SELF-TUNING PID BASED NAVIGATION FOR AUTONOMOUS MOBILE ROBOT

SARAVANAKUMAR A/L R SIVAM

A project report submitted in fulfilment of the
requirements for the award of the degree of
Master in Engineering (Mechatronic & Automation Control)

School of Electrical Engineering
Faculty of Engineering
Universiti Teknologi Malaysia

FEBRUARY 2021

DEDICATION

This thesis is dedicated to my father, who taught me that the best kind of knowledge to have is that which is learned for its own sake. It is also dedicated to my mother, who taught me that even the largest task can be accomplished if it is done one step at a time. Nevertheless, dedicated to my supervisor who guide me from the beginning of the project.

ACKNOWLEDGEMENT

In preparing this thesis, I was in contact with many people, researchers, academicians, and practitioners. They have contributed towards my understanding and thoughts. In particular, I wish to express my sincere appreciation to my main thesis supervisor, Professor Dr. Mohd Ariffanan Mohd Basri, for encouragement, guidance, critics and friendship. Without his continued support and interest, this thesis would not have been the same as presented here.

I am also indebted to Universiti Teknologi Malaysia (UTM) for support my Master study. Librarians at UTM, Cardiff University of Wales and the National University of Singapore also deserve special thanks for their assistance in supplying the relevant literatures.

My fellow postgraduate student should also be recognised for their support. My sincere appreciation also extends to all my colleagues and others who have provided assistance at various occasions. Their views and tips are useful indeed. Unfortunately, it is not possible to list all of them in this limited space. I am grateful to all my family member.

ABSTRACT

The aim of this project is to design a self-tuning PID control system for an autonomous mobile robot. Then run the simulation of the system designed to test the performance of the controller system. This self-tuning PID controller is designed for the robot PIONEER 3D-X. First, the robot's kinematic and dynamic model was obtained by refer to journal. Designed the mathematical STC PID controller model with mathematical calculation. This PID controller is correlated with pole-assignment technique of self-tuning method. Pole-Assignment Control Method is an indirect self-tuning method that built the controller function based on the device parameter. This STC approach is the approach for controller design, by setting a control parameter, to locate the closed loop system poles at stable position in s-plane. Conventional PID controller were designed and implemented in robot model in order to result comparison. The conventional PID controller designed using Auto-Tuning technique. MATLAB Simulink was used in this project to run the simulation of the models designed. Reference trajectory was insert as input signal to the robot model and actual trajectory was evaluated. Analysis about the actual trajectory and variables of both STC and conventional PID controller system. Response graph obtained and used in evaluation of the system.

ABSTRAK

Tujuan projek ini adalah untuk merancang sistem kawalan PID penyesuaian diri untuk robot mudah alih yang autonomi. Kemudian jalankan simulasi sistem yang dirancang untuk menguji prestasi sistem pengawal. Pengawal PID penyesuaian diri ini direka untuk robot PIONEER 3D-X. Pertama, model kinematik dan dinamik robot diperoleh dengan merujuk kepada jurnal. Mereka bentuk model pengawal STC PID matematik dengan pengiraan matematik. Pengawal PID ini berkorelasi dengan teknik penugasan tiang kaedah penyesuaian diri. Kaedah Pole-Assignment Control adalah kaedah penyesuaian diri tidak langsung yang membina fungsi pengawal berdasarkan parameter peranti. Pendekatan STC ini adalah pendekatan untuk reka bentuk pengawal, dengan menetapkan parameter kontrol, untuk mencari kutub sistem gelung tertutup pada posisi stabil dalam bidang-s. Pengawal PID konvensional dirancang dan dilaksanakan dalam model robot untuk menghasilkan perbandingan. Pengawal PID konvensional yang direka menggunakan teknik Auto-Tuning. MATLAB Simulink digunakan dalam projek ini untuk menjalankan simulasi model yang dirancang. Lintasan rujukan dimasukkan sebagai isyarat input ke model robot dan lintasan sebenar dinilai. Analisis mengenai lintasan sebenar dan pemboleh ubah sistem pengawal PID STC dan konvensional. Graf respons yang diperoleh dan digunakan dalam penilaian sistem.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

PID	-	Proportional Integration and Derivative controller
P	-	Proportional controller
PI	-	Proportional-Integration controller
PD	-	Proportional-Derivative controller
ZN	-	Ziegler-Nichols method
PAC	-	Pole-Assignment control
PID-PAC	-	Proportional Integration and Derivative controller associate with Pole-Assignment control
STC	-	Self-tuning control
UTM	-	Universiti Teknologi Malaysia

LIST OF SYMBOLS

u	-	Linear velocity
ω	-	Angular gain
k	-	Controller gain
I_x	-	Saturation constant
I_y	-	Saturation constant
x	-	X co-ordinates
y	-	Y co-ordinates
$\boldsymbol{\delta}$	-	Uncertain parameter
$\boldsymbol{\theta}$	-	Dynamic vector
I_z	-	Moment of inertia
m	-	Mass
R_a	-	Electrical Resistance
k_b	-	electromotive constant
k_a	-	torque constant
r	-	radius
B_e	-	Friction coefficient
K_p,	-	Proportional controller gain
K_i	-	Integral controller gain
K_d	-	Derivative controller gain
K_{cr}	-	Critical controller gain
Pcr	-	period of constant oscillation
T_I	-	Integral time constant
T_D	-	Derivative time constant

CHAPTER 1

INTRODUCTION

1.1 Problem Background

Autonomous robot navigation is a popular area in the study of robots. Mobile robots were widely used in various fields, such as scientific research, industrial manufacturing, and defensive system security, that prevented employees from engaging in certain aspects. In an obstacle-free environment, autonomous mobile robot navigation along with its trajectory tracking is to find a collision-free route from the start to the final destinations. This problem involves several difficult phases to be overcome, such as avoidance of obstacles, identification of positions, driving safety and etc. In other words, a robot controller must be able to track the robot's target location, prevent any collisions and decide an appropriate navigation to the spot.

Robot is known for system modelling with disturbance in the controller methods. What the controller will do is actually reduce the error between the target point and the actual outcome by controlling the dynamic and kinematic process of the robot. Self-tuning "PID controllers are programmed to optimize these complex robot operations by choosing their respective tuning parameters based on some kind of automatic study of the behavior of the managed device. Sometimes, these automated processes require a statistical analysis of the input and output relationship of the equipment from process data augmented by knowledge supplied by an experienced operator. But in reality, controller tuning is more of an art than a theory. The best choice of tuning parameters depends on a number of variables including the controlled process's complex behavior, the operator's efficiency targets defined and the operator 's awareness of how tuning works.

An improvement in self-tuning control using PID is studied in this research. The controls measure PID gains which are K_p, K_i, and K_d and they should be correctly calibrated. The inclusion of regular parameter tuning techniques like Ziegler-Nichols and self-tuning control techniques like pole assignment control (PAC) could support tuning the PID for optimal system response gain setups. The approach to control has good efficiency. It is however dependent on precise parameters of the model. When parameters of the model are unknown, adaptive control is required to adjust those parameters.

1.2 Problem Statement

Modelling and controlling of the non-linear and high-order systems is a difficult and complicated activity for engineers. At first, PID controllers were modified by adjusting their parameters and they were usually engineered by a human expert according to a set of rules. Nevertheless, since the robot experiences adjustments in its design and/or variations in the operating environment, its PID controls have to be re-tuned frequently. These cause dispute about conventional PID controller. However, further research in this area has progressed to the most effective way of implementing this controller tuning.

In autonomous mobile robots there are several issues using the conventional PID controller tuning. First, the controller is not really ideal for nonlinear plants by failing to provide the desired solution to a stable and non-linear device. The use of traditional PID controller does not provide an effective rejection of disturbance or error. It took longer time for the simple controller tuning to adjust a robot's control system and this affect the robot 's output. A variety of manual techniques have been developed to assist operators in tuning their loops, but even with the help of loop tuning software, loop tuning can be a tedious task that is both complex and time consuming.

1.3 Research Goal

1.3.1 Research Objectives

The objectives of the research are:

a. To design a Self-Tuning PID control for dynamic system of autonomous mobile robot.
b. Run simulation of the Self-Tuning PID control system with robot model.

1.3.2 Research Scope

a. Study on how to implement self-tuning PID controller in nonlinear model robot.
b. Creating a desired output response of the system by tracking set point.
c. Simulate the controller system in MATLAB Simulink

1.4 Gantt Chart

Table 1.1 Gantt Chart of Master Project 1

No	Project Activities	Week														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Literature Review															
2	Project Synopsis Preparation															
3	Submission of Project Synopsis															
4	Determine Model of the Mobile Robot															
5	Study about Self-tuning PID															
6	Seminar Material Preparation															
7	Submission of Seminar Material															
8	Presentation of Seminar															
9	Report Preparation & submission															

Table 1.2 Gantt Chart of Master Project 2

No	**Project Activities**	**Week**														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Mathematical design of Self-Tuning controller model															
2	Project Synopsis Preparation															
3	Submission of Project Synopsis															
4	Design Self-Tuning PID controller															
5	Run simulation of the designed PID and evaluate the controller response															
6	Seminar Material Preparation															
7	Submission of Seminar Material															
8	Presentation of Seminar															
9	Report Preparation & submission															

REFERENCES

[1] I. Carlucho, M. De Paula, and G. G. Acosta, “An adaptive deep reinforcement learning approach for MIMO PID control of mobile robots,” *ISA Trans.*, no. xxxx, 2020, doi: 10.1016/j.isatra.2020.02.017.

[2] V. Balaji, M. Balaji, M. Chandrasekaran, M. K. A. A. Khan, and I. Elamvazuthi, “Optimization of PID Control for High Speed Line Tracking Robots,” *Procedia Comput. Sci.*, vol. 76, no. Iris, pp. 147–154, 2015, doi: 10.1016/j.procs.2015.12.329.

[3] J. E. Normey-Rico, I. Alcalá, J. Gómez-Ortega, and E. F. Camacho, “Mobile robot path tracking using a robust PID controller,” *Control Eng. Pract.*, vol. 9, no. 11, pp. 1209–1214, 2001, doi: 10.1016/S0967-0661(01)00066-1.

[4] R. Aisuwarya and Y. Hidayati, “Implementation of ziegler-nichols PID tuning method on stabilizing temperature of hot-water dispenser,” *2019 16th Int. Conf. Qual. Res. QIR 2019 - Int. Symp. Electr. Comput. Eng.*, pp. 1–5, 2019, doi: 10.1109/QIR.2019.8898259.

[5] V. Bobál, J. Macháček, and R. Prokop, “Tuning of Digital PID Controllers Based on Ziegler - Nichols Method,” *IFAC Proc. Vol.*, vol. 30, no. 21, pp. 145–150, 1997, doi: 10.1016/s1474-6670(17)41430-3.

[6] Z. Wang, S. Qiu, R. Song, X. Wang, B. Zhu, and B. Li, “Research on PID parameter tuning of coordinated control for ultra-supercritical units based on Ziegler Nichols method,” *Proc. 2019 IEEE 3rd Adv. Inf. Manag. Commun. Electron. Autom. Control Conf. IMCEC 2019*, no. Imcec, pp. 1155–1158, 2019, doi: 10.1109/IMCEC46724.2019.8984069.

[7] T. Yucelen, O. Kaymakci, and S. Kurtulan, *Self-tuning PID controller using Ziegler-Nichols method for programmable logic controllers*, vol. 1, no. PART 1. IFAC, 2006.

[8] H. Xu and H. Y. Zhu, “Approach of robust pole assignment based on normal matrix,” *2011 Int. Conf. Electr. Control Eng. ICECE 2011 - Proc.*, pp. 3377–3380, 2011, doi: 10.1109/ICECENG.2011.6057805.

[9] T. Yanlamoto, K. Fujii, and M. Kaneda, “A DESIGN OF SELF-TUNING PID CONTROLLERS [Assumption AJ,” pp. 6866–6871, 1999.

[10] A. Aydi, M. Djemel, and M. Chtourou, “Robust pole assignment for the control of uncertain nonlinear discrete-time systems,” *12th Int. Multi-Conference Syst. Signals Devices, SSD 2015*, no. 3, pp. 1–5, 2015, doi: 10.1109/SSD.2015.7348182.

[11] Y. Ashida, S. Wakitani, and T. Yamamoto, “Design of an Implicit Self-tuning PID Controller Based on the Generalized Output,” *IFAC-PapersOnLine*, vol. 50, no. 1, pp. 13946–13951, 2017, doi: 10.1016/j.ifacol.2017.08.2216.

[12] V. Control, O. F. A. Unicycle, and T. Of, “Jurnal Teknologi VELOCITY CONTROL OF A UNICYCLE TYPE OF MOBILE ROBOT USING OPTIMAL CONTROLLER,” vol. 4, pp. 7–14, 2016.