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JUDUL: DESIGN AND DEVELOPMENT OF AN OPTICAL TRACKING SYSTEM FOR HOLONOMIC MOBILE ROBOT

IJAZAH: IJAZAH SARJANA KEJURUTERAAN DALAM BIDANG KEJURUTERAAN ELEKTRIK & ELEKTRONIK

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DESIGN AND DEVELOPMENT OF AN OPTICAL TRACKING SYSTEM FOR HOLONOMIC MOBILE ROBOT

CHOO CHEE WEE

THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR DEGREE OF MASTERS IN ENGINEERING

SCHOOL OF ENGINEERING AND INFORMATION TECHNOLOGY
UNIVERSITI MALAYSIA SABAH
2011

DECLARATION

I hereby declare that the material in this dissertation is my own except for quotations, excerpts, equations, summaries and references, which have been duly acknowledged.

18 July 2010

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ABSTRACT

DESIGN AND DEVELOPMENT OF AN OPTICAL TRACKING SYSTEM FOR HOLONOMIC ROBOT

The main task of a mobile robot is to perform navigation and positioning. Common mobile robot which employs line tracking system can only work on pre-constructed track where else infrared guided robot only can work within infrared's line of sight. In addition to that, the wheel driving system of the mobile robot plays a vital role in allowing the robot to navigate along a limited direction depending on its wheel architecture. To steer a robot in any direction and to know its precise location in the environment is the ultimate goal of mobile robot navigation. To achieve this, a methodology is laid out in this thesis. An Optical Tracking Device (OTD) module is utilized to provide the accurate coordinates of the current location of the robot virtually on many flat surfaces. A holonomic wheel system is designed to allow the robot to navigate through multiple destinations. A navigation algorithm is developed to position the robot to any point accurately on a flat surface. As a result, this will allow the robot to freely move in any direction to reach multiple target destinations without any difficulties. The navigation and the positioning device could be implemented in industrial robots that especially required navigating to different points of a workspace, such as carrying goods from one point to another, and also patrolling robots within a workspace. This thesis also covers experimented result of the OTD that could detect up to a resolution of 1000 dots per inch. Nine points were designated to test the OTD on a test grid. The testing process is repeated for 10 times. The result shows that the mobile robot is able to navigate holonomically according to preprogrammed paths with difference of not more than 0.1 inch (3 mm) from the targeted location or with less than 5% error. This work allows a high precision positioning system design for a robot that are also less dependent to the outside environment, and utilizes the workspace with higher efficiency compared to robots using conventional sensors.

ABSTRAK

Tugas utama robot mudah alih adalah untuk menjalankan pergerakan dan sampai pada kedudukan yang ditentukan. Robot mudah alih biasa yang menggunakan sistem penjejakan barisan hanya boleh berfungsi pada trek yang dibina sebelum ini manakala robot berpandukan inframerah hanya boleh berfungsi dalam garis penglihatan inframerah. Tambahan pula, sistem pemanduan roda robot mudah alih itu memainkan peranan yang penting dalam membenarkan robot bergerak sepanjang satu arah terhard bergantung pada binaan rodanya. Untuk memandu sebuah robot dalam arah yang berlainan dan juga mengetahui lokasi tepat pada persekitarannya adalah matlamat utama robot mudah alih itu. Bagi mencapai ini, satu kaedah dipamerkan pada tesis ini. Satu modul Alat Penjejakan Optik (OTD) digunakan untuk memberi koordinat-koordinat tepat untuk lokasi sekarang robot pada hampir semua permukaan rata. Satu sistem roda holonomi direka bentuk untuk membenarkan robot bergerak pada pelbagai arah. Satu algoritma pergerakan digunakan untuk membenarkan robot bergerak dengan tepat pada satu titik permukaan rata. Ini akan membenarkan robot bergerak ke pebagai arah secara bebas dan samapi pada pelbagai destinasi tanpa sebarang kesulitan. Alat navigasi dan posisi boleh digunakan dalam pada robot-robot industri yang diperlukan untuk bergerak ke ruang yang lain, seperti membawa barang-barang dari satu tempat kepada tempat lain, dan juga meronda dalam satu ruang. Tesis ini juga merangkumi hasil kajian OTD yang boleh mengesan sehingga 1000 titik-titik per inci. Sembilan titik dieksperimenkan pada satu grid eksperimen. Proses kajian itu diulangi dengan 10 kali. Keputusan menunjuk bahawa robot dabapt bergerak dengan holonomic menurut jalan yang diprogramkan dengan ralat yg tidak melebihi 0.1 inch (3 mm) atau tidak melebihi 5% ralat. Tesis ini menghasilkan sistem posisi dgn kejituan tinggi bagi sebuah robot yang juga kurang bergantung kpd persekitaran luar, dan menggunakan ruang kerja dengan cekap.

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LIST OF ABBREVIATIONS

DPI	Dots Per Inch
I^2C	Inter-Integrated Circuit
LED	Light Emitting Diode
OTD	Optical Tracking Device
PIC	Programmable Integrated Circuit
SPI	Serial Peripheral Interface

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CHAPTER 1

INTRODUCTION

1.1 Mobile Robot

In autonomous mobile robotics, the primary task performed is the navigation and positioning (Beom and Cho, 1995). One of the important elements of an autonomous mobile robot is the necessity to guide and orientate the mobile robot in its virtual map (Bhattacharya *et al.,* 2007 and Thomas and Tay, 2001), this is achieved by communicating with the environment, collecting data at a preset rate and finally decoding the data (Noorhosseini and Malowani, 1992 and Cameron, 1994). D'Souza, 1998 conducted an autonomous robot vehicle design workshop with emphasis on sensors and navigation algorithm. The various surfaces and the exact precise reliability of the encoder used in the robot to achieve this task make the navigation difficult. Hu and Gu, 2000 and Betke and Gurvits, 1997 stressed the importance of flexibility and agility of the movement of the robot that determines the efficiency of the navigation system.

1.2 Navigation and Positioning of a Mobile Robot

The process of planning, recording, controlling and executing the movement of a robot, preprogrammed or direct streaming is the function of the navigation and positioning system of a mobile robot. Various navigational techniques have been developed by researches and engineers all around the world. This includes line tracking, use of GPS system and wheel encoding. The basic concept of this system is to communicate with the environment, collect data at a preset rate and interpret the data. The interpreted data is used to guide and orientate the mobile robot in its virtual map. In addition to that, the wheel driving system of the mobile robot plays a vital role in allowing the robot to navigate along a limited direction depending on its wheel architecture (Daisuke *et al.,* 2009 and Brooks, 1986). For this reason, the navigation and positioning system must be reliable and respond with accurate data. However, common mobile robot which employs line tracking system can only work on pre-constructed track where else infrared guided robot only can work within infrared's line of sight (Belkhouche *et al.,* 2006). Furthermore, the sensitivity of the line tracker also limits the performances of the mobile robot. Camera sensing takes a long process time to construct a 3D model of the unknown surroundings and it cannot handle dynamically changing environments (Wu, 2005). It also increases the cost, size, weight and complexity of the robots. The GPS (or DGPS) is bound by the signal that is acquired from the satellites and when the robots were at certain places such as beside hill or building, under bridge or in forest, the positioning would be a failure. In addition to that the GPS is also invalid for indoor application for the same reason. As for driving the robot, Ackerman's steering and differential drive that used inmost mobile robots do not provide efficient navigational freedom to the robots as they only focus on one axis movement of the robot.

1.3 The Need for the Thesis

a) To know the position of the robot on a flat plane without preset gridlines.

The X-Y coordinate of the robot relative to the starting position can be known exactly. This system relies on a very simple input from virtually any surface without preset grid. Thus, making the system more reliable in various environments. The position of the mobile robot will be more accurate, which is the fundamental need for a navigation system.

b) Preprogrammed route on a flat plane with higher accuracy.

Preprogrammed route is the key aspect of an autonomous mobile robot; it allows the mobile robot to navigate autonomously to various desired destinations in a workspace without human intervention (Nishikawa, 1995). The microcontroller translates the obtained data to useful coordinates in higher resolutions as compared to conventional sensors.

c) Incorporate error correction

Error correction is important so that the robot can always stay at the right path. Path correction could be done by storing the path traveled by robot and compare it to the desired path. Path traveled can be register to the microcontroller for the robot to decide the return path or even for future usage (Ulrich and Borenstein, 2000).

1.4 Thesis Objectives

(a) Design and fabrication of Quad Channel Controller Board and holonomic mobile robot platform that implement an optical tracking device(OTD) to acquire instantaneous data on the position of the current coordinate relative to the origin so that the mobile robot able to know the position of the robot on a flat plane without preset gridlines

(b) Interface the developed module to a microcontroller and develop a navigation algorithm based on the data acquired from OTD to implement preprogrammed route on a flat plane with higher accuracy.

(c) Incorporate error correction so that the robot could stay on the correct path without affected by errors caused by outside disturbance.

1.5 Thesis Tools

The thesis involves various work scope. The work scope revolves around C Programming Language, microcontroller architecture, microcontroller interfacing, serial communication and electronics. All these scopes of work are very important for the development of this thesis as all of it is interrelated.

Holonomic platform is chosen for more efficient locomotion (Pin and Killough, 1994), the design of the robot is mainly based on the holonomic wheel that allow the robot to move in any direction on a flat surface (Huang *et al.,* 2010). In addition to that, a Quad Channel Controller Board together with the navigation algorithm is developed for the holonomic robot.

A microcontroller is used to communicate with the OTD using its own protocol (Poika *et al.,* 2007). Data is sent and received from the microcontroller to the OTD to setup and decode position data form the OTD. The interface of the holonomic system with the OTD is achieved by establishing serial communication between the two systems. The data that transmitted and received in bidirectional are mainly consist of the current location that detected by the OTD, targeted location, speed control and position computation from the Quad Channel Controller Board.

C programming Language is used to program the microcontroller module. The test robot, which is also power by a microcontroller, need to be program to recognize and respond to the signal from the transducer module.

In order to develop the system, the microcontroller's architecture is a very important aspect of the design. Based on the architecture, a microcontroller module that reads the output from the optical tracking device, decodes the data, and then passes the data over to the robot's processor is designed. Serial communication is the main platform to interface various parts of the robot.

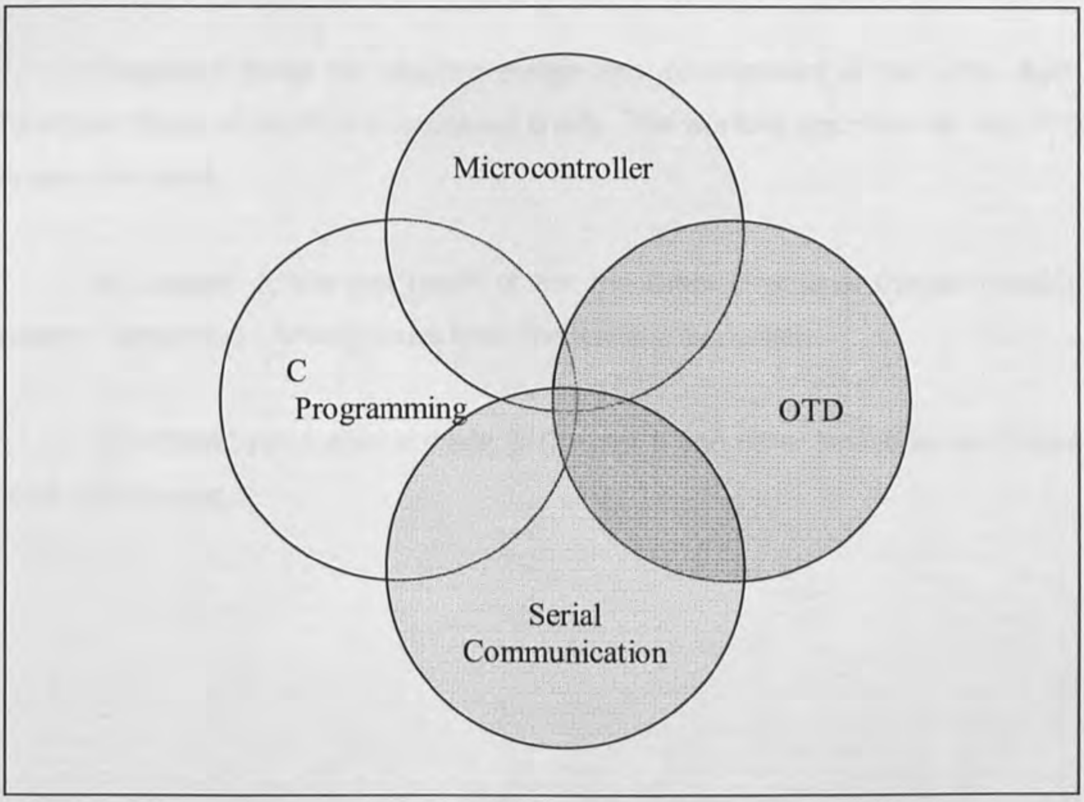

Figure 1.1: Thesis Tools

1.6 Thesis Organization

This chapter, Chapter 1, introduces the mobile robot, navigation and positioning system and also the importance of the system. The need for the project is underlined and the objective of the project is stated. It also briefly explains the work scope of the thesis.

Chapter 2 discusses different types of navigation sensors and driving systems. The sensors discussed include those used in industries, military and for hobbies. Examples of sensor from each type are reviewed. This chapter also highlights the criteria of an ideal sensor. A sensor should have all this criteria or as many as possible.

Chapter 3 explains the general design of the Omni directional Optical tracking robot. This includes the design of the OTD and the Quad Channel Controller Board.

Chapter 4 hosts the detailed design and development of the OTD. Each functional block of the OTD is explained briefly. The working algorithm for the OTD is also discussed.

In Chapter 5, the test result of the the Omni directional Optical tracking robot is presented . Arising issues from the result is discussed.

The thesis' conclusion is made in Chapter 6 and other limitation and future work is discussed.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Holonomicity in the field of robotics refers to the interrelation between the total and the controllable degrees of freedom of a robot. A robot platform is called holonomic if its controllable degrees of freedom are more or equal its total degrees of freedom and it is called non-holonomic otherwise. Holonomicity in mobile robots provides an added advantage in which it has the ability to perform navigation without making many repetitively switching of its orientation along the travel path.

A non-holonomic robot which uses Ackerman steering is usually executed by only one steering motor (DeSantis, 1995). This, however, involves some manipulation of linkages in order to steer the wheels at different angles. The robot is unable to move in any direction instantaneously and a "parallel parking" motion is required when performing sideways movement. Figure 2.1 illustrates the inner front wheel is steered a little more to the right in order to run the platform in the desired direction. Ackermann *et al.,* 1995 and Guldner *et al.,* 1998 had layout a robust control for automatic steering of passenger cars using front and rear sensors.

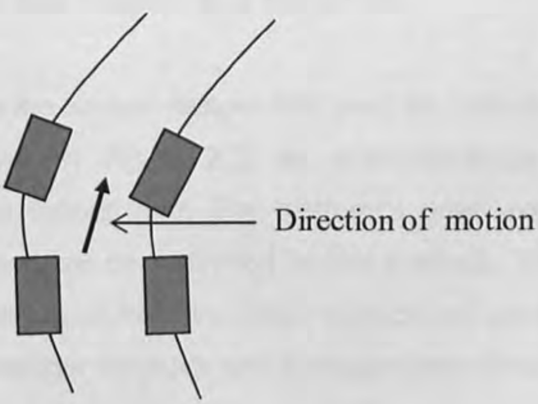

Figure 2.1: Ackerman steering

Another example of non-holonomic robot is using differential steering (Symes, 1958) which the robot is limited to one axis of movement as shown in Figure 2.2. Because of the limited movement of this steering method, lag time should be taken into consideration when navigating the robot (Fierro *et al.,* 1998 and Chung *et al.,* 2001). Zhu *et al.,* 1992 shows that error and lag time occurs between the robot, controller and the observers.

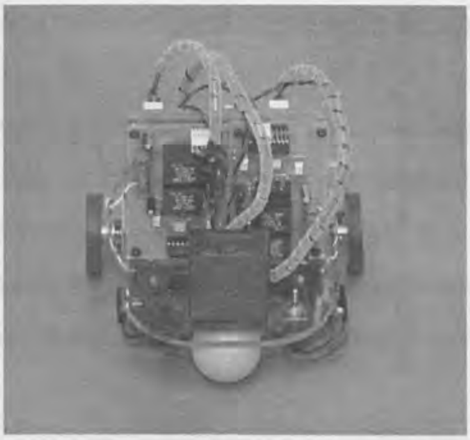

Figure 2.2: Differential steering

In an omni-directional drive robot with omni-directional wheels attached to it with rollers around its circumference allows the robot to move in direction orthogonal to the wheel rotation. These types of robot occupy two independent translational degrees of freedom and one rotational degree of freedom, for total of three degrees of motion freedom on a flat surface.

Currently there are several designs that exist for both research and commercial purpose. As shown in Figure 2.3, an omni-directional platform is used in conjunction with a robotic arm. The platform's drive axes do not intersect its geometric centre and can be controlled by two methods. First, the local method is by using a three degree-of-freedom (DOF) joystick and second is the global control method by using encoder feedback and a wireless pose detection system.

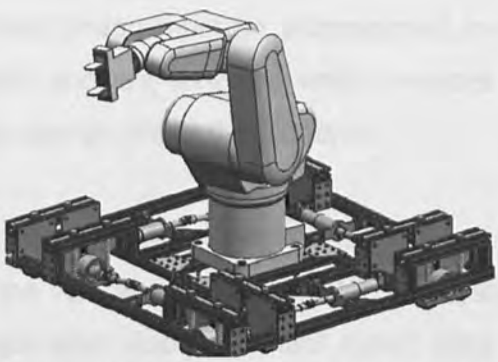

Figure 2.3: Omnibot prototype with a robotic arm

Asama, *et al.,* 1995 contributed in the development of a unique design for an omni-directional mobile robot with a decoupled drive mechanism. This design uses three actuators in a decoupled fashion with no redundancies. The axes of the four wheels in the system all intersect the geometric centre. Four differential gears are used in the system, and by activating the different motors, omni-directional travel is achieved.

Many major improvements have been done in this aspect which includes the modification from four wheels to the three wheels design, fabrication of two chassis for multiple robot experiments, and utilization of more robust metal chassis. Barycza *et al.,* 2004 in the OmniFleet project had designed and fabricated two fully functional chassis which are capable of holonomic motion complete with feedback motion control. Two chassis were constructed in order to provide a platform for future search on co-operative multiple robot experiment. Figure 2.4 demonstrates a holonomic motion robot research, that is, to move in a straight line while rotating at a constant angular velocity.

Figure 2.4: Interior of OmniFleet mobile robot

Any holonomic wheel design must be accompanied by an algorithm. Several algorithms were utilized and are analyzed which includes force coupling matrix witth Euclidean magnitudes to control the platform.

Leow *et al.,* 2002 and Low *et al.,* 2003 used the unit vectors for the wheel coordinates whereby the velocity of each wheel in the system can be determined by simple matrix multiplication. Another control aspect done by Kalmar-Nagy *et al.,* 2004 is the derivation of control algorithms for a three-wheeled omni-directional platform and the development of a Jacobian matrix.

Combining the wheel mechanism and the drive system provides a perfect maneuvering capability for a mobile robot. Since the Ackerman steering system has the constraint of complicated linkages and it is unable to spin, these weaknesses severely reduces the platform's agility in navigation. As a result, an Ackerman-steer platform would be very ineffective in a constrained area. On the other hand, the differential steering system has an increased friction which causes excessive wear to the passive support.

By using the holonomic (Omni-directional) robot the dexterity unavailable in non-holonomic robot can be achieved. It has the ability to travel in any direction while maintaining a certain orientation without a steering system. Gao *et al.,* 2009 shows an example of useful application of holonomic robot by building a floor cleaning robot, whereas Li *et al.,* 2005 built a micro holonomic robot for micro factories. Because of the versatility and complexity of holonomic robot, a tedious algorithm needs to be developed in order to control the holonomic wheels. The holonomic capability alone is not sufficient for an autonomous mobile robot. The primary task performed is the navigation and positioning of the robot. The process includes the planning, controlling and executing the movement of a robot on either a preprogrammed method or by streaming. These are the functions of the navigation and positioning system of a mobile robot.

Although various navigation techniques have been developed by researchers and engineers all around the world, the necessity to communicate with the

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