NEURAL NETWORK SELF-TUNING PID BASED NAVIGATION CONTROL OF AUTONOMOUS UNICYCLE-LIKE MOBILE ROBOT IN INDUSTRY 4.0

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DEDICATION

This thesis is dedicated to my parents, who have always supported me in my studies, not only by paying for my tuition but also by encouraging me when I felt pressure to study.

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ABSTRACT

In the recent years, mobile robots, one of the technologies under the "Industry 4.0" concept, have been used in a wide range of industry sectors, including manufacturing and production, agriculture, healthcare, etc. One of the applications of a mobile robot is transportation to deliver things from one place to another, following the planned trajectory. The conventional way of controlling the trajectory tracking of a mobile robot is by using the classical PID control schemes. However, it has been found that the performance was not very satisfying because PID controllers have a weak adaptability to the mobile robot dynamic system which consists of nonlinearity and uncertainty that varies with time. In order to achieve adaptive controller, this study proposes a Neural Network (NN) self-tuning PID based navigation control which is capable to perform on-line tuning of the PID parameters to meet the desired control performance and stability during operation. In this work, MATLAB-Simulink software is used to simulate the dynamic model of a unicycle-like mobile robot. PID controllers which are tuned with the Trial & Error method is firstly used to control the trajectory tracking of the mobile robot. Then, the same dynamic model is controlled by using the proposed NN self-tuning PID controllers. The simulation results obtained from both simulations are compared from the aspect of the distance error and energy consumption by calculating the IAE index and kinetic energy index, and the results show the capability of the NN self-tuning PID controllers to perform better than a PID controller in a non-linear system.

ABSTRAK

Dalam beberapa tahun kebelakangan ini, mobil robot, salah satu teknologi dalam konsep "Industri 4.0", telah digunakan dalam pelbagai sektor industri, termasuk pembuatan dan pengeluaran, pertanian, penjagaan kesihatan, dll. Salah satu aplikasi mobil robot sebagai alat pengangkutan untuk menghantar barang dari satu tempat ke tempat lain, mengikut trajektori yang dirancang. Cara konvensional untuk mengawal penjejakan trajektori mobil robot adalah dengan menggunakan skema kawalan PID klasik. Walau bagaimanapun, didapati prestasinya tidak begitu memuaskan kerana pengawal PID mempunyai kebolehsuaian yang lemah kepada sistem dinamik mobil robot yang terdiri daripada ketaklinieran dan ketidakpastian yang berubah mengikut masa. Untuk mencapai pengawalan adaptif, kertas kerja ini mencadangkan kawalan navigasi berasaskan PID penalaan sendiri Rangkaian Neural (NN-PID) yang mampu melakukan penalaan dalam talian bagi parameter PID untuk memenuhi prestasi kawalan dan kestabilan yang diingini semasa operasi. Dalam kertas kerja ini, perisian MATLAB-Simulink digunakan untuk mensimulasikan model dinamik mobil robot seperti unicycle. Pengawalan PID yang ditala dengan kaedah “Trial & Error” digunakan pertama kali untuk mengawal penjejakan trajektori mobil robot. Kemudian, model dinamik yang sama dikawal dengan menggunakan NN-PID yang dicadangkan. Keputusan simulasi yang diperoleh daripada kedua-dua simulasi dibandingkan dari aspek ralat jarak dan penggunaan tenaga dengan mengira indek IAE and indek tenega kinetik, dan keputusan menunjukkan keupayaan pengawalan NN-PID untuk berpretasi lebih baik daripada pengawalan PID dalam sistem bukan linear.

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LIST OF ABBREVIATIONS

IR4.0	–	Industry 4.0
AGVs	–	Automated Guided Vehicles
WBR	–	Wheeled Mobile Robot
NN	–	Neural Network
PID	–	Proportional Integral Derivative
IAE	–	Integral Absolute Error
GA	–	Genetic Algorithm
PSO	–	Particle Swarm Optimization

LIST OF SYMBOLS

u	–	linear velocities
ω	–	angular velocities
G	–	center of mass of the robot
C	–	position of the caster wheel
E	–	location of a tool onboard of the robot
h	–	point of interest with x-coordinate and y-coordinate in the XY plane
ψ	–	yaw angle of the robot with respect to the XY plane
B	–	the central point of the virtual axis linking the traction wheels
a	–	distance between point h and B
ω_r	–	right wheel velocities
ω_l	–	left wheel velocities
r	–	wheel radius
d	–	lateral distance between two wheels
θ	–	a vector of system identified parameters
δ	–	a vector of system parametric uncertainties
m	–	robot mass
I_Z	–	moment of inertia at point G
R_a	–	motor electrical resistance
k_b	–	motor back emf constant
k_a	–	motor torque constant
B_e	–	friction coefficient
I_e	–	moment of inertia of each group rotor-reduction gear-wheel
R_t	–	nominal radius of the tires
e	–	error signal
K	–	kinetic energy
L	–	length of mobile robot
W	–	width of mobile robot
h_i	–	hidden layer activation function

S_i	–	sum of the input/hidden layer weighting coefficients and the input data
O_l	–	output layer activation function
r_l	–	sum of the hidden/output layer weighting coefficients and the output data from hidden layer
$C(n)$	–	control signal
$w_{j,i,l}$	–	weighting coefficient
e_c	–	control input error
e_y	–	system output error

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CHAPTER 1

INTRODUCTION

1.1 Problem Background

Ever since the term “Industry 4.0” (IR4.0) has been introduced by the German government in 2011. It has been the subject of global discussion because people believe that this new concept will bring revolution to the current industries and improve the efficiency of the manufacturing process [1]. One of the concept that included in IR4.0 is fully automated so that every process in the industry does not require the presence of any human beings, including manufacturing, transportation, monitoring, etc. For load transportation, automatic guided vehicles (AGVs) are the most often used robots to transport heavy materials around a large industrial building [2]. In the real world, there are several types of AGVs with different hardware design, navigation system, and steering control. One type of AGVs is the conventional wheeled mobile robot (WBR) which consists two or more wheels to operate. A conventional wheeled mobile robot has fixed tires that could not perform side-way sliding. This factor has restricted the movements of the mobile robot and it could never move horizontally. The mathematical model of this type of mobile robot contains of velocity constraint that cannot be integrated to a constraint on the configuration of the robot. Hence, they also known as nonholonomic mobile robot. The wheeled mobile robots can be divided into several types depend on the amount of wheels and also the hardware design, such as unicycle model, differential drive model, bicycle model, etc. Among them, unicycle-like model has been used a lot to accomplish different tasks, because it has a good mobility and simple configuration. A WBR is a nonlinear system which consists of disturbances and uncertainties that varies with time, hence many researches have been done for this type of model for nonlinear control. For an example for load transportation, the dynamics of the mobile robot will change when it is unloaded or loaded with a weight or reached another area with different road surface. The change of the mobile robot dynamics will affect its navigation performance, such as trajectory tracking, path following, point to point motion, and purely reactive motion [3].

There are a lot of researches have been done for nonlinear control of the unicycle-like mobile robot for trajectory tracking purposes. At first, most controllers that designed are based only on the mobile robot kinematics [4, 5]. However, it has been found that the mobile robots will have a steady-state error and kinematic controllers are not suitable for heavy load transportation. Hence, it is essential to consider also the mobile robot dynamics and take the disturbances and uncertainties into account. (De La Cruz, et al., 2006) has formulated a mathematical dynamic model for the unicycle-like mobile robot, and introduced a identification method to identify the parametric values of the mobile robot [6]. In 2011, He also proposed a PID dynamic controller to control the dynamics of the mobile robot, but it has been found that the tracking performance of the PID dynamic controller is not very satisfying when the parametric values of the mobile robot are not correctly identified or there is a change in the mobile robot dynamics. In order to solve the nonlinearities problems, (Martins, F.N., et al., 2008) has proposed an adaptive dynamic controller which is capable to update the parametric values automatically when the mobile robot is running [7]. However, the proposed method has a slow updating speed and the tracking performance yet to achieve the expectation. Other than that, (Martins, F.N., et al., 2012) has proposed a velocity-based adaptive dynamic controller which the cost function used for the adaptation is generated using Genetic algorithm (GA) [8]. The results show a good tracking performance, however, this method requires offline tuning which is not suitable for system that its dynamics will change during operation such as load transportation. The parameters must be tuned again when the weight of the mobile robot or the operating environment changed. (Majid, N.A., et al., 2016) [9] has proposed a particle swarm optimization (PSO) based PID dynamic controller to control the unicycle-like mobile robot, and the results show better tracking performance than GA based controller from the aspect of smaller distance error. However, it has the same issues as GA which requires offline tuning and the process takes time, and it has a larger energy consumption. Both GA and PSO controllers are not suitable to use on load transportation application because the parametric values of a mobile robot will change when it is loaded with a weight or unloaded, and the performance of the controllers will be affected. To solve the above issue, a Neural

Network controller has been proposed by (Xianzhong Cui, Shin K.G., 1993) which the error is fed into the network to produce a control signal to the system [10]. However the performance of the controller is not quite satisfied yet for practical use. In order to improve the performance, some researchers proposed the Neural Network-based PID controller which the current process error, accumulated process error, and change rate of the process error are considered [11-13]. It has been proved that the PID gains will change according to the system dynamics, however, the PID gains are limited to a maximum of 1 due to the selection of the activation function which is not suitable for some application.

In this project, a Neural-Network (NN) self-tuning PID based dynamic controller which the PID gains are not restricted by the activation function is proposed in order to overcome the nonlinearities problems associated in the unicycle-like mobile robot. The design of the controller is divided into two parts with inner-outer loop [7]. The outer loop consists of a kinematic controller to control the kinematics of the mobile robot, while the inner loop consists of the proposed dynamic controller to control the dynamics of the mobile robot. Both controllers work together to form a complete trajectory tracking controller for the mobile robot. As a comparison, a PID dynamic controller has been designed at first to compare with the proposed NN self-tuning PID based dynamic controller about the performance which can be evaluated based on the Integral Absolute Error (IAE) index and energy consumption.

1.2 Problem Statement

The conventional way of controlling the trajectory tracking of a mobile robot is by using the classical PID control schemes. However, it has been found that the performance was not very satisfying because PID controllers have a weak adaptability to the mobile robot dynamic system which consists of nonlinearity and uncertainty that varies with time. In order to achieve adaptive controller, this project proposes a Neural Network (NN) self-tuning PID based navigation control which is capable to perform on-line tuning of the PID parameters to meet the desired control performance and stability during operation.

1.3 Aim and Objectives

The objectives of this project are 1) design a Neural Network (NN) self-tuning PID based navigation control for a unicycle-like mobile robot and 2) to evaluate the performance of the proposed control via simulation.

In order to achieve these objectives, the following works are to be performed:

(a) Research on applications of mobile robot in IR4.0, control of mobile robot and technique to tune PID.

(b) Formulate a mathematical model of a unicycle-like mobile robot.

(c) Design PID control of mobile robot.

(d) Simulate the PID control of mobile robot using MATLAB/Simulink.

(e) Design NN Self-Tuning PID control of mobile robot.

(f) Simulate the proposed self-tuning PID control of mobile robot using MATLAB/Simulink.

(g) Compare the results of PID and proposed self-tuning PID control of mobile robot.

1.4 Scope and Limitations

The scope of study is limited to the theoretical study which the real mobile robot is not be built for experiment. The research is restricted to the study of a mobile robot with conventional wheel which does not allow side-way sliding. This means that the mobile robot model is nonholonomic which the constraints cannot be written as an equation between coordinates. The study focuses on the kinematics, dynamics, and control of a unicycle-like mobile robot model which the unicycle-like model is a simplified modeling approach modified from the differential drive mobile robot. A circular trajectory is used as the reference for the mobile robot to follow and kinematic controller and dynamic controller are designed to control the kinematics and dynamics of the mobile robot. The performance the controllers will be evaluated based on the distance error by calculating its IAE index, and the energy consumption.

1.5 Output of the Project

The outputs of the project are:

(a) Mathematical model of a unicycle-like mobile robot.

(b) Mathematical model of a circular trajectory.

(c) Parameters of a PID control of mobile robot.

(d) NN Self-Tuning PID based navigation control of mobile robot.

(e) Graphs of the distance error of the mobile robot.

1.6 Project Timeline

Figure 1.1 shows the project timeline of the Master Project 1.

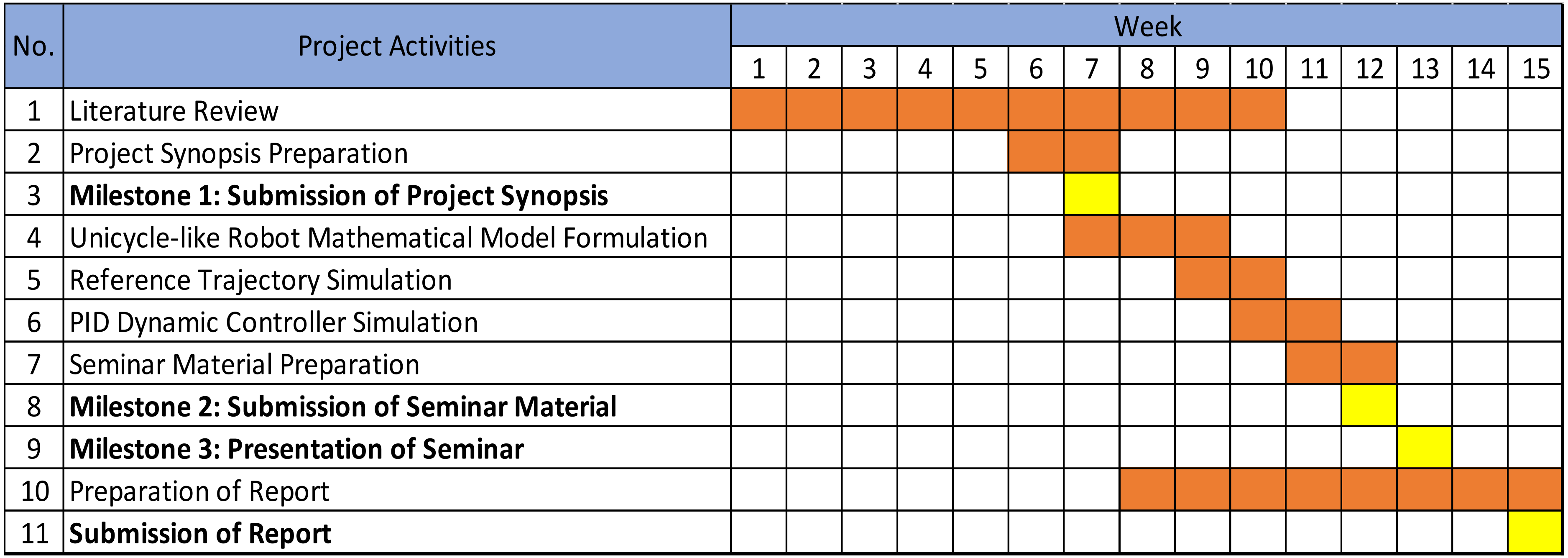

Figure 1.1 Project timeline 1

Figure 1.2 shows the project timeline of Master Project 2.

No.	Project Activities	Week																	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	Mathematical Design of PID Neural Network																		
2	Project Synopsis Preparation																		
3	**Milestone 1: Submission of Project Synopsis**																		
4	Coding PID Neural Network in MATLAB																		
5	Simulate the System Model with PID Neural Network																		
6	Evaluate the Performance of NN-PID Controller																		
7	Seminar Material Preparation																		
8	**Milestone 2: Submission of Seminar Material**																		
9	**Milestone 3: Presentation of Seminar**																		
10	Preparation of Thesis																		
11	**Milestone 4: Submission of Draft Thesis**																		
12	**Submission of Final Thesis**																		

Figure 1.2 Project timeline 2

1.7 Research Flow Process

Figure 1.3 shows the research flow process of the Master Project 1.

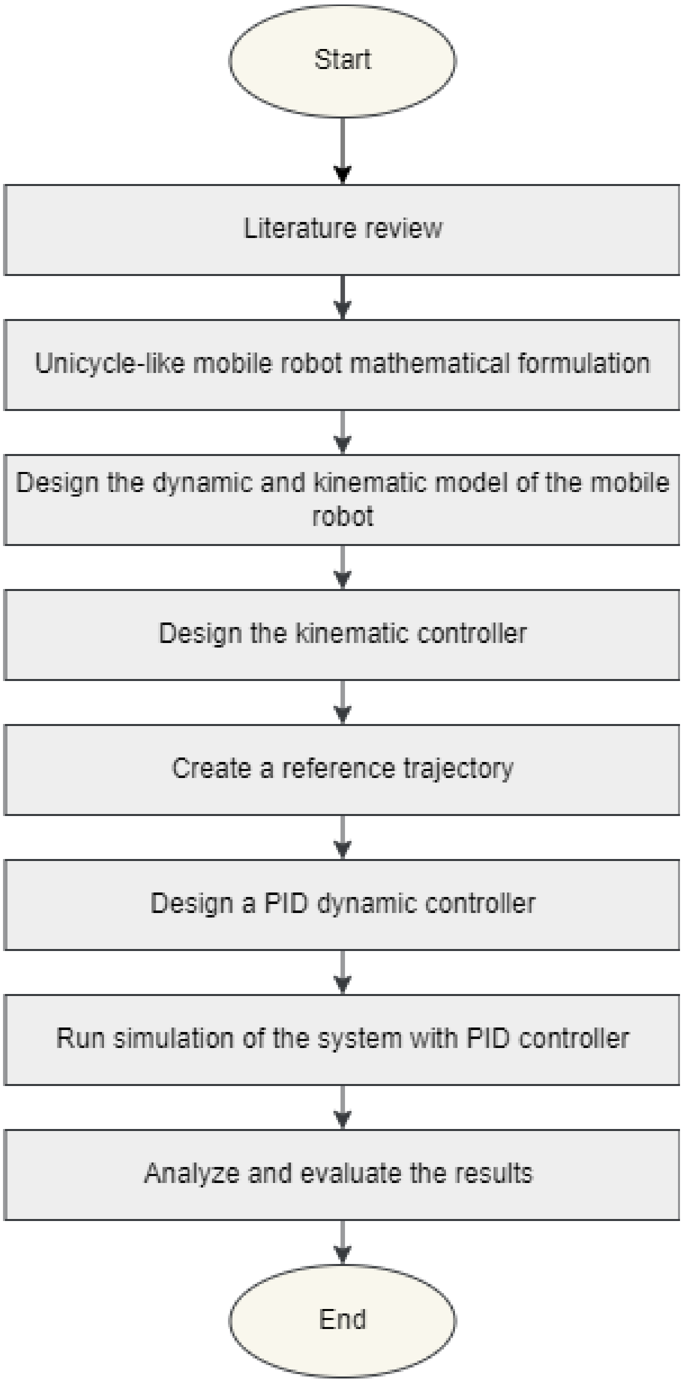

Figure 1.3 Block diagram of the flow process of Master Project 1

Figure 1.4 shows the research flow process of the Master Project 2.

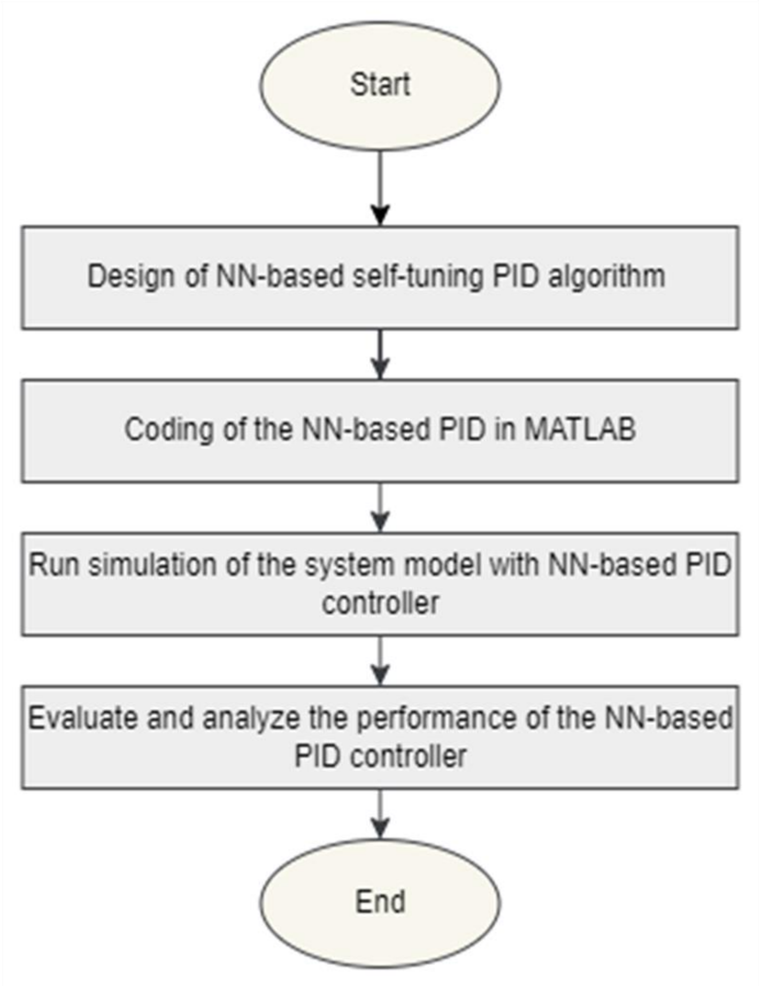

Figure 1.4 Block diagram of the flow process of Master Project 2

1.8 Thesis Outline

Chapter 1 covers the background of the problem, the problem statement, aim & objectives, scope and limitations, outputs, project timeline, and research flow process of this project.

Chapter 2 discusses the literature background on the unicycle-like mobile robot and its mathematical model. This includes the state-of-the-art of the vehicle models that have been formulated to control the robot motions and also the control techniques used. Besides that, this chapter also discussed about the theory and working principle of the circular trajectory, PID control scheme, and neural-network (NN) which have been used in this project.

Chapter 3 covers the overview of this project and the methodology used in this project such as the design and simulation of the whole unicycle-like mobile robot system including the dynamic and kinematic model of the mobile robot, kinematic controller, reference trajectory, PID dynamic controller, and NN-PID controller by using MATLAB & Simulink.

Chapter 4 covers the results and discussion of the experiments of the project. These include the graph of the trajectory response with and without a PID dynamic controller, the linear velocity and angular velocity response of the system using PID controller, the distance error using PID controller, followed by the trajectory response, linear velocity and angular velocity response, and distance error using the proposed NN-PID controller. A comparison between the PID controller and NN-PID controller has been done which their performance is evaluated by finding the integral absolute error (IAE) and the energy indexes.

Chapter 5 concludes the results of the research and gives suggestion to the future works and development.

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