DESIGN OF PID CONTROLLER WITH INTEGRATION OF ARTIFICIAL INTELLIGENCE FOR MACHINE TOOLS APPLICATION

Submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Manufacturing Engineering (Hons.)

by

NURUL QAMARIYAH BINTI MISBAHUL MUNIR

B051410114

940329-01-6658

FACULTY OF MANUFACTURING ENGINEERING

2018

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA MUDA

Tajuk: **DESIGN OF PID CONTROLLER WITH INTEGRATION OF ARTIFICIAL INTELLIGENCE FOR MACHINE TOOLS APPLICATION**

Sesi Pengajian: **2017/2018 Semester 2**

Saya **Nurul Qamariyah Binti Misbahul Munir (940329-01-6658)**

mengaku membenarkan Laporan Projek Sarjana Muda (PSM) ini disimpan di Perpustakaan Universiti Teknikal Malaysia Melaka (UTeM) dengan syarat-syarat kegunaan seperti berikut:

1. Laporan PSM adalah hak milik Universiti Teknikal Malaysia Melaka dan penulis.
2. Perpustakaan Universiti Teknikal Malaysia Melaka dibenarkan membuat salinan untuk tujuan pengajian sahaja dengan izin penulis.
3. Perpustakaan dibenarkan membuat salinan laporan PSM ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. *Sila tandakan (√)

☐ SULIT (Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysiasebagaimana yang termaktub dalam AKTA RAHSIA RASMI 1972)

☐ TERHAD (Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/ badan di mana penyelidikan dijalankan)

☑ TIDAK TERHAD

Disahkan oleh:

_____ _____

Alamat Tetap: Cop Rasmi:

_____

_____

_____

Tarikh: _____ Tarikh: _____

DECLARATION

I hereby, declared this report entitled "Design of PID Controller with Integration of Artificial Intelligence for Machine Tools Application" is the result of my own research except as cited in references.

Signature : ……

Author's Name : NURUL QAMARIYAH BINTI MISBAHUL MUNIR

Date : 1st July 2018

APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfilment of the requirement for degree of Bachelor of Manufacturing Engineering (Hons.). The member of the supervisory committee is as follows:

…….....

(Ir. Dr. Lokman Bin Abdullah)

ABSTRAK

Pada masa kini, industri alatan mesin mengehendaki prestasi ketepatan yang tinggi dengan harga berpatutan untuk bersaing dengan baik di pasaran. Dalam projek ini, pengawal Proportional Integral Derivative (PID) digunakan sebagai pengawal asas sebelum membentuk pengawal lain dengan integrasi kepintaran buatan (AI). Malah, reka bentuk pengawal adalah berkait langsung dengan isu kedudukan tepat alat mesin yang akan menyebabkan ralat pengesanan alat apabila bergerak dari titik sebelumnya ke titik sasaran. Oleh itu, projek ini bertujuan untuk merancang pengawal PID dengan pengintegrasian kepintaran buatan (AI) menggunakan Particle Swarm Optimisation (PSO) dan Firefly Algorithm (FFA) untuk mengoptimumkan kedudukan tepat untuk aplikasi alat mesin melalui analisis ralat pengesanan, ralat root mean square (RMSE), dan masa pengiraan. Kajian ini juga dijalankan bagi mengesahkan pengawal yang dicadangkan melalui analisis simulasi dan eksperimen. Untuk mencapai matlamat penyelidikan ini, terdapat beberapa langkah yang perlu dilakukan, iaitu; kajian literatur; pengenalan sistem dan mengenal pasti tenaga potongan; reka bentuk pengawal dan analisis berangka; simulasi dan analisis eksperimen; perbandingan dan perbincangan mengenai hasil; dan akhirnya, menulis laporan. Analisis eksperimen dilakukan menggunakan sistem meja XY yang mewakili alatan mesin. Penemuan projek ini telah mencapai matlamat dengan mendapatkan penyelesaian yang optimum bagi ketepatan kedudukan alat mesin melalui integrasi PSO dan FFA ke dalam pengawal PID dengan mengurangkan ralat; iaitu ralat pengesanan dan ralat RMSE berbanding dengan pengawal PID asas. Melalui analisis RMSE, didapati integrasi AI ke dalam pengawal PID meningkatkan prestasi sebanyak 26% hingga 37%. Projek ini menekankan bahawa FFA telah menunjukkan prestasi ketepatan yang lebih baik umumnya dengan mempunyai ralat pengesanan dan nilai RMSE yang lebih rendah dan memerlukan masa pengiraan yang lebih pendek berbanding PSO.

ABSTRACT

Nowadays, the industry of machine tools requires high precision performance with affordable price in order to compete well in the market. In this project, proportional integral derivative (PID) controller is being used as the basic controller before designing the other controllers with the integration of artificial intelligence (AI). In fact, the design of the controllers is directly related to the issue of precise positioning of the machine tool performance which will affect the tracking error of the tool when moving from the previous point to the targeted point. Hence, this project purposed a solution to design PID controller with integration of AI, namely Particle Swarm Optimisation (PSO) and Firefly Algorithm (FFA) for optimisation in precise positioning for machine tools application through the analysis on the tracking error, root mean square error (RMSE), and the computational time. This research is also to validate and compare the proposed controllers through simulation and experimental analysis. To reach the aims of this research, there are several steps to be done, which are; the literature review; system identification and cutting force identification; controller design and numerical analysis; simulation and experimental analysis; comparison and discussion on results; and lastly, the report writing. The experimental analysis is done using XY table to represent the machine tool. The findings of this project have achieved the aims by obtaining the optimal solution for precise positioning of the machine tools through the integration of PSO and FFA into PID controller by reducing the errors; which are the tracking error and RMSE compared to the basic PID controller. Through the analysis of RMSE, it is found that the integration of AI into PID controller improved the performance by approximately 26% to 37%. It is highlighted that the FFA had shown better precision performance generally by having lower tracking error and RMSE values and required shorter computational time compared to PSO.

DEDICATION

Alhamdulillah, all praises and grateful to the Almighty God, this project has been completed with the blessings from Allah.

Specially to my beloved family,

my dearest mother, Sulastri

my appreciated father, Misbahul Munir

my adored little sisters Nor Fatimah, Nur Hidayah, and Rabiatul Adawiyah

for the love, prayers, moral support, encouragement, sincere advices, and sacrifices.

Thank you very much and love all of you always.

ACKNOWLEDGEMENT

I would like to firstly express my highest appreciation and gratitude to my respected supervisor, Ir. Dr. Lokman Bin Abdullah. It is a great honour as to be able to complete this project supervised by him. Thank you for lending the time during the hours of need. Every sacrifice that you did in order to give me the teaching and explanation during the hours of need, and every other recommendation for this project, along with the support and patience you provided for me to complete this project may be given the best reward from Allah the Almighty God. Millions of thanks I would like to deliver for everything during this one year.

I would also deliver this appreciation to the staffs and academicians of UTeM especially FKP UTeM in terms of facility and moral support. Thank you for the extra knowledge gained for this project through the learning of the subjects.

A special gratitude and thanks to the most helpful person throughout completing this project, Sahida binti Che Ku Junoh for the teaching and for every single knowledge, support and advice that you gave me. The helpful hand will always be remembered in the heart and may Allah showers you with blessings and health. As for my other colleagues, especially Nur Zalikha and Ampuan, thank you for your help through the tough days. And to my family, I am grateful to have you close inside my heart. May Allah always provide all of you with the best thing in this life and hereafter.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

PID	-	Proportional integral derivative
AI	-	Artificial intelligence
PSO	-	Particle Swarm Optimisation
FFA	-	Firefly Algorithm

CHAPTER 1

INTRODUCTION

1.1 Background

Nowadays, machine tool manufacturers are required to manufacture high precision machines but maintaining affordable prices in order to compete in the market. The role of controller in machine tools application is crucial for precise tools positioning. For instance, Figure 1.1 represents the machine tool used in CNC milling machine.

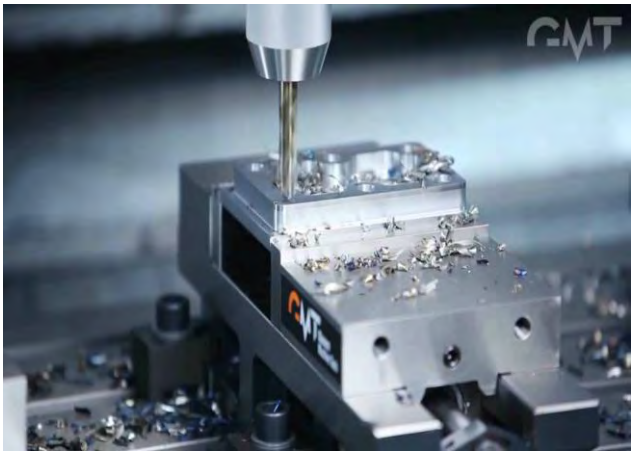

Figure 1.1: Machine tool used in CNC machine

In manufacturing field, high precision positioning machines should be produced by the machine tools manufacturers but still maintaining affordable prices in order to compete in the market. According to Lopez *et al.* (2009), high precision in machine tools significantly enhanced the production of machined parts, in terms of escalating the added value of the parts, as well as to bring advantage in the machining process by reducing finishing process. Besides, high precision machining is directly related with other manufacturing requirements, for instance, the necessity in increasing productivity. The machining cost for the machined parts can be lowered when using a high precision machine compared to conventional machining. This situation brings goodness technically and economically which results in higher reliability of the system by decreasing the tolerances during machining process and reducing the operations for manual adjusting in finishing process.

1.2 Problem Statement

The performance of a machine depends on the efficiency of the machine tools handling disturbance forces such as cutting force and frictional force. The main indicators for machine tools performance are precise positioning, accuracy, robustness, flexibility and highly automated. Through an online article published by Olexa (2005), the issue related to precise positioning is when a machine tool moves from the datum of (0,0,0) to the targeted point, the tracking error of the machine actuators caused by the failure in moving to the exact position results in the position deviation of the tool from the true position. This is caused by the inaccuracies of the machine geometry which acts to move the work piece along the axes of the machine. This deficiency is also related to the volumetric accuracy of the machine tool which is the ability of the tool to reach to the true position from the previous point inside the reachable limit of the working envelope in the machining area.

On the other hand, the control system of proportional integral derivative (PID) controller is used vastly in many industrial applications due to its simplicity and robustness

(Yadav *et al.,* 2016). However, there is a problem presents when implementing PID controller. Through the past research of Gaing (2004), it is quoted that the gains of PID controller namely Kp, Ki, and Kd are difficult to be tuned properly since some of the industrial plants face problem such as the implementation of nonlinear system, time delays, and high order system. During the past years, the world of control system has discovered methods to tune the PID controller gains through heuristic methods such as Ziegler-Nichols method. However, the implementation of Ziegler-Nichols formula had caused the optimal PID gains difficult to be determined. Hence, many artificial intelligence (AI) approaches have been implemented to enhance the performance of the controllers while keeping their basic characteristics consistent.

Due to these reasons, this project is proposed to solve the issue of precision and accuracy performance of the machine tools by integrating AI approaches namely Particle Swarm Optimisation (PSO) and Firefly Algorithm (FFA) into the PID controller.

1.3 Objectives of Research

The objectives of this research are as follows:

(a) To design proportional integral derivative (PID) controller with integration of artificial intelligence techniques namely Particle Swarm Optimisation (PSO) and Firefly Algorithm (FFA) for optimisation of precise positioning in machine tools application.

(b) To validate and compare the proposed controller through simulation analysis using MATLAB / Simulink and experimental analysis using XY table screw drives system.

(c) To compare the result data between basic PID controller, PID with PSO controller, and PID with FFA controller.

1.4 Scope of Research

The scope of this research is stated in the following:

(a) The basic controller used only involves proportional integral derivative (PID).

(b) The optimisation approach by using artificial intelligence for precise positioning of machine tool application only includes:
   (I) Particle Swarm Optimisation (PSO), and
   (II) Firefly Algorithm (FFA).

(c) The disturbance force to be implemented into the system during simulation and experimental analysis only involves the cutting forces of
   (I) 1500 revolutions per minute (rpm),
   (II) 2500 rpm, and
   (III) 3500 rpm

(d) For the experimental analysis using the XY table ball screw drives system as displayed in Figure 1.2, only the x-axis motion is taken into account.

(e) The parameters used to measure and compare the performance on precise positioning of each controllers only includes:
   (I) Tracking error
   (II) Root means square error (RMSE)

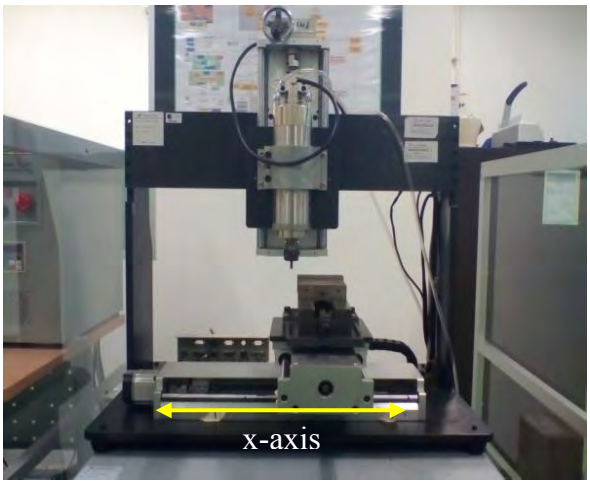

Figure 1.2: XY table system

1.5 Significance of Study

This research contributes in providing the knowledge by investigating the integration of artificial intelligence into PID controller for machine tools application.

(a) Design of PID controller by integrating Particle Swarm Optimisation (PSO) and Firefly Algorithm (FFA) which are the approaches in artificial intelligence.

(b) Integration of artificial intelligence through PSO and FFA approaches into PID controller for the optimisation in term of precise positioning in machine tools application.

(c) Comparison of the outcomes by evaluating the errors through different types of controllers by implementing various cutting forces as disturbance force into the system.

(d) Providing solutions to optimise the machine tools for manufacturers to ensure the productivity fulfils the need to have high precision machine.

1.6 Thesis Outlines

The research report is organised as the following. Chapter 1 of this research elaborates on the introduction related to the title of the research which includes the problem statement, the aim of this research, as well as the scope and the significance of this research. In Chapter 2, relations of this research to the previous researches are made to analyse the gap analysis between each resources. The methodology which is the step-by-step procedures of this research is explained further in details in Chapter 3. The design of controllers used in this research is displayed and discussed in Chapter 4. The outcomes and the discussion on the results will be discussed later throughout Chapter 5 of results and discussion part. The final part which is the conclusion and future recommendations will be made in Chapter 6 of this research. The references are listed at the end of this report.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The issue of high precision in machine tools had been raised not only recently, but starting decades back a long time ago. Through Evans (1977), the development of controlling the precision of machine tools through control system embedded in the machine just started to be explored. During those days, the machine manufacturer only focused to overcome the problem related with machine tools precision through mechanical precision which results in expensive machine price. To be exact, the computer is not used to sense and control the actual position of the cutting tool, but instead the positioning accuracy is achieved through highly precise ways and lead screws of the machine.

It is also mentioned that the productivity rate in industry is directly related to the precise positioning of the machine tools while producing parts where the machine tool is controlled by the computer through information processing. Nowadays, the expanding knowledge in precise positioning of machine tools application through control system has boosted the performance of the machine tools itself (Lopez *et al.,* 2009).

In this chapter, the information regarding this research is being referred from the previous studies. Section 2.2 elaborates the application of controllers in machine tools application, Section 2.3 on various controller designs, Section 2.4 on artificial intelligence approach and Section 2.4 for the summary part.

2.2 Controllers for Machine Tool Application

The current researches on the machine tool application portray various implementations of controllers done through previous studies. There are several controllers highlighted, as mentioned in a review of past researches done by Anang *et al.* (2016). Throughout the review which focused on the control strategy for machine tools, the list consisted of linear control strategies and adaptive nonlinear control strategies. As for the linear control strategies, there were several controllers discussed, namely Proportional Integral Derivative (PID) controller and Cascade P/PI controller. In addition, the nonlinear control strategies comprised of Nonlinear PID (NPID), Feedforward NPID (FNPID), Adaptive NPID (ANPID), Adaptive Robust Controller (ARC), Nominal Characteristics Trajectory Following (NCTF) controller, as well as neural network control and fuzzy logic control. The review made a few summarisations; firstly, the nonlinear function should be considered to enhance the overall performance, precision, and robustness of machine tools; secondly, to improve the precision of machine tools, the combination of controllers showed better performance compared to stand-alone control strategies; and lastly, the integration of neural network and fuzzy logic highlights the recent enhancement of precise positioning for nonlinearity function of machine tools.

A detail research was done before by Abdullah *et al.* (2013) which stressed the implementation of self tuned NPID controller for machine tools application represented by the XY table ball screw drive system. The research done proved the NPID controller showed superiority over PID controller by 8 % to 40 % for the average tracking

performance. This occurrence displayed NPID controller which is an adaptive type controller offered flexibility and thus, showed advantage for machining application.

Hence, it is summarised from the previous researches that the nonlinear control strategies portrayed better performance in precise positioning compared to the linear controllers for the application of machine tools. The integration of computational intelligence such as fuzzy logic and neural network into the nonlinear controllers further improved the precision performance for machine tools application.

2.3 Various Controller Designs

2.3.1 PID Controller

Back to current industrial field, the control system is used globally in many applications. In control system, PID controller is still dominating in the usage since it is robust, simple to be used and easy to be implemented (Yadav *et al.,* 2016). There are various applications where PID controller is being applied. For instance, in electric power system, the PID controller is implemented into the Automatic Generation Control (AGC) which is essential to ensure tie-line power flows in particular range of tolerances and to sustain the frequency of the bounded area (Sahu *et al.,* 2016). Besides, PID controller is implemented in the system of Electro-hydraulic Servo Valve because of easy implementation and greatly effective (Smakwong and Assawinchaichote, 2016). Yadav *et al.* (2016) also applied the optimized PID controller into the system of magnetic levitation to control the ball position through various applications such as the high-speed trains.