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SARJANA MUDA (PSM2)

FUZZY LOGIC INVERTED PENDULUM

AHMAD BADRUN HISHAM BIN ABDUL RAHIM

Bachelor of Mechatronics Engineering

JUNE 2014

DECLARATION

I declare that this report entitle "*Fuzzy Logic Inverted Pendulum"* is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

Authors Name: AHMAD BADRUN HISHAM BIN ABDUL RAHIM

Date : JUNE 2014

SUPERVISOR'S ENDORSEMENT

I hereby declare that I have read through this report entitle "*Fuzzy Logic Inverted Pendulum"* and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Mechatronics Engineering

Signature :

Supervisor's Name: CIK NUR MAISARAH BINTI MOHD SOBRAN

Date : JUNE 2014

DEDICATION

To my beloved mother and father

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First and foremost I would like to express my profound gratitude to my supervisor, Cik Nur Maisarah Binti Mohd Sobran, whom had guided me throughout this Final Year Project. Her precious guidance, knowledge and support allowed me to accomplish my work successfully. Her continuous advices, feedback and comments are very much appreciated. Her willingness to discuss and accept ideas has been crucial in further improving my project. Her also extensive knowledge in coding MATLAB and derivation for Fuzzy Logic were had guided me during the beginning of the learning process.

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ABSTRACT

Inverted Pendulum (IP) System is a device that uses a cylindrical rod that is usually made of aluminum and free swinging around on a fixed axis. This pivot mounted on a cart that can move in the horizontal direction. The rod is normally will tend to fall down from the top vertical position due to the instability in the control system. The goal of this project is to control and develop the hardware to stabilize the vertical position of the inverted pendulum system approach for purpose in the education tranning kit. The system consists of rotary variable resistance as input sensor that determines the angle variable for each movement of the pendulum. In order to maintain the pendulum in upright position of 90^0 degree, the motor horizontal position control via PWM will eventually become the response mechanism for the system. As an initial insight of the desired performance of Inverted Pendulum system, a simulation via MATLAB was done using the mathematical modely of the system. The inabilities for the Inverted Pendulum to maintain the upright position lead to the usage of the Fuzzy Logic controller onto the system. After that, the hardware development of the Inverted Pendulum system was done using selected materials. The performance of both, expected result from simulation and actual result were analysed. The performance of Inverted Pendulum has shown the reliability and accuracy of the pendulum in the upright position even though there was some error around 0.02% during the test performed.

ABSTRAK

"*Inverted Pendulum* (IP) system" ialah sebuah alat yang mengunakan satu batang rod berbentuk silinder yang biasanya diberbuat daripada aluminium dan bebas berayun di sektar satu paksi yang tetap. Rod ini dipasang di atas sebuah kereta yang boleh bergerak dengan arah melintang. Rod ini biasanya akan cenderung untuk jatuh dari keadaan menegak disebabkan oleh ketidakstabilan bagi sistem kawalan. Sasaran bagi projek ini ialah untuk mengawal dan menghasilkan perkakasan bagi menstabilkan kedudukan menegak untuk sistem "*Inverted Pendulum*" (IP) bagi pendekatan latihan pembelajaran. Sistem ini terdiri daripada putaran rintangan yang dijadikan sebagai masukan kepada sistem untuk mengesan pembolehubah bagi setiap sudut pegerakan bandul. Bagi memastikan bandul dalam keadaan tegak 90^0 darjah, pengawalan motor dalam kedudukan mendatar yang dikawal oleh PWM menjadi mekanisme yang bertindak balas dalam sistem ini. Sebagai gambaran awal bagi menetukan prestasi yang diperlukan oleh bandul terbalik, simulasi melalui perisian MATLAB telah dilakukan dengan menggunakan matematik model sistem. Ketidakmampuan bandul terbalik bagi mengekalkan kedudukan diatasi dengan penggunaan pengawal *"Fuzzy Logic"* ke dalam system. Selepas itu, pembinaan peralatan sistem bandul terbalik ini dilakukan dengan menggunakan peralatan-peralatan yang terpilih. Prestasi kedua-dua bahagian yand dibandingkan, hasil yang dijangkakan dari simulasi dan keputusan sebenar telah di analisis. Prestasi bandul terbalik telah menunjukkan kebolehpercayaan dan ketepatan bandul dalam kedudukan tegak walaupun terdapat sedikit ralat sekitar 0.02% semasa ujian dilakukan.

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LIST OF ABBREVIATIONS

AI	-	Artificial Intelligence
DE	-	Difference Error
E	-	Error
FLC	-	Fuzzy Logic Controller
FSF	-	Full State Feedback
G(s)	-	Transfer Function
IP	-	Inverted Pendulum
LQR	-	Linear Quadratic Regulator
l	-	Length of pendulum
M	-	Mass of pendulum and mobile robot
PID	-	Proporational Integral Derivative

CHAPTER 1

INTRODUCTION

1.1. Motivation

Today, control of inverted pendulum system is shown as a benchmark problem for various controller designs and widely used. It is use in a very detailed, especially in the control laboratories for research and educational purpose. This inverted pendulum system became popular because of the easy preparation and some interesting features such as instability and nonlinearity. The application of this system as show in Figure 1.1 on the next page where it used to missile launchers Segway, rocket launching, luggage carrying Pendubots and etc [6]. In addition inverted pendulum (IP) is needed in the learning approach for the students knowledge, especially in learning Artificial Intelligence (AI) which require practical methods for comprehension in learning.

For instance in University of Technical Malaysia Melaka (UTEM), used the Inverted Pendulum system in Control courses as a part for learning approach in laboratories. The experimental in this learning part are used Inverted Pendulum Rotary types where the limitation of the movement is fixed. In this project, it used in the same system but different concept for Inverted Pendulum (IP) System where by using a Mobile Robot system. Compared of this type with the old version in University, Inverted Pendulum (IP) in system of cart will be functioning in widely limitation range and more suitable for learning approach.

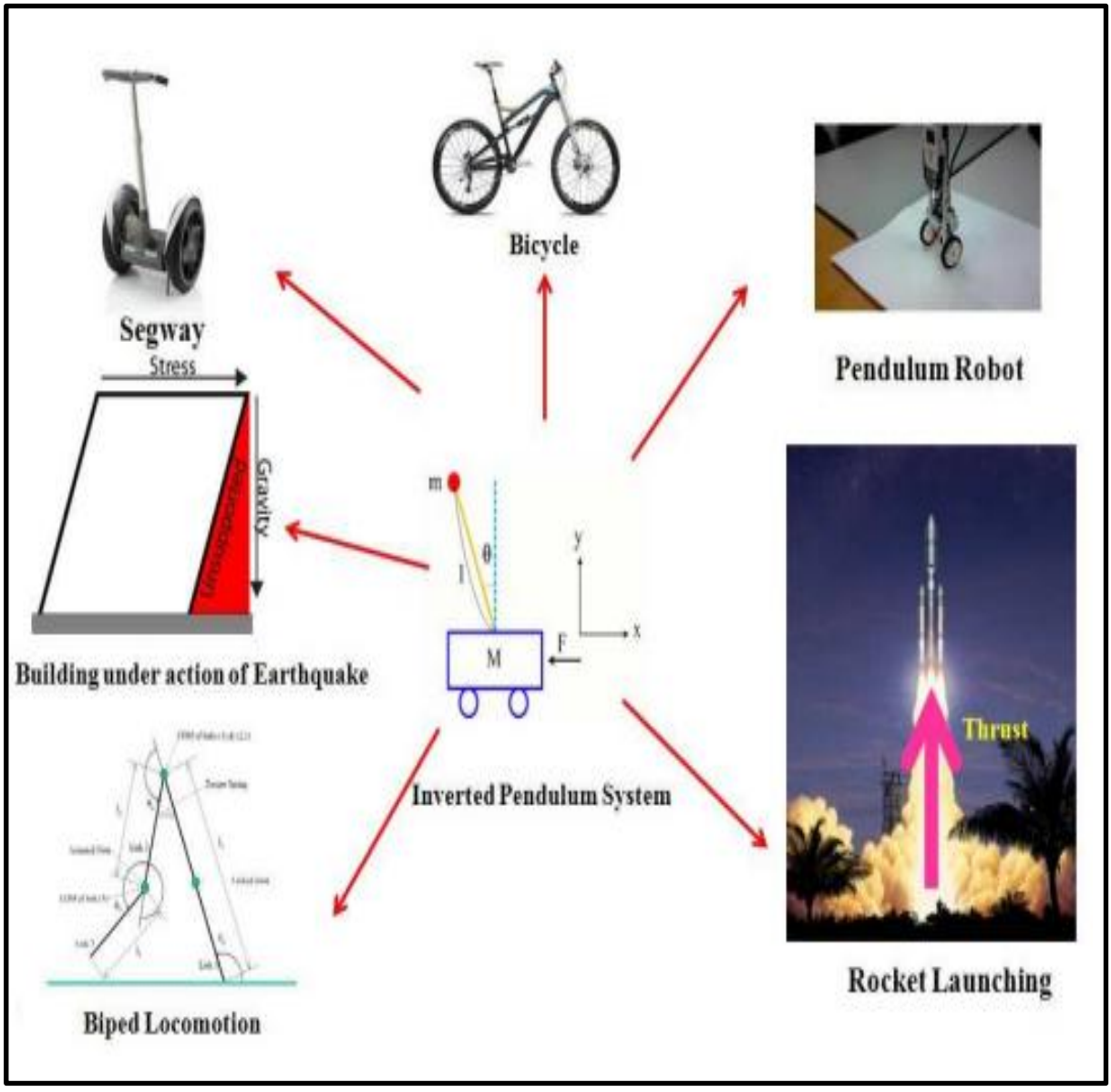

Figure 1.1: Application for Inverted Pendulum system. [6]

1.2. Problem Statement

Inverted Pendulum (IP) is a very complex system and wide application used in industry. Since this system is very complicated, their implementations is the need to ensure the accuracy and efficiency of the Inverted Pendulum (IP) system is always in a stable upright position. In this situation has been described by all researchers that this system is the influence from various aspects, especially in terms of stabilizing the pendulum.

However, for this project there are several problems that must be faced to complete the whole of this Inverted Pendulum (IP) system. The problem is divided into two parts where it started in the execution system by using simulation software development and execution systems in real situation from hardware development. In the software parts, the most importance things is to develop a system to ensure the pendulum always maintain in upright position. This process requires to get proper transfer function G(s) and excellent in drive. All of the variables are describe by the movement of a pendulum which every angle that involve with rate of speed a cart driven to ensure the pendulum does not falling. In fact, this also include mass (*M*) of the pendulum and a cart, length of centroid pendulum (*l*) and friction of cart (*b*) where all the variable is fixed to get transfer function by using mathematical method.

Next problem in this project is faced by hardware part, where the selection of the appropriate tools and equipment to ensure the system is always running smoothly. The device selection is involved in this project including microcontroller circuit and also the device to allow the pendulum to know differ angles depending on the situation. In terms of equipment, the selection of designing a cart, the materials used for the pendulum and also the selection motor to drives a cart from dropping the pendulum. Lastly, the problem is faced from installation software into the hardware part which is to ensure the pendulum always maintain in upward position by using controlling the speed of wheel. Then to strength the result for performance this system, data from simulation will be compared where all the equipment and tools will combine together to get the Inverted Pendulum (IP) systems with movement a cart in full functioning.

1.3. Objective of the project

The objective for this project is

1. To design and develop the control algorithm of controller for Inverted Pendulum (IP) system.
2. To develop hardware of the Inverted Pendulum (IP) system for classroom approach.
3. To analyze the performance of the Inverted Pendulum (IP) system.

1.4. Scope of the project

The scope for this project, it just focuses as a part of learning approach that will cover in Artificial Intelligence subject. A mobile robot that will use in this project is function as a cart where it is easier for learning part proses. The pendulum can only move in X-Y plane and the system fixed in mass of cart (M), mass of pendulum (m) and length of rod (l). For pendulum angle (ϕ) and cart position coordinate (x) it vary depend on to maintain the system**.**

CHAPTER 2

LITERATURE REVIEW

2.1. Controller selection analysis

"Robust Control of Inverted Pendulum Using Fuzzy Logic Controller" – Sandeep Kr. Tripathi, Himanshu Panday and Prerna Gaur. This journal describe about the different design of controller techniques that to analysis the performance and reliability of the system. This is also present to get optimize the work of Inverted Pendulum (IP) system and robust performance for a nonlinear system by using fuzzy logic algorithm. There has two method of controller to archive their research by using simulation MATLAB Simulink namely fuzzy logic controller and Robust control in association with fuzzy produce. This experiment started from mathematical analysis by using newton 2^{nd} law of motion in horizontal and vertical direction applied on free body a cart. The resulting of the mathematical method can get the plan for transfer function of the system where it will see on step respond and also impulse response. However, to get the robust controller there have some sort of method to complete the system such as by applying complex mathematic equation. From the robust equation, new transfer function will produce due to presence of noise and disturbance. The performance of this system where comparing between system simulation on Simulink of fuzzy logic and robust controller. Performance index shows that the robust controller with Fuzzy Logic Controller much better than conventional Fuzzy Logic Controller. [1]

"Real-Time Controlling of Inverted Pendulum by Fuzzy Logic" – Yanmei Liu, Zhen Cheng Dingyu and Xue Xinhe Xu. This journal explain about to balance a real pendulum in the position and also built the mathematical model for fuzzy logic controller. The method of this

system using MATLAB Simulink to show real time of applying fuzzy logic controller to get the good performance of system. Due to controlling is difficult to stabilize the pendulum in short time, Takagi-Sugeno has been choose for data-driver of the system to functioning in stabilizing control and test the system with semi-physical simulation. The system consist of an Inverted Pendulum with type hinged on a cart rail which free movement in *x* direction. For mathematical model, these systems apply newton 2nd law where it by assuming neglected for nonlinear friction applied to the linear cart. These experiments showed controlling result in Simulink on simulation in MATLAB software. This will consist by using MATLAB RTW real time toolbox where it to develop and build a real time control then to add in simulation structure of Inverted Pendulum. The resulting by using RTW real time toolbox in the simulation structure just takes 1 sec to bring a real pendulum in upright position. From the overall in this system is state fuzzy controller proving more effective and precise of angular control and this result is shown from Figure 2.1 below.[2]

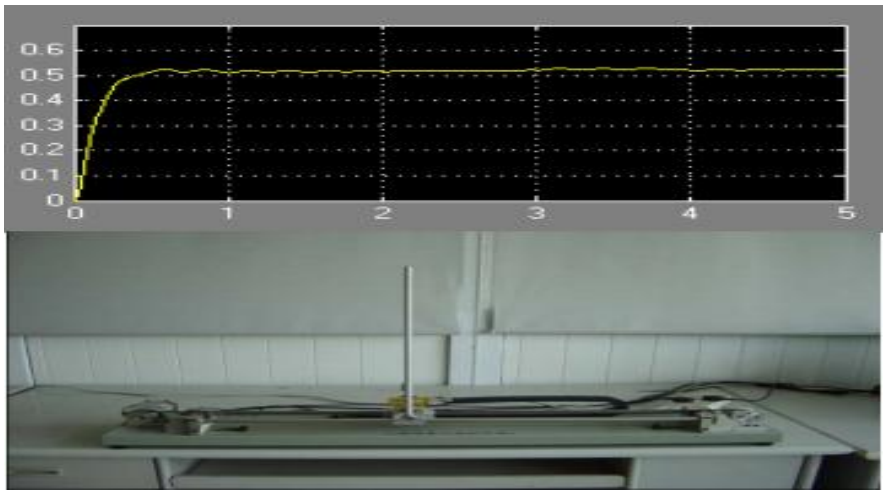

Figure 2.1: Result of experiment the Inverted Pendulum [2]

"Modeling and Control of a Rotary Inverted Pendulum Using Various Methods, Comparative Assessment and Result Analysis" – Md. Akhtaruzzaman and A.A.Shafie. This conference paper discuss about the steps to design controller for rotary inverted pendulum type and to analyze the controller system. This system will be compared in three control system namely 2DOF Proportional-Integral-Derivative (PID) controller, Full State Feedback (FSF) and Linear

Quadratic Regulator (LQR) to get the best performance of rotary motion. The method in this system started by using mathematical modeling of rotary motion where the derivation system in dynamics equation. Then to complete this system, controller has been design in terms of t hree controllers by using Simulink in simulation MATLAB software. However, for this over all result state that the LQR controller more suitable to control rotary type because of it easier to swing up the pendulum and maintain in upright position. By following in this concept by using rotary motion is shown on Figure 2.2 below. [3]

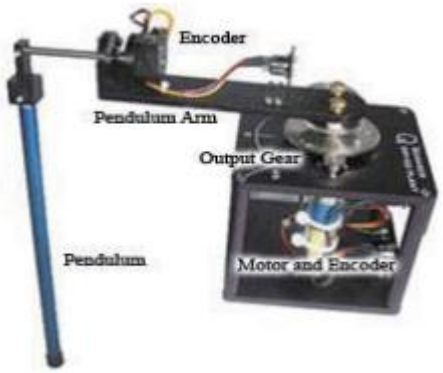

Figure 2.2: Rotary motion of Inverted Pendulum [3]

"Control of Non-Linear Inverted Pendulum Using Fuzzy Logic Controller" – Arpit Jain, Deep Tayal and Neha Sehga. This journal describe about to implement the fuzzy controller and apply it into Inverted Pendulum system. In this system by using a cart concept, mathematical modeling is produce by using derivation of Lagrange's equation but in this equation not really mention in more details of the system. For the designing fuzzy logic controller, Simulink has been test in simulation MATLAB software by using 3 membership functions namely pendulum angle and angular velocity on input variable and for output variable it used force. The result is to check the stability and validation of performance by applied to pendulum.[4]

"Fuzzy Logic Control vs. Conventional PID controller of an Inverted Pendulum Robot" – M.I.H. Nour, J.Ooi and K.Y.Chan. This conference paper is focus about to implement and optimize the fuzzy logic control algorithms for to balance the inverted pendulum. In other that

these systems want to reduce the computation time of the controller. This system will be compared the performance between fuzzy logic controller and PID controller by using simulation in MATLAB software. By applied simple mathematical model by using drawing of the cart, the equation of this require to obtain the *m* is mass of the pendulum, μ is the coefficient of friction and *I* is the moment of inertia the pendulum. In fuzzy logic system, there have required 3 membership functions namely angle, angular velocity and position for input variable and for output variable, membership function is used force. In analysis by using Simulink, Fuzzy logic controller more robust comparing conventional PID controller where fuzzy give smallest overshoot of the system and shorter settling time. [5]