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TRAJECTORY TR HEELS MOBILE ROBOT

(TRAJEKTORI KAWALAN PENJEJAKAN SISTEM ROBOT DUA TAYAR)

NOR MANIHA BINTI ABDUL GHANI
RAJA MOHD TAUFIKA BIN RAJA ISMAIL
NURUL HAZLINA BINTI NOORDIN
MOHD ASHRAF BIN AHMAD

RESEARCH VOTE NO:
RDU 0903115

Fakulti Kejuruteraan Elektrik & Elektronik
Universiti Malaysia Pahang

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ABSTRACT

TRAJECTORY TRACKING CONTROL OF TWO WHEELS MOBILE ROBOT

(Keywords: infra-red sensor, PID algorithm, line follower Balancing Robot)

This project focuses on the development of a line follower control algorithm for a Two Wheels Mobile Robot. In this project, ATMEGA32 is chosen as the brain board controller to react towards the data received from the Balance Processor Chip on the balance board which monitoring the changing of the environment through two infra-red distance sensor to solve the inclination angle problem. Hence, the system will immediately restore to the set point (balance position) through the implementation of internal PID algorithms at the balance board. Application of infra-red light sensors with the PID control is vital, in order to develop a smooth line follower robot. As a result of combination between line follower program and internal self balancing algorithms, we able to develop a dynamically stabilized Balbot with line follower function.

Key researchers: Nor Maniha Abdul Ghani, Raja Mohd Taufika Raja Ismail, Nurul Hazlina Noordin, Mohd Ashraf Ahmad

Email : **normaniha@ump.edu.my**
Tel No : **09-4242110**

Vote No. : **RDU 0903115**

ABSTRAK

TRAJEKTORI KAWALAN PENJEJAKAN SISTEM ROBOT DUA TAYAR

(Kata kunci : **pengesan infra-red, PID algoritma, pengikut garisan robot**)

Projek ini tertumpu kepada pembangunan pengendali pengikut garis dan algoritma untuk robot dua roda mudah alih. Dalam projek ini, ATMEGA32 dipilih sebagai pengendali papan utama untuk bertindak balas terhadap data yang diterima dari Cip Keseimbangan pada papan keseimbangan yang memantau perubahan persekitaran melalui dua pengesan jarak infra-merah untuk menyelesaikan masalah sudut cerun. Oleh kerana itu, sistem akan mengembalikan ke titik penentuan (kedudukan keseimbangan) melalui pelaksanaan algoritma PID dalaman di papan keseimbangan. Penerapan pengesan sinar infra-merah dengan kawalan PID sangat penting, dalam rangka untuk mengembangkan sebuah robot pengikut garis halus. Sebagai hasil dari kombinasi antara pengaturcara pengikut garisan dan dalaman algoritma menyeimbangkan diri, kita mampu mengembangkan Balbot stabil secara dinamik dengan fungsi pengikut garisan.

Penyelidik : Nor Maniha Abdul Ghani, Raja Mohd Taufika Raja Ismail,
Nurul Hazlina Noordin, Mohd Ashraf Ahmad

Email : **normaniha@ump.edu.my**
Tel No : **09-4242110**

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LIST OF ABBREVIATION

TWIP	-	Two Wheeled Inverted Pendulum
Balbot	-	Balancing Robot
PID	-	Proportional Integral Derivative
BPC	-	Balance Processor Chip
BEMF	-	Back Electromotive Force
GUI	-	Graphical User Interface
IR	-	Infrared
I^2C	-	Inter Integrated IC
LED	-	Light Emitting Diode
CV	-	Control Variable
SP	-	Set Point
PV	-	Process Value
MIPS	-	Microprocessor without Interlocked Pipeline Stages
EEPROM	-	Electrically Erasable Programmable Read Only
SRAM	-	Static Random Access Memory
PWM	-	Pulse Width Modulation
DAC	-	Digital Analog Converter
ADC	-	Analog Digital Converter

CHAPTER 1

INTRODUCTION

1.1 Background of Project

Over the past decades, the research on two wheeled inverted pendulum mobile robot or commonly known as balancing robot have gain momentum in a number of robotic centers around the world due to natural unstable dynamics of the system. [1] Since a Two wheeled balancing robot need a good controller to maintain itself in upright position without the needs from external forces. Thus, providing a good platform for researcher to explore the efficiency of various controllers in control system based on the inverted pendulum model. Nowadays, various controllers were implemented on two wheeled balancing robot for example's Linear Quadratic Regulator, Pole-Placement Controller, Fuzzy Logic Controller, and Proportional Integrated Derivative Controller. [3]

A two wheeled balancing robot is categorized by the ability to balance on its two wheels and spin on the spot. As a result from this additional maneuverability allows easy navigation on the various terrains, turn sharp corner, traverse small step or curbs and ability on carry load. Two wheeled robots also have a small footprint than three or four wheeled robots thus enable it to travel around corridors and tight corners more easily. [4] These capabilities have the potential to solve many challenges in industry and society. As the two wheeled balancing robot has been investigated and developed to become human transport machine. The Segway, Pegasus, and iBot models are the example of the design of two wheeled balancing robot as a human transport machine. In addition, a motorized wheelchair utilizing this technology would give the operator greater maneuverability and thus access to places most able-bodied people take for granted. Small carts built utilizing this technology allows humans to travel short distances in a small area or factories as opposed to using cars or buggies which is more polluting. [2]

In this project, Balbot Advanced is an autonomous, active-balancing robot that is fully customizable been design and fabricate as two wheeled balancing robot platform that has ability to balance itself on a flat terrain with add-on line follower function. The robot chassis design is robust and symmetrical with high centre of gravity. These mobile robots not only solve the balancing problem but also can automatically move around and avoid basic obstacles through the implementation of Dual ground Sensor and looking forward infrared sensor respectively. The Dual ground sensor is located at the bottom of the Balbot which is the infrared IR distance sensor, where ground sensors are used to measure the tilting angle. Powerful ATMEGA32 processor is used to be the brain of the robot. BEMP motor velocity sensor is used to obtain the speed of the platform. The entire controller algorithm will be compute into C programming and store inside the microcontroller. Without an active control system, the robot would just fall over. Thus, the controller plays an important role in this project. Lastly, three pairs of infra-red sensor are used to guide the line follower task during balance state.

There are a few specific tasks included such as:

1. Integration of sensor to determine and updating the status of the platform.
2. Integration of hardware for data acquisition.
3. Integration and testing of the performance of the controllers for trajectory control.
4. Integration of hardware for line follower application.

1.2 Problem Statement

The problem statement for this project work is expressed as follows:

"To develop a stable line follower circuit and control algorithm for the purpose of line following of two wheels balancing robot"

1.3 Objective of Project

There are three main objectives in this project which are;

1) To control the Balbot with line following function using Atmel Microcontroller.

2) To design and construct a simple and functional IR sensors circuit for line detection.

3) To program the microcontroller to perform stable and smooth line following task during balanced state.

1.4 Scope of Project

In order to achieve the objective of the project, there are few scopes had been outlined which involve hardware and software:

1) A Balbot is to be considered able to conduct self-balancing and position control using Linear Controller via the existing balance board and default program.

2) Construct a line following hardware system using Infra-red sensor.

3) Develop a line follower algorithm to perform line following task.

1.5 Project Methodology

The research project are divided into chapters, each recorded a chronological step in the process of developing and structure the Line Follower Balbot. This approach was utilized in attempt to progress the project from one task to the next as it was undertaken. Each is clear so that it builds on the preceding task thus evolving the robot within the goals and requirements generated. This eventually led to the completion of the Balbot that met the objectives within the timeframe available.

Chapter 1 formed the first step where key points and objectives were established including the idea of actually what is a two wheeled balancing robot. Understanding about this project is critical in determining plans for conducting research and performing the design work.

Chapter 2 provides the second step in which a comprehensive understanding of previous projects and approaches is required. This established the foundations for making informed decision based on the past experiences and problem encountered. This can help set up an avoidance of problems, sufficient planning of resources and the helpful application of effort.

Chapter 3 entailed the software review, hardware review, and balancing with line following algorithm in Balbot. Detailed information about the basic operation of Balbot and hardware specification such as microcontroller Brain Board and Balance Board was listed and explained. The Balbot is considered to be balances on its body first then line following can be conducted. The line following feature for Balbot is based 3 infra-red sensors and the line follower programming algorithm that had designed. This step expanded to include a method to setup the Balbot and loading program on to the Balbot.

The subsequent step was to analyze the actual performance of the Balbot and ascertain its ability in achieving the objectives of balance and following line. This also provided the opportunity to calibrate and perform additional fine tuning of the output allowing it to become more effective and efficient in its performance.

The final component comprises of a complete assessment of each process undertaken, the choices made and achievements obtained during the project as well as evaluation of the final Balbot effectiveness. This expanded to include recommendations for future work that could be undertaken in an effort to improve areas of the process or design, addition of capabilities, or how to overcome problems that may have been encountered.

1.6 Flow of Project

The project implementation and works flow for Balbot are summarized into flow chart as shown in figure 1.1. The details of the works of the project that had been implemented are shown in the form of Gantt chart for both PSM 1 and PSM 2 as in Table 1.1 and Table 1.2.

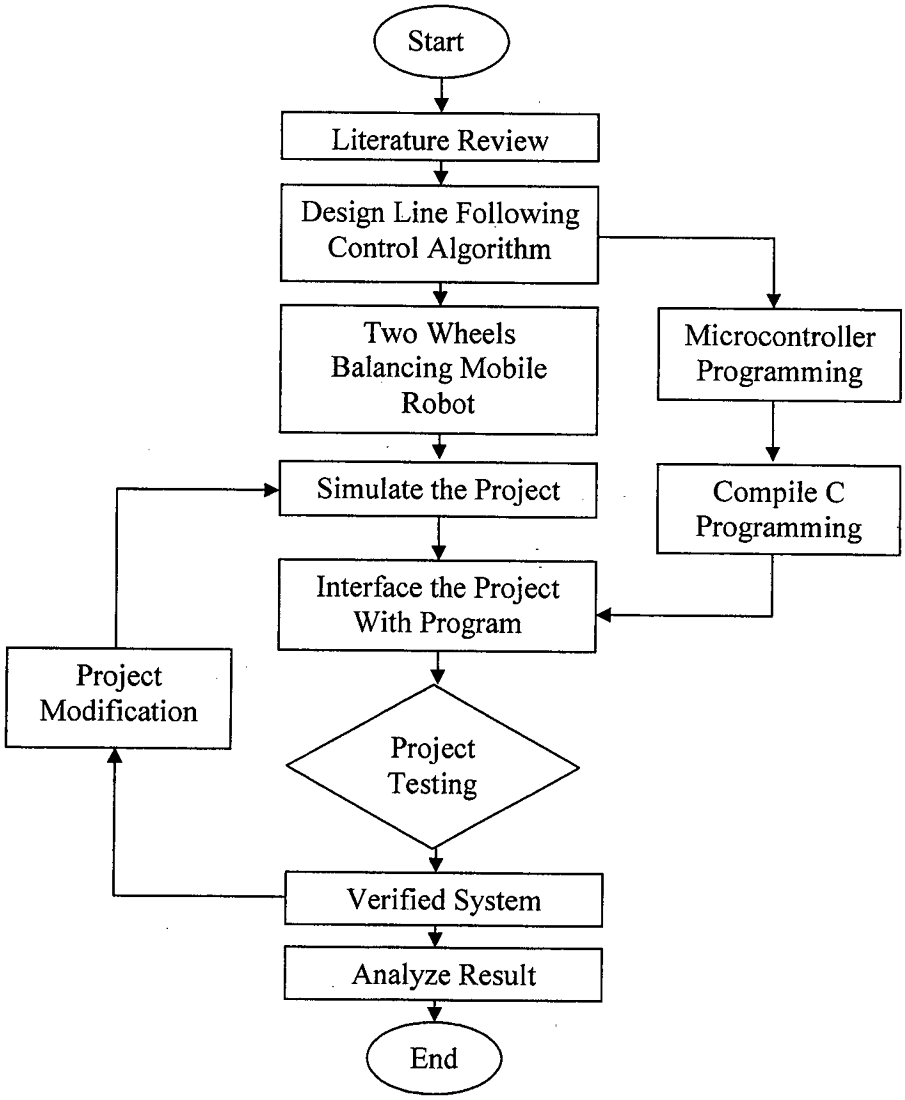

Figure 1.1: Project Work Flow

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Conducting literature review prior to begin a research project is vital in understanding two wheels balancing robot control technique, as this will supply the researcher with much needed additional information on the methodologies and technologies available and used by other research counterparts around the world. This chapter provides a condensed summary of literature reviews on key topics related to balancing a two-wheeled robot. [2] Comparisons between the present project and the related topics of existing information will also be discussed.

The two wheels balancing concept has been a topic of high interest among the control engineering community. The uniqueness and complexity of the two wheels balancing concept has made it an ideal concept that can be used for both commercial and military (government) applications. In past few years, researcher and engineers have applied the two wheels balancing model to various fields, which include walking gait for humanoid robots, personal transport systems and robotic wheelchairs. As examples, the Segway is used for commercial purposes and the prototype of the VECNA B.E.A.R robot project can be used for government military operation. Humanoid like robots that gain the mobility through two wheels have become popular in the past few years in commercial and government.

The control problem can be simulated and implemented on a classroom setting to teach control engineering students the need for control in the unstable two wheeled robot. The following research literature abstracts summary of some popular balancing robot platforms and extra features technologies that are related and used by researchers and engineers around the world which are available in an attempt to gain an understanding and appreciation of two wheels balancing robot.

2.2 Previous Project Work

2.2.1 BallBot

A research professor at Carnegie Mellon University, Ralph Hollis who has developed a totally unique balancing robot that balances on top of a bowling ball. He calls his robot design "BallBot" [5, p. 72]. Mr. Hollis and his research associates believe that robots in the future will play a vital role in the daily lives of humans. He believes that in order for robots to be productive in our daily lives, some key problems need to be solved first. One the important problem he states in his article about mobile self balancing robots is the overall structure of the robot itself.

As stated by Ralph Hollis," Robots tall enough to interact effectively in human environments have a high centre of gravity and must accelerate and decelerate slowly, as well as avoid steep ramps, to keep from falling over. To counter this problem, statically stable robots tend to have broad bodies on wide a wheelbase, which greatly restricts their mobility through doorways and around furniture or people" [5, p. 74]. The size of the robots will ultimately affect its mobility of the robot. In order to solve the problem, Hollis came up with a new design that improved the robot's overall structure and mobility. Hollis and his associates have built a five foot tall, agile, and skinny robot. The robot's design is to balance itself on top of a spherical wheel. Hollis compares his robot structure design much like a giant ball pen or a circus clown trying balance on top of a ball. [6]

A side from acknowledging and solving the structure and mobility difficulty, Hollis also faced a major challenge when it came to keeping the self-balancing robot on a stable vertical position. Hollis found that the best way to solve this new issue was by implementing into his design advance sensors and control algorithms. The sensors that he incorporated included a gyroscope and an accelerometer. They were set and placed orthogonal to each other. Hollis implemented a Linear Quadratic Regulator (LQR); a control algorithm technique used to keep the BallBot in a stable vertical state. The LQR is based on optimal control theory.

The main objective when using optimal control techniques on a system is to minimize the effort to stabilize the BallBot in the vertical position. The Ballbot's incorporates optimal control algorithms. These control algorithms helped increase stability and system robustness. BallBot major strength is the inertial measurement units used to provide the tilt angle information. The Ballbot's size and inability to climb staircases were obvious weaknesses. Hollis's article "BallBot" is informative piece of literature that has presented a technological innovation in robotics. It has inspired parts of this master's project.

Just like Hollis BallBot, this master's project two wheeled balancing robot also incorporates the control techniques in order to achieve a vertical stability. After acquiring additional information on both the gyroscope and accelerometer sensors, it was determined that it was the best choice of sensors to be implemented in the self-balancing two wheel robot. As there are similarities between Hollis's BallBot and self-balancing two wheel robot, there are also differences. The structures and control algorithms used were a major difference. As stated before, the BallBot uses optimal control theory to minimize the robot's effort to stabilize. The self-balancing two wheel robot used for this master's project will use classical control theory.

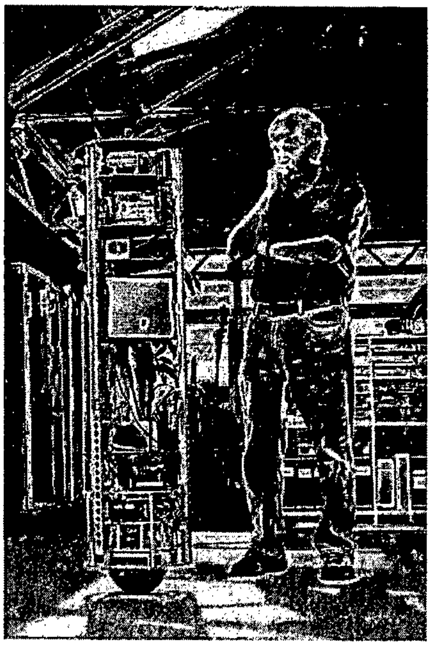

Figure 2.1: Ralph Hollis and his team's BallBot

2.2.2 nBot and Legway

Two wheel balancing robots have also gain popularity among hobbyists and engineering students. Examples of such popular two wheeled balancing include the nBot and the Legway. The two wheeled robot platforms have drawn high interest from the robot enthusiast communities.

nBot is a two-wheeled balancing robot built by David P. Anderson. This robot uses commercially available inertial sensors and motor encoders to balance the system. Such inertial sensors that are used on nBot are an accelerometer and a gyroscope. The basic idea for a two-wheeled dynamically balancing robot is pretty simple which is driving the wheels in the direction that the upper part of the robot is falling. If the wheels can be driven in such a way as to stay under the robot's center of gravity, the robot remains balanced. In practice this requires two feedback sensors: a tilt or angle sensor to measure the tilt of the robot with respect to gravity, and wheel encoders to measure the position of the base of the robot. Four terms are sufficient to define the motion and position of this "inverted pendulum" and thereby balance the robot. These are

1. The tilt angle and
2. Its first derivative, the angle velocity,
3. The platform position, and
4. Its first derivative, the platform velocity.

These four measurements are summed and fed back to the platform as a motor voltage, which is proportional to torque, to balance and drive the robot. (Anderson D.P. 2003)

A researcher, Steve Hassenplug has successfully constructed a balancing robot called Legway using the LEGO Mindstorms robotics kit. Two Electro-Optical Proximity Detector sensors from HiTechnic Sensors to provide the tilt angle information and detect lines. The controller is programmed in high level programming language specifically created for LEGO Mindstorms which was written in brickOS (LegOS) and uses EOPDs to maintain a constant distance from the ground. As the distance decreases, Legway moves forward. As the distance increases, Legway moves backward. Every 50 ms, Legway attempts to recalculate the balance point by measuring the current distance and motor speed. To move forward for line following, Legway actually sets the motors to run backward, causing a tilt, which it automatically corrects by moving forward. When one sensor is over the line, it stops that motor, and Legway balances using only the other motor, causing it to turn. To spin in place, both motors are shifted "off center" in opposite directions, the same amount, but they still correct for tilting. Legway uses its two optical proximity detectors to balance the two wheel LEGO robot. (Hassenplug S. 2003)

Major strengths of the both the nBot and the Legway are the accessibility and availability of parts and the lower building cost. The fact that these two designs use off the shelf parts with no custom parts make them easier to build and in turn bring down the price. With that in mind, the autonomous self-balancing two wheel robot was also designed to accommodate commercially available parts. The autonomous self balancing two wheel robot presented on this master's project report will have almost similar design structure as that of David P. Anderson, nBot. A weakness of both the Legway and nBot is the limited environment and terrain that both robots can travel.

The articles on the nBot and Legway briefly explained the control algorithms used to balance and keep the both robots in a stable state. The nBot created by David P. Anderson and the Legway created by Steve Hassenplug are both two wheeled balancing robots can be made from little control theory knowledge. Both robots are modelled after the inverted pendulum.

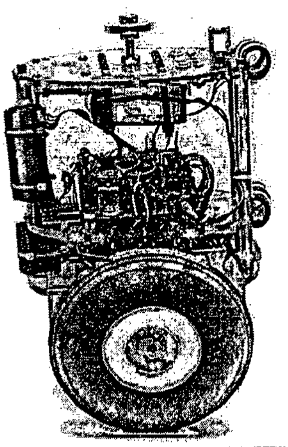

Figure 2.2: nBot
(Anderson D.P. 2003)

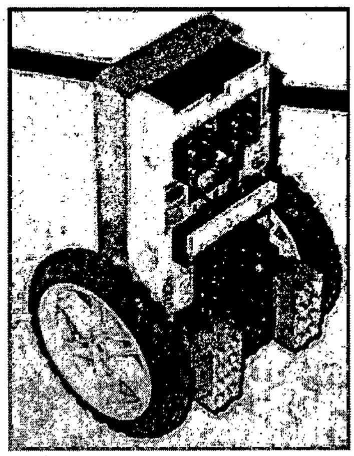

Figure 2.3: Legway
(Hassenplug S. 2003)

2.2.3 Segway

In past few years, the use of personal human transport vehicles has gained popularity. The Segway PT is a popular personal vehicle that is available to the public. Invented by Dean Kamen, the Segway PT's dynamics are identical to the inverted pendulum. For added mobility, the Segway is also based on the two wheel platform design. The advanced control algorithms behind the Segway transporter are a company trade secret. The basics of a Segway are computers that process the control algorithms, two tilt sensors, five gyroscopes, and two electric motors. Only three of the five gyroscopes are used to balance the Segway. The remaining two gyroscopes are used as backup. These critical components that make up a Segway are important to keep the vehicle in perfect balance. Current models of the Segway personal transporter can achieve top speeds of 12.5 mph. The Segway is able to navigate thru rough terrain, while successfully carrying a human onto of the platform. The Segway is typically found in urban settings; used for guided tours and city government officials.

The strengths of the Segway are that the personal transporter can be used in outdoor recreation. It is an alternative for people that are unable to walk long distances or ride a bike to enjoy the outdoors without the use of a vehicle. Since the Segway runs on rechargeable batteries, it is environmental friendly. A disadvantage of Segway is its cost which can run in the few thousands of dollars.

In contrast to this master's project on the autonomous self balancing two wheel robot, it has only a cost of few hundred dollars. The autonomous self balancing two wheeled robot presented on this master's project report can implement basic control algorithms similar to the Segway.

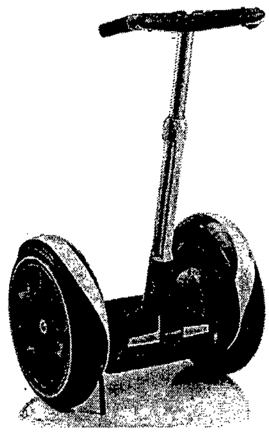

Figure 2.4: SEGWAY
(Dean Kamen 2001)

2.2.4 Introduction of Line Follower Robot

Line follower robot is one of the self operating robot that follows a line that drawn on the floor. Generally, the path is predefined and can be either visible like a black line on a white surface with a high contrasted colour or it can be invisible like a magnetic field. The basic operations of the line following are as follows:

1. Capture line position with optical sensors mounted at front end of the robot. Most are using several numbers of photo-reflectors, and some leading contestants are using an image sensor for image processing. The line sensing process requires high resolution and high robustness.

2. Steer robot to track the line with any steering mechanism. This is just a servo operation; any phase compensation will be required to stabilize tracking motion by applying digital PID filter or any other servo algorithm.