah satu kaedah pembangunan yang kos efektif adalah melalui pemodelan matematik bersama simulasi berkomputer. Model kinematik dan dinamik robot bertayar dua disimulasi dengan sifat-sifatnya diserapkan oleh sebuah pengawal digital. Robot dalam projek ini mempunyai dua tayar bergerak manakala bahagian lain yang bersentuh dengan permukaan lantai dilihat sebagai tidak mempunyai geseran. Projek ini mengenalpasti dua pengawal digital iaitu pengawal Berkadar Terus – Kamiran – Terbitan atau *Proportional-Integral-Derivative (PID)* dan [pole placement]. Teknik-teknik kawalan ini diimplimentasi menggunakan perisian MATLAB/Simulink ke dalam model kinematik dan dinamik robot tersebut. Pengawalan digital dipilih mengikut model robot yang didapati. Teknik kawalan jejakan bagi setiap pengawal digital dikaji bagi memastikan kestabilan model. Dalam simulasi ini, robot diberi sasaran perjalanan yang ditentukan terlebih dahulu. Robot ini perlu mengadaptasikan dirinya dan bertindak dengan sesuai mengikut sasaran yang berbeza. Pengawal robot dianggap berjaya apabila ia mampu mengawal robot untuk mengikut sasaran perjalanan tersebut. Perbezaan antara pengawal-pengawal ini dikaji dan dibandingi.

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LIST OF SYMBOLS

™	-	Trademark
®	-	Registered
$\sum$	-	Sum
m	-	Meter
mm	-	Milimeter
$\dot{\varphi}$	-	phi for wheel rotation speed
$\dot{\varphi}_1$	-	left motor speed
$\dot{\varphi}_2$	-	right motor speed
x	-	Robot x-axis location
y	-	Robot y-axis location
$\dot{x}$	-	Robot motion in x-direction
$\dot{y}$	-	Robot motion in y-direction
θ	-	the previous angle orientation
$\dot{\theta}$	-	theta for robot rotational motion
R	-	Robot reference frame
ξ	-	zeta for robot pose
r	-	Radius of robot wheel
l	-	Half the distance between wheels
ω	-	Instantaneous wheel rotation
$R(\theta)$	-	Standard orthogonal rotation transformation
$\circ$	-	degrees
K_P	-	Proportional gain
K_I	-	Integral gain
K_D	-	Differential gain

$G_C(s)$	-	Transfer function as a function of s
$\%OS$	-	percent overshoot
c_{max}	-	maximum point
c_{final}	-	final or steady state value
$\mathbf{K}$	-	feedback vector for pole placement

CHAPTER 1

INTRODUCTION

1.1 Overview

A mobile robot is a robot that is has the capability to move about and interact with its environment. There has been extensive research into mobile robotics as almost every major engineering university has one or more labs that focus on mobile robot research. Mobile robots are also found in industry, military and security environments, and appear as consumer products. According to the Japanese Industrial Robot Association (JIRA) [1], robots can be divided into several classes that describe its function and to some extent, its level of complexity.

Mobile robot navigation is an important aspect of mobile robotics system design since its functionality is greatly depends on “mobility”. As the utilization of robot goes beyond industrial applications, the practical implementation in human environment requires the robot to move efficiently in our daily surroundings. The work on mobile robots is of interest to the researchers to explore the potential of robots in handling daily chores such as house cleaning, baby sitting, tour guide, shopping assistant, and many other applications. Such systems require accurate navigation and guidance control system.

The main concern in designing robotics system is the high development cost, a possible solution to evaluate various designs without adding the cost is to model the system in order to simulate and analyze before actual fabrication. Therefore, a general modelling and simulation platform for mobile robot system is important. Many modelling solutions are mainly concentrated on the design of the control system and application algorithm. It is normally done with a fixed mechanical design in order to optimize the control system.

In the military and heavy industries, mobile robots are used in environments that are deemed hazardous to humans. This provides a convenient and safe condition for humans to work in and still get the job done. The United States government is expected to spend billions of dollars on the development of robots for its military use. Already in the news we have seen robots being deployed in Iraq and Afghanistan while Unmanned Aerial Vehicles (UAV's) are sent spying over China [2].

Table Error! Style not defined.**.1 :** Classes of robots as classified by the Japanese Robot Association [1].

Class 1	Manual handling device: a device with several degrees of freedom actuated by the operator.
Class 2	Fixed sequence robot: handling device which performs the successive stages of a task according to a predetermined, unchanging method, which is difficult to modify.
Class 3	Variable sequence robot: the same type of handling device as in class 2, but the stages can be easily modified.
Class 4	Playback robot: the human operator performs the task manually by leading or controlling the robot, which records the trajectories. This information is recalled when necessary, and the robot can perform the task in the automatic mode.
Class 5	Numerical control robot: the human operator supplies the robot with a movement program rather than teaching it the task manually.
Class 6	Intelligent robot: a robot with the means to understand its environment, and the ability to successfully complete a task despite changes in the surrounding conditions under which it is to be performed.

Most robots in industrial use today are manipulators that operate within a bounded workspace and are bolted to the ground or ceiling. Mobile robots, on the other hand, are completely different. The degree of the ability of a mobile robot to move around autonomously in its environment determines its best possible application such as tasks that involve transportation, exploration, surveillance, inspection, etc. Some examples include underwater robots [3] [4], planetary rovers [5], or robots operating in contaminated environments. The most common type of mobile robot for industrial use is the Automated Guided Vehicle (AGV). AGVs function in specially modified environments.

However to achieve the desired movements in real world environments is not straightforward. This is why much effort has been put into the development of the best path planning algorithms for mobile robots. Mobile robotics is a vast research area. Although industry is actively engaged in robot development, the new robots produced by industries have little to do with research performed in the academic sector. A lot of resources are being poured all over the world into advancing robotics technology research, and hopefully will reach the practical stage soon [1].

When a mobile robot is designed, the three key questions that need to be answered by the robot are:

Where am I? Where am I going? And *how do I get there?*

To answer these questions the robot has to have a model of the environment (given or autonomously built). After that it needs to perceive and analyze the environment to find its position within the environment. The plan and execution of the movement will then be finally defined by its control method. Most of the current practical robot technology in industries are focused on areas such as positioning, teaching-playback, and two-dimensional vision [1].

Non-developed research areas are to be selected for upcoming priority research by JIRA. By developing a robot model, the very same model can be applied to test obstacle avoiding technology and learning control systems. Coupling it with the applications of map referenced navigation systems and self decision making will produce an attractive direction for research. Making the model as simulation based will make it cost effective overall.

Cyberbotics Ltd. Has developed Webots™, a commercial software used for mobile robotics prototyping simulation and can be transferred to real robots. In 1998 and 1999 Cyberbotics developed an Aibo® simulator for Sony Ltd. Cyberbotics has now collaborations with the Biologically Inspired Robotics Group (BIRG) and the Swarm Intelligent System Research Group (SWIS) of the EPFL through the Swiss CTI technology transfer program [6]. This shows that major entertainment and research companies are already trusting simulations to develop mobile robots.

Table Error! Style not defined.**.2 :** Practical robot applications versus technology that has not been developed past the research stage – some examples.

Practical robot applications	**Non-developed research**
• Fast, accurate positioning servos • Teaching-playback control systems • Off-line teaching systems • Map reference mobile robot navigation systems • 2-D vision technology • Unilateral remote control systems etc.	• Force control technology • Compliance control technology • Distribution tactile sensors • Test environment awareness technology based on 3-D vision • Multi-fingered hand • Obstacle avoidance technology • Walking robots (with legs) • Learning control systems etc.

Modelling hardware using virtual platforms is becoming mainstream – so now attention is turning to the speed of simulation [7]. The advantage of modelling is that a simulation can be very fast, making it feasible to run applications software on top of the virtual hardware and not just boot code or small test routines.

1.2 Objectives

Design and development of mobile robotics system is relatively time consuming and costly. Solution: Develop a platform to simulate the system design before hardware implementation. Several objectives have been set out as the working focus points. The main objectives of this project are:

1. to control a two-wheeled mobile robot model by using 2 different types of controllers, and
2. to simulate and compare the controllers applied on the system using the MATLAB/Simulink software.

1.3 Project Scope

The project will cover development of a two-dimensional environment for the robot to traverse. A mathematical approach is taken to model the robot to define its kinematic and dynamic features. The simulation model will focus on the control of the robot and its ability to respond to changing target destinations.

The scope of the project is set to develop a simulation model for basic mobile robot navigation by using the Simulink tool in MATLAB. The simulation engine used in this work is MATLAB Simulink. The main reason is of course the popular and standardized programming environment and incorporated with many research valuable toolboxes. Controllers are studied and two are chosen to define the behaviour of the robot model. After implementation of the controllers into the robot via Simulink, the controllers are then compared.

1.4 Thesis Outline

CHAPTER 1 gives an introduction to this work and serves as an overview to the study and states the objectives and scope of this work.

CHAPTER 2 reviews the background study of this work. It contains the fundamental knowledge of mobile robot navigation and the available modelling and simulation solutions for such a system.

CHAPTER 3 explains the overall system modelling and the basic components that were developed in this work. It covers areas from mathematical explanations to the integration of these all elements via the Simulink models.

CHAPTER 4 applies the information on developing digital controllers and applies the controllers into the robot model in Simulink. Evaluation of the simulation platform is done by performing simulation on two controller systems namely the proportional-integral-differential controller and the pole placement controller. These are given a test, simulated and finally compared.

CHAPTER 5 discusses and concludes the results obtained from this work. A few suggestions had been drawn out for future development.

APPENDIX A

List of Mobile Robotics Simulation Software Discussed in this Document

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