UNIVERSITI TEKNIKAL MALAYSIA MELAKA

# Faculty of Electrical Engineering

# VERTICAL MOTION CONTROL OF A ONE LEGGED HOPPING ROBOT

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**VERTICAL MOTION CONTROL OF A ONE LEGGED HOPPING ROBOT**

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**in fulfillment of the requirements for the degree of Master of Science**
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**2015**

**DECLARATION**

I declare that this thesis entitled "Vertical Motion Control of A One Legged Hopping Robot" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree

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| Date | :………………………………… |

## APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Mechatronics Engineering.

Signature : ………………………………

Supervisor Name : DR. CHONG SHIN HORNG

Date : ……………………………….

**DEDICATION**

To my beloved family

# ABSTRACT

Hopping movement is a desirable locomotion for a mobile robot to adapt on unknown surface and overcome the obstacles avoidance problem. The hopping locomotion is one of locomotion produced by legged robot. The legged type robot has difficult mechanism and complexity in control system. The hopping robot is designed to avoid the obstacles vertically. So, if the hopping robot takes too long time to reach the desired height, it will produced damages to the hopping robot physical. Therefore, the research on develop control strategies of one legged hopping robot is useful so that the developed control strategies can be used and extended to the multi-legged system. Central Pattern Generator (CPG) is a neural network that capable to generate continuous and rhythmic pattern. Since the hopping movement is a continuous and rhythmic jumping movement, it is synthesized that CPG neural network capable to generate hopping movement. Thus, the objectives of this research is to model the one legged hopping robot experimentally, to design a classic controller and integrate with CPG to compensate the steady-state error at each different height, and to optimize the parameters values of Central Pattern Generator (CPG) for the optimum rise time and steady-state error. A hopping peak height detector algorithm is designed to determine hopping peak height as feedback loop. The PI-CPG neural network parameters are optimized for each reference hopping height via simulation. The performance of optimized PI-CPG neural network is evaluated and compared with optimized PI and PID controller. The result shows that the optimized PI-CPG neural network controller produced better response which is 21.36 %, 24.20 %, and 44.13 % average rise time faster than PI-CPG, optimized PI, and optimized PID controller respectively. Moreover, the optimized PI-CPG controller more accurate in term of 4.91 % steady-state error compared to PI-CPG controller; 8.69 %, optimized PI controller; 6.03 %, and optimized PID controller 12.52 % average steady-state error for each reference hopping height. As a conclusion, the hopping height produced by the optimized PI-CPG neural network is more accurate and precise.

**ABSTRAK**

*Pergerakan melompat adalah satu cara pergerakan bagi robot untuk menyesuaikan diri pada permukaan yang tidak diketahui disamping mengatasi halangan. Pergerakan melompat adalah salah satu pergerakan yang dihasilkan oleh robot berkaki. Robot berkaki mempunyai mekanisma yang sukar serta kompleks dalam system kawalan. Robot melompat direka untuk mengelakkan halangan-halangan menegak. Jadi, jika robot melompat mengambil masa terlalu lama untuk mencapai ketinggian yang dikehendaki , ia akan menyebabkan kerosakan pada fizikal robot melompat. Oleh sebab itu, kajian tentang strategi kawalan terhadap robot berkaki satu amat berguna supaya dapat digunakan pada sistem robot yang mempunyai kaki lebih daripada satu. Pusat corak penjana (CPG) adalah rangkaian neural yang mampu menghasilkan corak yang berterusan serta berirama. Oleh sebab pergerakan melompat adalah berterusan dan berirama, rangkaian neuron pusat corak penjana (CPG) dianggarkan dapat menghasilkan pergerakan melompat. Oleh sebab itu, objektif kajian ini adalah untuk memodelkan robot satu kaki secara eksperimen, merekabentuk kawalan klasik dan mengintegrasikannya dengan pusat corak penjana (CPG) bagi mengimbangi ralat pada ketinggian berbeza serta mengoptimumkan nilai parameter pusat corak penjana (CPG) bagi mengawal pergerakan robot melompat untuk mencapai masa naik dan keadaan ralat mantap yang optimum. Algoritma lompatan tertinggi direka untuk menentukan nilai lompatan tertinggi sebagai maklumbalas. Parameter rangkaian neural PI-CPG dioptima dengan simulasi bagi setiap ketinggian lompatan yang dirujuk. Prestasi rangkaian neural PI-CPG yang telah dioptima kemudiannya dinilai dan dibandingkan dengan pengawal PI dan PID yang optima. Hasil kajian menunjukkan bahawa pengawal rangkaian neural PI-CPG yang telah dioptimumkan menghasilkan tindak balas yang lebih baik iaitu 21.36 %, 24.20 %, dan 44,13 % purata masa naik lebih pantas berbanding pengawal PI-CPG , PI yang dioptimumkan, dan PID yang dioptimumkan. Selain itu, pengawal rangkaian neural PI - CPG yang dioptimumkan lebih tepat dari segi purata keadaan ralat mantap iaitu 4.91 % berbanding purata ralat keadaan mantap pengawal PI-CPG ; 8.69 % , pengawal PI yang dioptimumkan ; 6.03 %, dan pengawal PID dioptimumkan 12.52 %. bagi setiap tinggi lompatan rujukan. Kesimpulannya, tinggi lompatan yang dihasilkan oleh pengawal rangkaian neural PI-CPG yang dioptimumkan adalah lebih tepat dan tepat.*

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# TABLE OF CONTENT

# LIST OF TABLES

## LIST OF FIGURES

## LIST OF ABBREVIATIONS

| ABBREVIATION | DETAILS |
|---|---|
| CPG | Central Pattern Generator |
| FSR | Force Sensitive Resistor |
| GA | Genetic Algorithm |
| IRS | Infrared Ranging Sensor |
| PI | Proportional-Integral |
| PID | Proportional-Integral-Derivative |

## LIST OF PUBLICATION

1. A. H. Azahar, C. S. Horng, and A. M. Kassim. 2013. Vertical Motion Control of A One Legged Hopping Robot by Using Central Pattern Generator (CPG). *2013 IEEE Symposium on Industrial Electronics & Application (ISIEA2013),*September 22-25 2013, pp. 7-12.
2. A. H. Azahar, C. S. Horng, and A. M. Kassim. 2015. Hopping Peak Height Algorithm for A One Legged Hopping Robot Height Control. *Proceedings of Mechanical Engineering Research Day 2015 (MERD'15)*, pp. 87-88, March 2015.

## CHAPTER 1

## INTRODUCTION

### 1.0 Background

Nowadays, robotics has become as one of important field that being explored for the real life application. Figure 1.1 shows the three main types of robot which are robot manipulators, biologically inspired, and mobile robots. Based on the time evolution of the robotics research, the robotic research started in years 1960 with industrial robots application, mobile robots and walking robots in years 1968, and humanoid robots in years 1972. The robotics research has evolved from time to time and now it is evolving towards service application robots.

Robotics covered autonomous and manual type of application. Autonomous robot is a machine that can be operated independently according the programming that been compiled. Opposite to manual robot, it cannot make its own decision and need supervision from human to make any decision for the robot in each situation face. In the simple word, human is the interface medium of the robot to make the decision. Recently, most researchers are attracted to move on for autonomous type application exploration especially in autonomous locomotion robot.

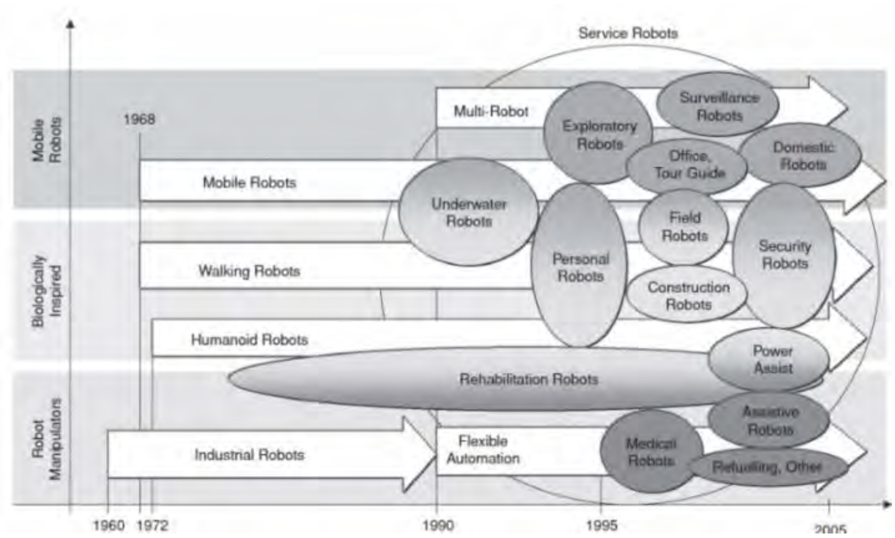


Figure 1.1 Time evolution of the robotic research towards service robots

(Garcia et al. 2007)

In half of century, autonomous locomotion robot can be described in a lot of types such as mobile robot and animal-like robot locomotion. There are had been studied and developed from many years before. Mobile robots are synonym with wheeled type because of the robot construction is simpler. Most of the wheeled type robots are excelled and designed for the prepared, regular, and flatted surface such as roads and rails but not all of them had been explored.

In fact, earth surface contains 71 percent of ocean and 29 percent of land. From 29 percent of land, there is only about less than half of that is accessible by the wheeled type locomotion. Animals demonstrate great mobility and agility. Therefore, the animal-like robot locomotion such as multi-legged, snake-like, bipedal walking, and hopping mechanism are studied.

Animal-like robot locomotion has attracted the researcher's attention as another alternative way of locomotion to solve the problems that frequently faced by a mobile robot to adapt on unknown surface and avoid obstacles. Flexibility mechanism is the advantage element of the animal-like locomotion that attracts the researcher. The flexibility mechanism in the animal-like is capable to generate or produce walking, hopping, jumping, and running locomotion.

In avoiding obstacles, jumping and hopping locomotion type robot are having high capability and advantage. Theoretically, both mechanisms are potential to overcome obstacles. But the big difference between jumping and hopping type robots is that the jumping type robot can make only one big jump moving performance. Otherwise, the hopping type robot can generate the continuous and rhythmical jumping performance. Thus, time can be reduced to achieve the target destination and larger area can be covered. Recently, Central Pattern Generator (CPG) is used among researchers in order to generate rhythmic pattern output based on animal behavior.

Central Pattern Generator (CPG) is a neural network that frequently used among researchers in generating rhythmic pattern. Many researcher used and implemented CPG neural network to generate rhythmic pattern output like swimming, crawling, walking, flying, breathing, and etc. Most of the researches are related to the animal-like locomotion like produced by fish, lamprey, salamander, and etc. Therefore, the CPG neural network is proposed to control the vertical motion of a one legged hopping robot.

## 1.1 Motivation of Research

Robot locomotion is an important aspect in mobile robot field. Mobile robot is one of robotic types that have ability to move on the changes environment. Wheeled type robot is a classical drive system and well established in research. The wheeled type robot has easy mechanism, control system, and also can perform on prepared surface such as rails and roads. Unfortunately, the wheeled type robot has limitation to overcome obstacles and cannot excel on unknown surface environment like stair or small gaps in the terrain.

As there is a need for a mobile robot to travel wherever as human can go, so one solution can be proposed is legged locomotion. The research on legged type robot quite isolated compared to the wheeled type robot. The legged type robot has difficult mechanism and complexity in control system, but this robot can adapt on any unknown surface. Besides, the robot has to be stable. In developing the running robot, a few of one-legged hopping robot is combined to become a quadruped robot, biped robot or else multiple legged robot. Therefore, the research on develop control strategies of one-legged hopping robot is useful so that the developed control strategies can be used and extended for the multi-legged system.

## 1.2 Problem Statement

The performance parameters for vertical control are rise time, steady-state error, settling time, and stability. The main problem of controlling vertical hopping robot is the rise time. Rise time is the most important parameter for hopping mechanism. The shortest rise time to reach reference height will increase the hopping performance. The rise time also one of the factor that influenced the response of the hopping robot. The hopping robot is designed to avoid the obstacles vertically. So, if the hopping robot takes too long time to reach the desired height, it will produced damages to the hopping robot physical. Therefore, a controller is needed to avoid the damages. Until today, the research on the hopping rise time is not yet being explored.

The second problem in controlling vertical hopping height is steady –state error. In order to control the one legged hopping robot, commonly two conventional controllers; PI and PID controller are designed. However, the conventional controllers cannot control the hopping robot and steady-state error due to hopping mechanism behavior. This is because both controllers cannot compensate the oscillation steady-state error produced during hopping. Hence, the conventional controllers require an algorithm to identify or detect hopping peak height for each hopping cycle as a feedback to compensate the steady-state error.

In order to solve the problems, this thesis proposes three solutions. The first solution concerns about to compensate the oscillation steady-state error produced during hopping mechanism. An algorithm based on basic rules is proposed. The rules work by comparing three data to identify the highest value that should be in between the others two data for a feedback signal to the controller. By this method, it is hypothesized that the controller will recognize actual the hopping peak height for each hopping cycle to compensate the steady-state error during hopping, thus will reduce the steady-state error.

The second solution involved the integration of a neural network controller with PI and PID controllers. A CPG controller is proposed to integrate with PI and PID controllers. It is a technique of interconnecting between two neurons which are the excitatory and inhibitory neuron that represented the neural oscillator. The idea is to boost up the command signal of the hopping robot. The conventional controllers will drop off the boosted command signal according to the current steady-state error. Through this method, it is hypothesized that this will increase the hopping robot response by reducing the rise time.

The last solution applied the optimization technique to optimize the CPG parameters. An optimum performance of hopping robot is determined by applying Genetic Algorithm (GA) technique. It is an artificial intelligent technique to optimize the CPG parameters that before this commonly used the try and error technique. The technique works by generating population, pairing, crossover, mutation, evaluate new fitness, and choosing best value. By using this technique, the duration of determining the optimum CPG parameters will reduce and it is hypothesized that the optimum CPG parameters obtained will provide the optimum rise time and steady-state error.

## 1.3 Objective of Research

The objective of this research is mainly focused on developing a control system for the one legged hopping robot to adapt on the changes surface. Additionally, a designed algorithm of the system must also be able to accommodate the changes of trajectory quickly. The objectives of this research are:

1. to model a one legged hopping robot and validate via experiment.
2. to design a classic controller and integrate with CPG to compensate the steady-state error at each different height.
3. to optimize the parameters values of Central Pattern Generator (CPG) for the optimum rise time and steady-state error.

## 1.4 Scope of Research

The research focuses on implementing a legged robot for vertical motion control purposes. The scope of work includes:

i. A one legged hopping robot with infrared sensor is used as a tool and for modeling purposes via experiment.
ii. Proportional-Integral (PI), Proportional-Integral-Derivative (PID), and proposed Central Pattern Generator (CPG) integration controllers are used for controlling the vertical motion and compensate the error.
iii. The performance parameters that be evaluated are rise time and steady-state error.
iv. Genetic Algorithm (GA) method is used as a tool for optimizing CPG parameters to improve the hopping performance.
v. The validation of optimization process is through experimentation using customized hopping mechanism.

## 1.5 Contribution of Research

In this research, an integration controller is designed in order to control the vertical motion of a one legged hopping robot. It is involves designing an algorithm of minimizing the steady-state error and improving the hopping performance in term of reducing the rise time of the hopping response. Indirectly, it has to be contributed for locomotion and surveillance activity. Specifically, the contributions of this research are as follows:

i. A new integration method for feedback control signal identification using a basic S-Function real time rules called Hopping Peak Height Detector to reduce the steady-state error.
ii. A new integration controller for vertical motion control of the one legged hopping robot based on a neural network controller.

iii. A new optimization approach using Genetic Algorithm (GA) to optimize CPG parameters for optimum steady-state error and rise time.

### 1.6 Thesis Outline

This thesis basically is divided into five chapters as described below:

**Chapter 1 Introduction**

This chapter provides readers a first glimpse at the basic aspects of the research undertaken, such as overview of robotic technology of legged robot, problem statement, objectives, and scopes of this report.

**Chapter 2 Literature Review**

This chapter reviews the previous research on one legged hopping robot, classic controller, CPG neural network, optimization technique, and other reviews related to this project are presented.

**Chapter 3 Methodology and Materials**

This chapter presents the methodology being used in this research. The system development designed is illustrated and the instruments used for the system development are described in detail as a part of this chapter. Implementation of optimization techniques in parameter tuning searching will also be included in this chapter. The designed peak to peak hopping height algorithm for hopping mechanism is also included.