UNIVERSITI MALAYSIA PAHANG

DECLARATION OF THESIS AND COPYRIGHT

Author's Full Name : NURSYAMIERA YASMIN BINTI MOHD ZAWAWI
Date of Birth :
Title : DEVELOPMENT OF BASIC MOTION AND GAIT PATTERN FOR MULTI-LEGGED ROBOT
Academic Session : SEMESTER 1 2021/2022

I declare that this thesis is classified as:

☐	CONFIDENTIAL	(Contains confidential information under the Official Secret Act 1997) *
☐	RESTRICTED	(Contains restricted information as specified by the organization where research was done) *
☐	OPEN ACCESS	I agree that my thesis to be published as online open access (Full Text)

I acknowledge that Universiti Malaysia Pahang reserves the following rights:

1. The Thesis is the Property of Universiti Malaysia Pahang
2. The Library of Universiti Malaysia Pahang has the right to make copies of the thesis for the purpose of research only.
3. The Library has the right to make copies of the thesis for academic exchange.

Certified by:

(Student's Signature)

New IC/Passport Number
Date: 18/02/2022

(Supervisor's Signature)

ASSOC. PROF. IR. DR ADDIE IRAWAN BIN HASHIM

Name of Supervisor
Date: 22/2/2022

Universiti
Malaysia
PAHANG
Engineering • Technology • Creativity

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis, and, in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering Technology in Electronics (Computer System) with Honors.

____

(Supervisor's Signature)

Full Name : ASSOC. PROF. IR. DR ADDIE IRAWAN BIN HASHIM
Position : ASSOCIATE PROFESSOR
Date : 22/2/2022

Universiti
Malaysia
PAHANG
Engineering • Technology • Creativity

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

(Student's Signature)
Full Name : NURSYAMIERA YASMIN BINTI MOHD ZAWAWI
ID Number : TG18039
Date : 18/02/2022

DEVELOPMENT OF BASIC MOTION AND GAIT PATTERN FOR MULTI-LEGGED ROBOT

NURSYAMIERA YASMIN BINTI MOHD ZAWAWI

Thesis submitted in fulfillment of the requirements
for the award of the degree of
Bachelor of Electronics Engineering Technology (Computer System) with Honours

Faculty of Electrical & Electronics Engineering
UNIVERSITI MALAYSIA PAHANG

FEBRUARY 2022

ACKNOWLEDGEMENTS

First and foremost, I want to express my gratitude to Allah for blessing me with good health and allowing me to complete this final year project and thesis. All of this would not be possible without the assistance of others; therefore, I would want to use this opportunity to convey my heartfelt gratitude to everyone who assisted me in completing my final year project, whether directly or indirectly.

Second, I'd want to convey my heartfelt gratitude to my supervisor, Assoc. Prof. Ir. Dr. Addie Irawan Bin Hashim, for his invaluable guidance and commitment during this study. From the beginning to the end of this project and thesis, I was grateful for his guidance, patience, and support, as well as his motivation.

Finally, none of this would have been possible without my family's support and patience. I'd want to offer my profound gratitude to my family for their unwavering love, support, and encouragement throughout my life, particularly during my education.

ABSTRAK

Robot berbilang kaki adalah salah satu robot yang diilhamkan secara biologi oleh serangga atau makhluk artropod. Robot ini biasanya dibangunkan sebagai robot mudah alih untuk sebuah operasi tanpa krew yang boleh mengatasi apa yang tidak dilakukan oleh robot beroda. Selain itu, robot ini boleh memegang kedua-dua kestabilan statik dan dinamik dalam pergerakannya. Dalam projek ini, robot berbilang kaki boleh dikonfigurasikan bernama robot Hexapod-to-Quadruped (Hexaquad) difokuskan dan dipertingkatkan dengan konfigurasi kawalan jauh dan unit kawalan teguh. Projek ini memberi tumpuan kepada mewujudkan pergerakan ketepatan setiap kaki robot dan reka bentuk urutan gerakan kaki yang stabil. Papan unit kawalan berpusat disediakan dengan pengawal mikro 32-bit sebagai unit pemprosesannya dalam reka bentuk unit kawalan. Reka bentuk pengawal terbenam dilakukan sepenuhnya menggunakan kod Simulink untuk kaedah masa nyata dan perkakasan dalam gelung. Dalam suasana tidak bergerak, hasil projek ini menyampaikan untuk membangunkan setiap kaki Hexaquad dengan kawalan ketepatan, dan boleh berdiri dengan kaki yang kukuh.

ABSTRACT

The multi-legged robot is a biologically inspired robot that resembles an insect or an arthropod organism. This robot is frequently built as a mobile robot for a crewless operation that can outperform a wheeled robot. Furthermore, in its mobility, this robot can maintain both static and dynamic stabilities. The Hexapod-to-Quadruped (Hexaquad) robot, a configurable multilegged robot, is focused and developed in this project with a remote-control configuration and sturdy control unit. The goal of the project is to establish the leg motion and create a sequence. In the control unit design, a 32-bit microcontroller is used as the processing unit on a centralized control unit board. For the real-time and hardware-in-loop methods, the embedded controller is designed fully in Simulink code. In the idle mood, the project's result delivers and develops joint leg control for each Hexaquad leg with precision control, and can stand with a sturdy and reliable foot.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ADC	Analog to Digital Converter
CoG	Centre-of-Gravity
DC	Direct Current
DoF	Degree of Freedom
FTG	Foot-to-Gripper
Hexaquad	Hexapod to Quadruped
IO	Inputs/Outputs
DIO	Digital input/output
PWM	Pulse with modulation
VS	Versus
COM	Centre of Mass
POS	Polygon of support
CPU	Central processing unit
A/D	Analog/Digital
D/A	Digital/Analog
ASV	Active suspension vehicle
PID	Proportional Integral Derivative

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

To cross unstructured terrain successfully and safely, almost all terrestrial animals evolved with sturdy, nimble legs. Thus, robotic expertise has made multiple attempts over the last several decades to produce bio-inspired legged robots that are as lifelike as feasible in synchronising and coordinating the robot's body to leg joints. As a result, many robots and machine designs in the automotive technology industry select wheels because of their energy efficiency and mobility. It's important to remember, nevertheless, that only vehicle systems with legged mechanisms can operate as a legged creature capable of navigating unstructured terrain [1]. Also, because a legged robot only requires discrete contact with the ground surface, it may step over obstacles and maintain stability by varying the height of its legs.

The wheeled robot, on the other hand, must keep continual contact with the flat surface in order to go steadily. This feature highlights how a legged robot may reduce damage to terrain structures while enhancing mobility in every situation, especially in applications where the terrain must stay undisturbed for specific reasons [2]. Until recently, developed legged robots were used to demonstrate their competence in a variety of essential applications, including undersea exploration [3], planetary or space exploration [4], nuclear power plant operations [5], and search and rescue operations [6].

Multi-legged robots are frequently impacted by living organisms such as humans, animals, and insects. Multi-legged robots follow a predetermined gait pattern/algorithm when walking. Multi-legged robots are being used to transfer payloads and investigate difficult terrain. Big Dog, a multi-legged robot created by Boston Dynamic, is an example. It has a top speed of 4 miles per hour (mph) and can climb slopes up to 35 degrees in inclination [7]. To perform joint movement, robots require drive systems, and all robot designers desire or need correct joint actuation. [8]. It is possible to better regulate the robot's movement and walking pattern (gait) with precision control.

Without an appropriate controller for robot legs, the robot's future evolution could be hampered in a certain setting. When the robot is ready to go, good wiring and connections are required to ensure that it can be used to its full potential. Any component of the robot's movement must be optimised and analysed to guarantee that the robot's movement is exact and free of errors that could hurt the robot or its surroundings in the future.

1.2 OBJECTIVES AND SCOPES

Concerning the problem statements outlined in the previous section, the objective is listed below:

I. To design and developed basic motion of Hexaquad robot.
II. To design and develop an optimal gait pattern for Hexaquad robot.

The scope of the project should be focused on:

I. To establish and optimize each robot leg basic movement and cycle of motion.

1.3 THESIS OUTLINE

This thesis is organized as follow:

Chapter 1:

Chapter 1 of this proposal will explain this SDP, covering the project's introduction, objective, scope, and thesis outline. The introduction will discuss the Hexaquad current problem and provide background information on the project.

Chapter 2:

This chapter includes a literature review about the previous development of the Hexaquad robot. In addition, the current information on Hexaquad and its work process will be discussed in this chapter. This chapter will also discuss the development of robot legged and the type of robot walking pattern.

Chapter 3:

This chapter will give the detail about the methodology used to complete the project. The method for completing the work and a description of the tools, resource utilisation, and general flow of the project are covered in length in this part. References to related knowledge will be explored, and the details of the project will be discussed.

Chapter 4:

This chapter will show the result get from the driver setup and Simulink program made.

Chapter 5:

The project's results and comments will be provided here to validate the proposed solution. In addition, the problem encountered will be described, as well as the remedy if available.

CHAPTER 2

LITERATURE REVIEW

2.1 REVIEW ON RESEARCH AND DEVELOPMENT OF LEGGED ROBOT

As with manipulators, the legged robot needs interaction with the surrounding environment and its robotic leg for sensing and foot placement, particularly in unstructured terrain (complex) that may contain unanticipated obstructions or have varying ground stiffness. The key to maintaining the robot's body posture and stability in a legged robot is to recognize and regulate the impacts that occur during leg landing into the surface and transfer force onto the surface to move the robot's body. Thus, compliance components like suppleness and flexibility are incorporated into motion control to provide a stable body posture and adaptation to the surroundings for a legged robot during locomotion. For a non-compliant (stiff) robot, the end-effector is constructed with pre-set and set locations or trajectories in mind. Even when an external force is applied to the manipulator, the robotic end-effector will perfectly follow the specified route. At the same time, a compliant end-effector may relocate the manipulator linkage or end-effector location when a different force is applied to it [9]. There are two ways to ensure that the robot complies with environmental regulations: passive compliance and active compliance. Passive compliance can be achieved by rebuilding the robot's body, focusing on the leg structure, modifying the leg's joint actuation mechanism, or by equipping the leg with springs, dampers, or both as a compliant device. It is distinct from passive compliance control, which gained extra active compliance by incorporating force feedback or joint torque feedback into the robot's leg end-effectors to dynamically manage the system's behaviour, such as precise force control and impedance management. Both approaches to developing an environment-compliant robot will provide flexibility for a legged robot to adapt, particularly during locomotion over unstructured terrain or when confronted with ground stiffness while retaining the robot's body's stability.

2.2 MULTI-LEGGED ROBOTS

Multi-legged robots or active suspension vehicles (ASV) provide several advantages over motion control, particularly when coping with uneven and steep terrain. Leg manipulation stability is crucial since it determines how well a robot leg can move. Each robot's leg is simply a manipulator unit (a single robot arm) that is generally set up with fixed design motion during mobility. The robot arm manipulator is particularly adept at applying force to items to move them across the workspace in terms of object interaction. For a legged robot's reliable mobility, compelling trajectory tracking in leg manipulation is essential. For the leg to perfectly follow the needed motion during trajectory tracking, each leg's joints must have a robust closed-loop control. Certain nonlinear situations, such as the windup phenomenon and gravity effects, should be considered while designing a closed-loop control. Close-loop control inputs such as the proportional integral derivative (PID) control input (u(t)) accrue and continue to increase when the physical variable approaches its saturation point due to the action of the integral element. As a result, one or more leg joints may be involved in raising and lowering the leg to complete the position control, or some joints may be static while others keep the system moving. During these leg motion phases, particularly during foot planting, gravitational influence can cause an internal disruption to each leg's joint.[10].

2.3 OVERVIEW OF HEXAQUAD ROBOT

The paper explored the many types of multi-legged robots. The walking robot mechanism mentioned is the leg-type mobile robot. The Hexaquad robot is a legged robot. Compared to crawler and wheel type robots, the leg type robot has several benefits, including the flexibility to choose the ground contact point, which means it will be more adaptable to the terrain with which its leg comes into touch. In addition, the capacity of a legged robot to walk and navigate without sliding is critical for positional stability. The method of multilegged robot walking is classified into two types: static walking and dynamic walking. For instance, static walking in a four-legged robot means that just one leg swings while the other three remain in a supporting posture, but dynamic walking always requires one or two supporting legs [12].

Hexapod-to-Quadruped (Hexaquad) is a reconfigurable multi-legged robot with a bioinspired design that will be used for underwater operations. Hexapod is a configuration of multi-legged robots that is statically stable, whereas quadruped is a configuration of multilegged robots that is dynamically stable. In terms of robot configuration, multi-legged robots are extremely adaptable, and their greater gait stability [13] enables them to travel to locations/terrains where a robot with conventional wheels would ordinarily fail. While multilegged robots offer several benefits over propeller-based robots for underwater operation, the benefits of legged robots include their ability to undertake underwater walking and manipulation in the face of strong tidal currents and their manoeuvres at the bottom, as mentioned in [14], will have a lower influence on muddying the sea water [15]. It is feasible for the robot to climb at a specific incline by having a suitable walking algorithm (gait pattern). As seen in Figure 2.2, the dimension of Hexaquad are given

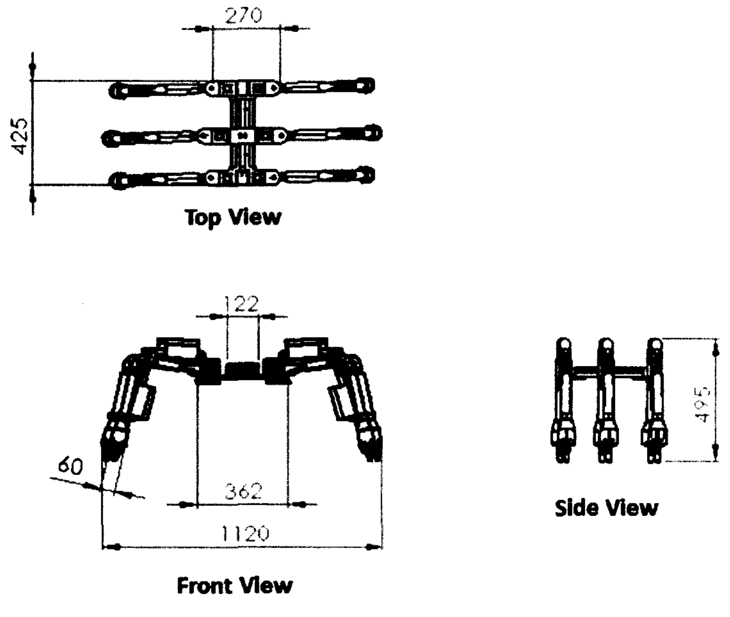


Figure 2.2: Dimension of Hexaquad [14]

Each of the six Hexaquad legs is configured identically. Each of them has two joints, the merus, and the carpus (both parallel actuated by linear actuator). A dual driver is employed to drive the merus and carpus joints two linear actuators. Figure 2.3 illustrates the real design Hexaquad Leg configuration and connection.

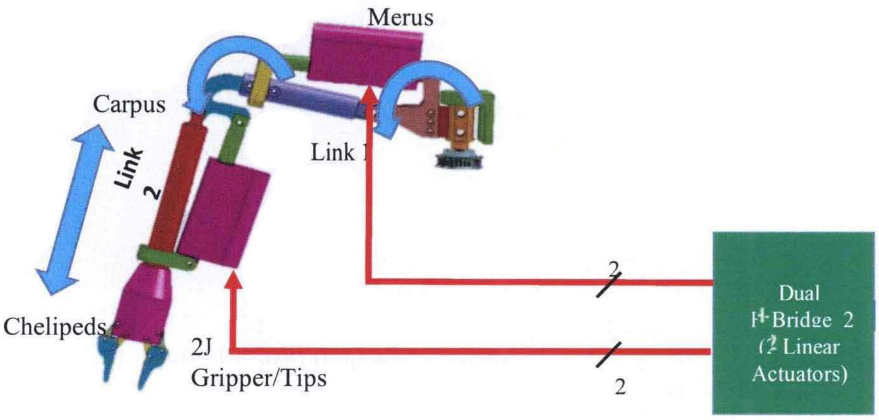


Figure 2.3: Hexaquad leg configuration and connection [14]

The component (actuator) needed to control the Hexaquad robot was included in the set detailed in [16]. The article described the sort of actuator used for the Hexaquad robot and how it met the requirements for performing leg actuation. The article conducted simulations and estimated the torque requirements for each joint [16]. The Hexaquad Robot's design is summarized in Figure 2.4 and figure 2.5.

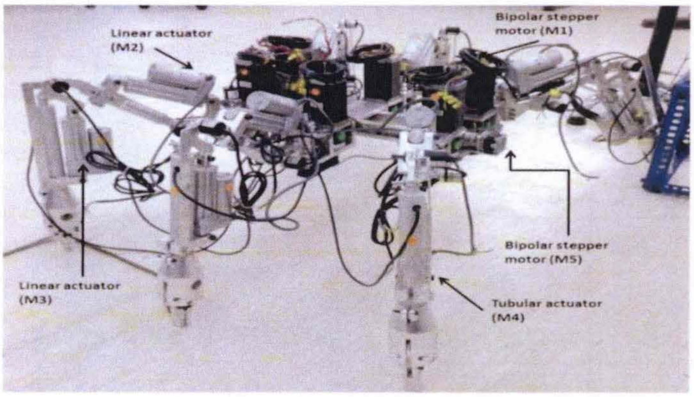


Figure 2.4: Hexaquad Robot Design Overview. [14]

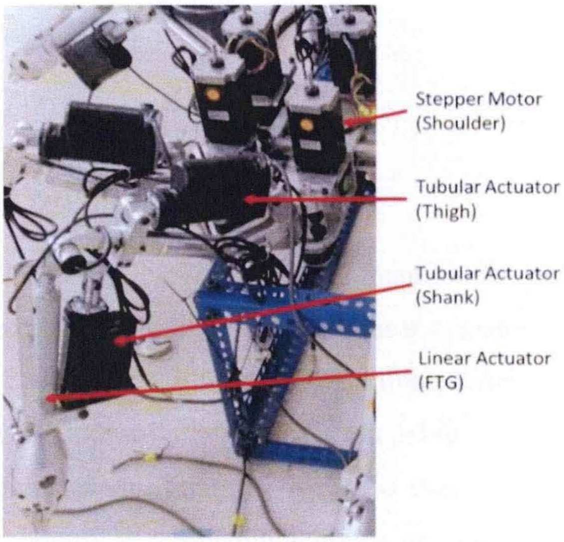


Figure 2.5: Actuator and respective joint

The specification of the robot leg and the size are discussed in table 2.1 below. The detail of this discussion can be referred to the previous journal [16]

Table 2.1: Hexaquad detailed

Item	Value	Unit Total
Length (m)	0.9	-
Width (m)	0.42	-
Height (m)	0.43	-
Total weight (Kg)	50	-
Potentiometer	-	12
Linear actuator Load (N), Voltage (V) and Current (A)	200,12,2	12

2.4 SUMMARY

From the previous development, it is convincible that Hexaquad is a well-designed robot with a high torque linear actuator as its leg. The system of the robot is almost completed, with only a few minor things that are missing. The development of its joint leg and walking pattern is crucial to make sure all legs of Hexaquad can be run. To allow Hexaquad legged robot to successfully navigate its workspace, accurate position control in leg manipulation is necessary for manipulating the leg's joints while walking according to a specified motion. Gravity is a nonlinear factor contributing to the reduction of position control precision quality, as all robotics legs must lift up and down while maintaining discrete contact and compensating for gravity force during locomotion. However, by having a perfect trajectory that precisely matches the preset motion, the legged robot will traverse only on flat terrain. It will fail while walking on the unstructured ground. A dynamic control technique called impedance control may be employed to ensure the legged robot's compliance with its surroundings. This will allow it to be more adaptable when traveling over unstructured terrain. Mechanical impedance control can be utilized to adapt the location of the legend effector to the terrain structure or boost the leg movement speed.

CHAPTER 3

METHODOLOGY

3.1 MODULE DRIVEN SYSTEM DESIGN

The main controller used for Hexaquad is Arduino Mega 2560 microcontroller. This microcontroller consisted of 54 (39 DIO +15 PWM) and 16 ADC +10 external ADC channels. Table 3.1 explains the slot used from one joint leg of Hexaquad to the Dual H-bridge driver connect to the Microcontroller. In Figure 3.1, can be seen the block diagram connection of the 6 joint leg of Hexaquad to microcontroller.

Table 3.1: Total IO need for 1 joint leg of Hexaquad

Component	IO needed		
	Digital IO	PWM Output	Analog Input
DC motor Linear actuator	2	2	-
Potentiometer	-	-	2
Total needed	2	2	2

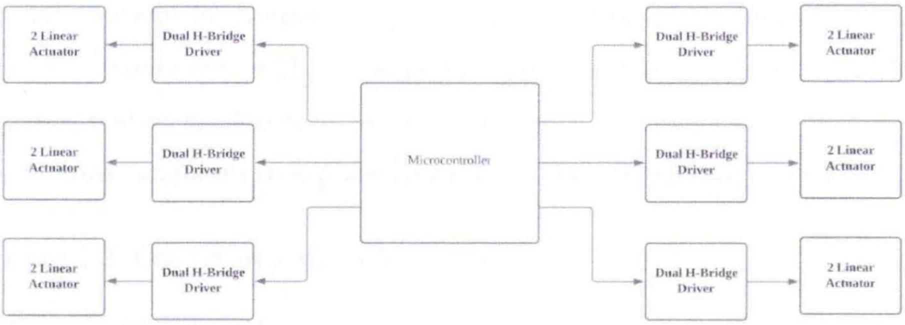


Figure 3.1: Block diagram of 6 joint leg of Hexaquad to microcontroller

As stated, before Hexaquad are using microcontroller to control its whole leg operation. Dual H-Bridge drivers are required to manipulate a single leg of Hexaquad. This driver will be connected straight toward two linear actuators of the leg. Hexaquad is composed of 12 adjustable joints that require a response from the data collecting system. To get the data from all the leg's joint, a continuous analogue potentiometer with 360 degrees rotation is used as the motion tracker. This data feedback is used to manage the location of the 3 joints of Coxa, Merus and Carpus. Figure 3.2 shows the control system connection of the Hexaquad robot's leg system.

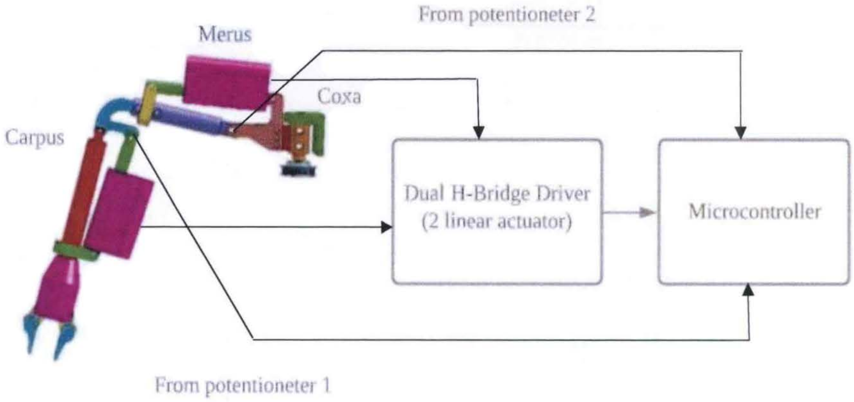


Figure 3.2: Diagram connection of 1 joint leg of Hexaquad to microcontroller.

The analogue pin of the potentiometer connected to the microcontroller will produce a graph signal made from the electrical signal. This graph will control the leg position to be in the place as we want, thus creating a walking pattern that we want to program later easy to be control and more precise. In order to control the two linear actuators, the experiment will use 4 Digital pins on the microcontroller. The two analogue pins will be used to read the electrical signal. In table 3.2 below, the example of how one linear actuator run is given an example. The digital pin number is random.

Table 3.2: One linear actuator logic input

Pin as in figure 4.1		Motor rotation
Pin 4	Pin 6	
Steady state	Steady state	No rotation
0	0	Motor Stop
1	0	Clockwise
0	1	Counter-clockwise
1	1	Motor Stop

3.2 LEG MOTION DESIGN

A hexapod robot was chosen for this study, with one of its legs serving as a target plant for the proposed idea's installation and examination. The previous researcher introduced an Anti-windup feature to the joint position control of Hexapod's leg, developed initially with PI control [17]. The controller, however, was only tested on a step response trajectory of the Hexapod's leg joints, making it unsuitable for a continuous trajectory. Figure 3.4 always shows 6-legged insects walking with three legs on the ground and the other three legs raised in a swinging motion to display this walking gait. The length of time the legs swing depends on how fast the insect is moving. The tripod gait positions the insect so that the front and hind legs on one side move/swing in synchrony with one middle leg on the other side. Insects always have three legs on the ground, but the sticky attachments on the extremities of their appendages provide them even more stability, allowing them to walk on vertical or horizontal structures. Thus, the insect's walking stride, which the Central Pattern Generator generates, is both stable and controlled (CPG). The CPG is a group of neural circuits that collaborate to create rhythmic motor movement patterns. The CPG may control various locomotion, such as fighting and swimming, survival processes such as breathing and walking. Without requiring sensory inputs, the Central Pattern Generator applies input based on time and rhythmic information. To control the locomotor system, the CPG requires a series of core oscillations generated by the ganglion. All insects exhibit this waving behaviour at some point during their lives.

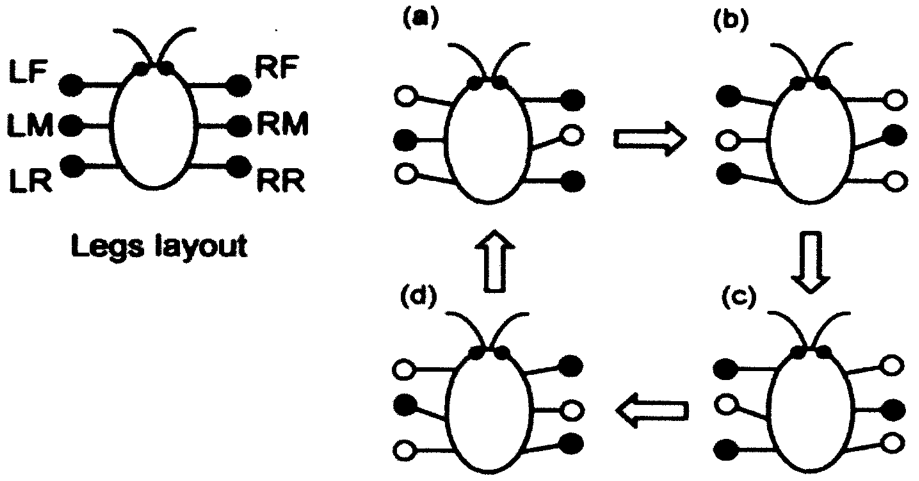


Figure 3.4: The walking motion of the insect tripod gait.

For a gait to be called periodic, both legs must be in the same state at the same time during the cycle, and each leg cycle must occupy the same amount of time. For the foregoing conditions to be met, each leg must have the same duty cycle. A leg's duty cycle is similar to a pulse width modulated signal. It's the percentage of time a leg spends in instance mode during a leg cycle, as shown by:

$$\beta = \frac{t_{s\tan ce}}{t_{s\tan ce}+t_{swing}} \qquad 3.1$$

The less time a leg spends in instance mode, the quicker and more unstable the gait becomes. The robot goes quicker as it drops, but there's a greater chance of stumbling or falling over during transitions between swing and stance mode. A tripod gait is the hexapod's fastest and most statically stable gait. Two sets of three legs in a tripod gait are 180 degrees out of phase in terms of leg cycle; one set is in instance mode, while the other is in swing mode. The tripod gait is rapid because just three legs are on the ground at any given moment, but it also makes the robot the least stable. The legs of a tripod gait have a duty cycle because they spend the same amount of time on the ground as they do in the air.

A duty cycle generates instability in a walking system because those legs spend more time in the air than on the ground. This means that at some point throughout the gait cycle, there will be no legs on the ground. This is not unusual, especially in nature. When an animal attempts to move quickly, it commonly reaches a point in its gait where none of its legs are in contact with the ground. To prevent toppling over, the animal usually propels itself upwards slightly, giving the swinging legs enough time to return to the ground before switching to stance mode. If a force is applied to the animal during this transition time, it will frequently stumble and fall over. As a result, this isn't typically seen in robot walking because, in most applications, stability trumps speed.

Inverse kinematic for robots with parallel construction to display joint variables of legs utilising the position and orientation of the robot platform. The spider-like robot's limbs are separated into two groups: contact legs that stay connected to the ground as the robot walks, and noncontact limbs that move across space as the robot walks. The position and velocity inverse kinematics of each of the two group legs are analysed separately in order to study the robot's inverse kinematics.[18]

Inverse kinematics is used to figure out the connections and joint settings. The intended position for each link and joint is determined via inverse kinematics. The desired positions of each link and joint can be used to plan the robot's mobility and decide its workspace. Inverse kinematics begins by determining the pose and orientation of the end effector using a geometrical calculation of all joints and connections to reach a specific position and orientation of the end effector. The end effector in this study is a model of the end of legs.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 HEXAQUAD JOINT LEG SIMULINK CONTROL

Simulink are used in this project to control the Hexaquad legs to get the basic motion also the gait pattern. As Figure 4.1 showed the graph of basic motion for swing and drag phase should be in semi-circle shape.

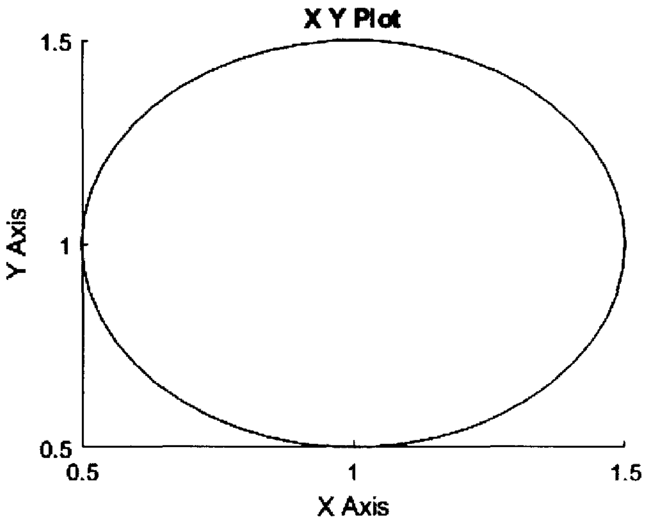


Figure 4.1: Graph of basic motion on graph plotter

CHAPTER 5

CONCLUSION

5.1 INTRODUCTION

The development of the Hexaquad joint leg driver setup and controller unit for 2-DoF and six legs has been successfully made but failed to developed the gait pattern and sequence so that Hexaquad only can-do basic motion and movement and the objective for this project was not achieved.

5.2 RECOMMENDATION FOR FUTURE RESEARCH

In the future, instead of applying a block timing delay, the Hexaquad robot might use potentiometer to form a walking pattern for future development and research. It will be easy to regulate the trajectory of each leg with a feedback system.

REFERENCES

[1] Raibert, M. H. (1986). Legged robots that balance: MIT press.

[2] Cigola, M., Ceccarelli, M., & Carbone, G. (2005). Application of robots for inspection and restoration of historical sites.

[3] Jun, B.-H., Shim, H., Kim, B., Park, J.-Y., Baek, H., Yoo, S., & Lee, P.-M. (2013). Development of seabed walking robot CR200. Paper presented at the OCEANS-Bergen, 2013 MTS/IEEE.

[4] Preumont, A., Alexandre, P., Doroftei, I., & Goffin, F. (1997). A conceptual walking vehicle for planetary exploration. Mechatronics, 7(3), 287-296.

[5] Bartholet, T. (1985). Robot applications for nuclear power plant maintenance: Odetics, Inc., Anaheim, CA (USA).

[6] Eich, M., Grimminger, F., & Kirchner, F. (2008). A versatile stair-climbing robot for search and rescue applications. Paper presented at the Safety, Security and Rescue Robotics, 2008. SSRR 2008. IEEE International Workshop.

[7] E. M. Petriu, "Bio-inspired solutions for intelligent android perception and control," in Technology and Society (ISTAS), 2013 IEEE International Symposium on, 2013, pp. 18-18.

[8] B. Aranjo, P. K. Soori, and P. Talukder, "Stepper motor drives for robotic applications," in Power Engineering and Optimization Conference (PEDCO) Melaka, Malaysia, 2012 IEEE International, 2012, pp. 361-366.

[9] C. W. Thompson, & Floyd, R.T. (1994). Manual of Structural Kinesiology, "Biomechanics," ed, 2014.

[10] A. Irawan, "Optimizing Hexapod Robot Reconfiguration using Hexa-Quad Transformation" International Journal of Robotics and Automation (IJRA) Vol. 3,No. 2, June 2014, pp. 139-150.

[11] Zainol, M. A. F. (2016). Precision Control on Hexaquad Robot's Leg Using Antiwindup PID Control Approach. Universiti Malaysia Pahang.

[12] N. Takase, J. Botzheim, and N. Kubota, "Robot Edutainment on Walking Motion of Multi-legged Robot," in Robot, Vision and Signal Processing (RVSP), 2013 Second International Conference on, 2013, pp. 229-233.

[13] B. Na, H. Choi, and K. Kong, "Design of a Direct-Driven Linear Actuator for a HighSpeed Quadruped Robot, Cheetaroid-I," IEEE/ASME Transactions on Mechatronics, vol. 20, pp. 924-933, 2015.

[14] A. Irawan, H. L. Jiun, and M. M. Alam, "Control input converter for robot's leg joint with parallel actuation configuration," in Electrical and Computer Engineering (ICECE), 2014 International Conference on, 2014, pp. 757-760.

[15] K. Jung-Yup and J. Bong-Huan, "Mechanical design of six-legged walking robot, Little Crabster," in OCEANS, 2012 - Yeosu, 2012, pp. 1-8.

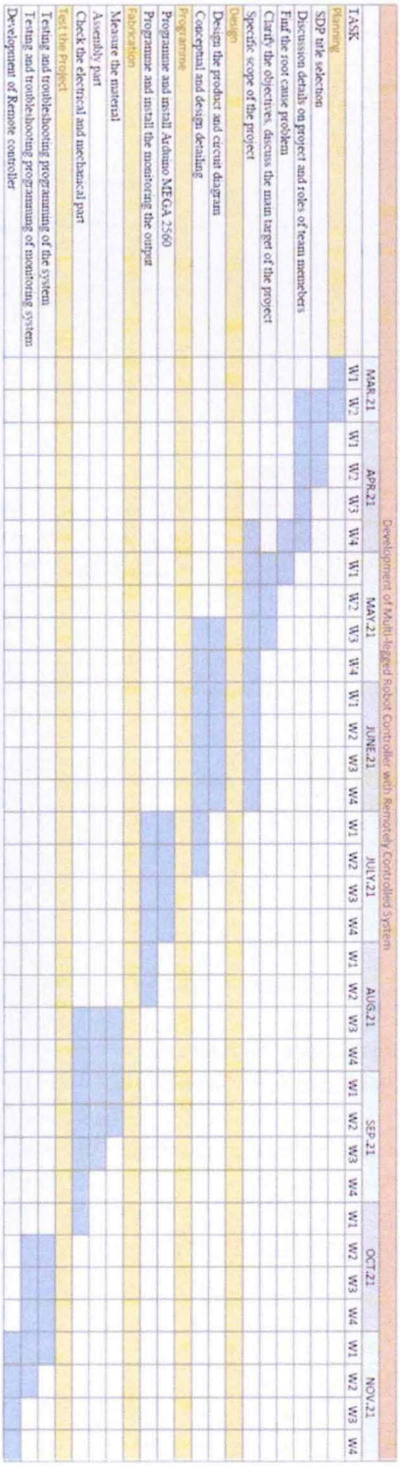
[16] A. Irawan, "DEVELOPMENT OF HEXAQUAD ROBOT: MODELING AND FRAMEWORK," ARPN Journal of Engineering and Applied Sciences vol. 10, p. 8, December 2015.

[17] Eric H. Anderson, Michael F. Cash, Jonathan L. Hall and Gregory W. Pettit CSA Engineering Inc., Mountain View, CA. HEXAPODS FOR PRECISION MOTION AND VIBRATION CONTROL. American Society for Precision Engineering, Control of Precision Systems, April 2004.

[18] Muslimin, Selamat & Istardi, Didi. (2018). Inverse Kinematics Analysis for Motion Prediction of a Hexapod Robot. 1-5. 10.1109/INCAE.2018.8579402.

APPENDICES

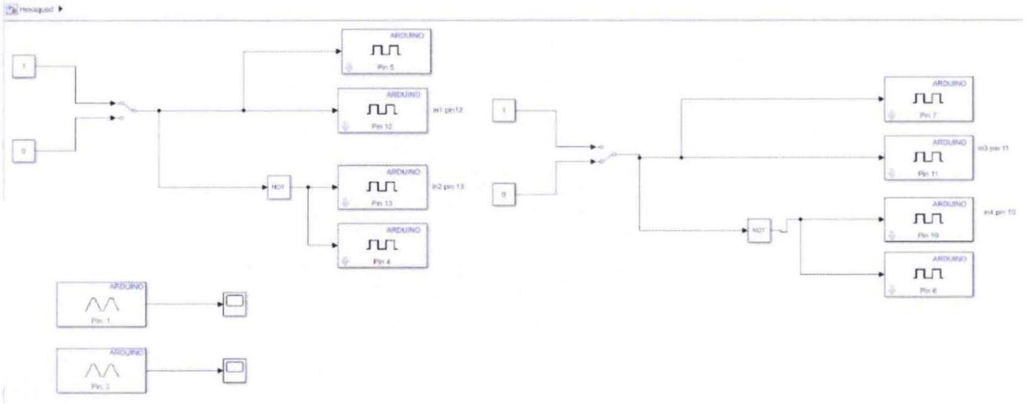
Appendix A: Gantt chart

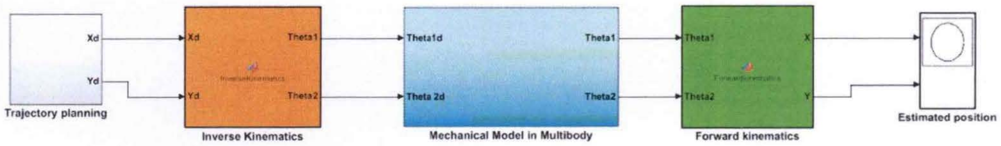


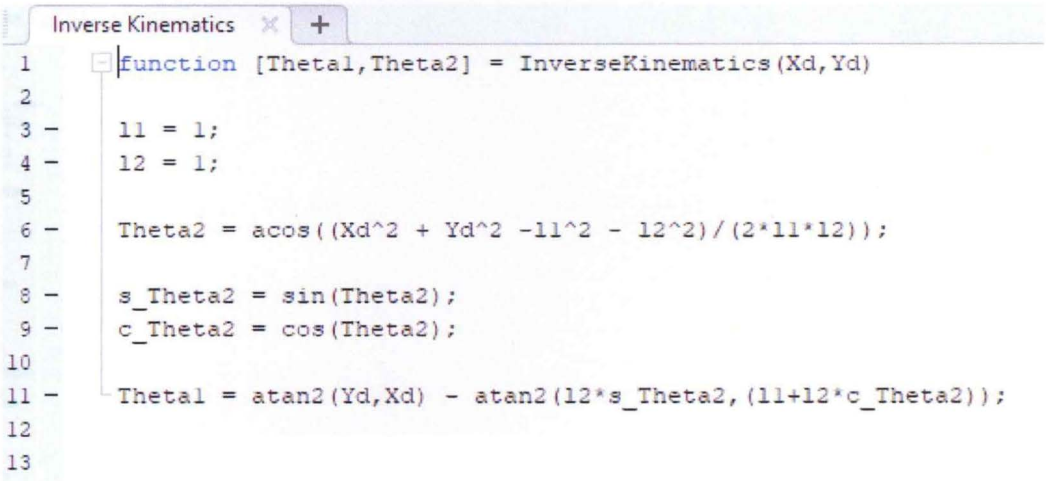
Development of Multi-legged Robot Controller with Remotely Controlled System

	MAR.21		APR.21				MAY.21				JUNE.21				JULY.21				AUG.21				SEP.21				OCT.21				NOV.21			
TASK	W1	W2	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4
Planning	■	■																																
SDP title selection		■	■	■																														
Discussion details on project and roles of team memebers		■	■	■	■	■																												
Finf the root cause problem						■	■																											
Clarify the objectives, discuss the main target of the project							■	■	■																									
Specific scope of the project						■	■	■	■	■	■	■	■	■																				
Design																																		
Design the product and circuit diagram									■	■	■	■	■	■																				
Conceptual and design detailing									■	■	■	■	■	■	■	■																		
Programme																																		
Programme and install Arduino MEGA 2560															■	■	■	■																
Programme and install the monitoring the output															■	■	■	■	■	■														
Fabrication																																		
Measure the material																					■	■	■	■										
Assembly part																					■	■	■	■	■									
Check the electrical and mechanical part																					■	■	■	■	■	■	■							
Test the Project																																		
Testing and troubleshooting programming of the system																												■	■	■	■			
Testing and troubleshooting programming of monitoring system																												■	■	■	■	■		
Development of Remote controller																															■	■	■	■

Appendix B: Softw gram







```
function [Theta1,Theta2] = InverseKinematics(Xd,Yd)

l1 = 1;
l2 = 1;

Theta2 = acos((Xd^2 + Yd^2 -l1^2 - l2^2)/(2*l1*l2));

s_Theta2 = sin(Theta2);
c_Theta2 = cos(Theta2);

Theta1 = atan2(Yd,Xd) - atan2(l2*s_Theta2,(l1+l2*c_Theta2));


```