A SINGLE UNIT CONCEPT AND DESIGN OF A HIGH MANEUVERABILITY MOBILE ROBOT

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June 2017

This dissertation is submitted to

Universiti Sains Malaysia

As partial fulfilment of the requirement to graduate with honors degrees in

BACHELOR OF ENGINEERING (MANUFACTURING ENGINEERING WITH MANAGEMENT)

School of Mechanical Engineering

Engineering Campus

Universiti Sains Malaysia

DECLARATION

This thesis is a presentation of my original research work. Wherever contributions of others are involved, every effort is made to indicate this clearly, with due reference to the literature, and acknowledgement of collaborative research and discussions. This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidate for any degree. The work was done under the guidance of Dr. Norzalilah Mohamad Nor, at the University Science of Malaysia.

Signed:...(Nurul Busra binti Awi)

Date :

In my capacity as supervisor of the candidate's thesis, I certify that the above statements are true to the best of my knowledge.

Signed:..(Norzalilah Mohamad Nor)

Date :

ACKNOWLEDGMENT

After undergoing countless of efforts and discussions, Alhamdulillah praise to Allah for giving me strength and guidance to me in completing my final year project as partial fulfillment of the requirement to graduate. First and foremost, I would like to express my gratitude to my project's supervisor, Dr Norzalilah Mohamad Nor for giving me suggestions and advices as well as encouragements along the project. This project would not be completed without her help.

Besides, I would like to thanks to Nor Hayati binti Abu Bakar, Nurul Safinaz binti Mustapa, Mohamad Aqil bin Azman and Arif Izzudin bin Mohammad for helping me to understand the hardware and software throughout this research. Suggestions and motivations are very useful for me to finish my project. They also helping me to do some troubleshooting on the problems that I faced when handling the hardware and software of this project.

Moreover, my special thanks to the authority of Universiti Sains Malaysia (USM) especially to School of Mechanical Engineering for providing me with all the facilities needed to complete this project. Next, I also would like to thanks to my parents for always giving advice and encouragement whenever I had problems. Last but not least, I would like to thanks all the people who involved directly or indirectly in helping me during the project.

Table of Contents

LIST OF TABLES

LIST OF FIGURES

ABSTRAK

Tujuan projek ini adalah untuk mengkaji dan menghasilkan sebuah robot mudah alih sebagai alat yang boleh menggantikan manusia untuk melaksanakan tugas tertentu, misalnya mencari, pemeriksaan, navigasi dan menyelamat ketika dalam persekitaran bahaya. Robot mudah alih ini mempunyai keupayaan untuk bergerak dalam pelbagai persekitaran seperti udara, tanah dan air. Beberapa jenis robot mudah alih telah direka cipta seperti robot berkaki, robot beroda, robot tanpa tangan, robot mendaki dinding dan robot amfibia. Robot mudah alih juga dikenali sebagai bio-inspirasi robot.

Robot ular adalah salah satu contoh robot mudah alih. Robot ular sesuai untuk persekitaran yang sangat terhad kerana keratan rentas yang kecil dan kinematik yang bagus yang membolehkan ia memasuki dan bergerak melalui ruang yang kecil. Robot ular menjanjikan mekanisme untuk aplikasi dunia sebenar seperti mencari dan menyelamat bandar yang musnah dan pemeriksaan perindustrian. Darjah kebebasan memberi ia potensi untuk menyesuaikan diri dengan persekitaran yang kompleks dan dalam ruang yang terkurung. Robot ular menawarkan kelebihan berbanding robot mudah alih yang tradisional kerana ia memberikan sifat boleh mencapai terutamanya dalam persekitaran yang berbelit-belit. Oleh itu, sebuah robot ular mudah alih telah dihasilkan dengan menggunakan sistem perisian SolidWorks CAD dan sebuah prototaip dihasilkan untuk menguji kebolehannya. Perkakas fizikal juga telah digunakan seperti Arduino UNO, servo motor, dan perkakas eletrik yang lain. Selepas itu, ujian fungsi dan mekanisme prototaip robot ular telah dilaksanakan.

ABSTRACT

The aim of this project is to design and produce a mobile robot as a tool that could replace humans to perform certain tasks such as search, inspection, navigation and rescue in hazardous environments. The mobile robot has the ability to move in the environment such as air, soil and water. Some types of mobile robots that have been widely developed such as legged robots, wheeled robot with no arms, wall climbing robot and robot amphibians. The mobile robot is also known as bio-inspired robot.

Snake robot is one example of a mobile robot. Snake robots are suitable for environment that is very limited because of the small cross section and highly redundant kinematics enables them to enter and move through narrow spaces. Robot snake promising mechanism for real-world applications such as search and rescue in destroyed city and industrial inspection. The degree of freedom gives them the potential to adapt to complex environments for confined spaces. Snake robots offer advantages over traditional mobile robots because they provide properties that can be achieved especially in an environment that convoluted. Thus, a mobile robot is generated using CAD software systems of SolidWorks and a prototype is produced to test it abilities. Physical appliances that have been used are an Arduino UNO, servo motors, and other electrical equipment. After that, the functional test and mechanism of the snake robot prototype has been carried out.

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CHAPTER 1 INTRODUCTION

1.1 Introduction

Robots are very crucial in the world of research because they can perform tasks or reach locations that would be impossible for human. Some of the most dangerous and challenging environments are found beyond the earth. Roboticists are developed man-made mechanical devices that can move by themselves, whose motion must be modelled, planned, sensed, actuated and control the motion influenced by a programming. Robots are called intelligent if they succeed in moving in safe interaction with an unstructured environment, while autonomously achieving their tasks.

Snake robots are ideally suited to highly confined environments because their small cross-sections and highly redundant kinematics allow them to enter and move through tight spaces with a high degree of dexterity. Despite these theoretical advantages, snake robots also pose a number of practical challenges that have limited their usefulness in the field. Snake robots are a promising class of mechanisms for real-world applications such as urban search, rescue and industrial inspection. The degrees of freedom give them the potential to adapt to complex terrain in order to locomote and manipulate in confined spaces [1]. Snake robots offer advantages over traditional mobile robots and robot arms because they provide enhanced edibility and reachability, especially in convoluted environments. These robots are well suited to inspection work such as in the future space station and can also be used to inspect the Space Shuttle cargo bay before launch.

Snake robots are useful in many situations where their unique characteristics give them an advantage over any type of environment. These environments can be long and thin like pipes or highly cluttered like rubble. During disasters in urban areas, it is common for buildings to collapse and for debris to be present, complicating the search and rescue process. Such environments make survivors difficult to find amongst the debris, because they may be buried.

Additionally, debris and partially-collapsed buildings can also make the searching environment become dangerous for both human rescuers and even trained dogs because of the potential for collapse. Even more dangerous would be the when the case of toxic, chemicals or radiation are presented in the cleanup site [2].

In the past decades, there was a major earthquake in San Francisco Bay Area, old Victorian houses lie in the ruins. This situation give difficulty to the willing rescuers to climb and dig the collapse building and find someone buried under the rubble. Therefore, search-and-rescue snake robots have been developed by roboticist to help the rescuers. The snake robot can adapt the uneven ground and rises up over small obstacles while maneuvering around the larger ones. By sending the stereo sound to the operators, they can hear no cries for help and continue moving to find victims. While infrared is used to illuminates the scene with high power of LEDs. The snake can sweeps the area up ahead with pyroelectric device to look for body heat. The microphones will pick up the victims sound of breathing. This new generation technology allows engineer to develop the advance and good features of snake robot for rescuing mission.

1.2 Problem statement

Research on snake robots has increased vastly during the past ten to fifteen years and the published literature is mostly focused on serpentine motion. The fastest and most common serpentine motion pattern used by biological snakes is called lateral undulation. Forward motion is obtained from this motion pattern by propagating friction from the front to the rear of the snake while exploiting roughness in the terrain. This is also been the most implemented motion pattern for snake robots. Snakes exploit irregularities in the terrain to push against to move forward by lateral undulation. This method of locomotion is attempted to be recreated for snake robots moving on a smooth surface by adding passive caster wheels on the underside of the snake robot body.

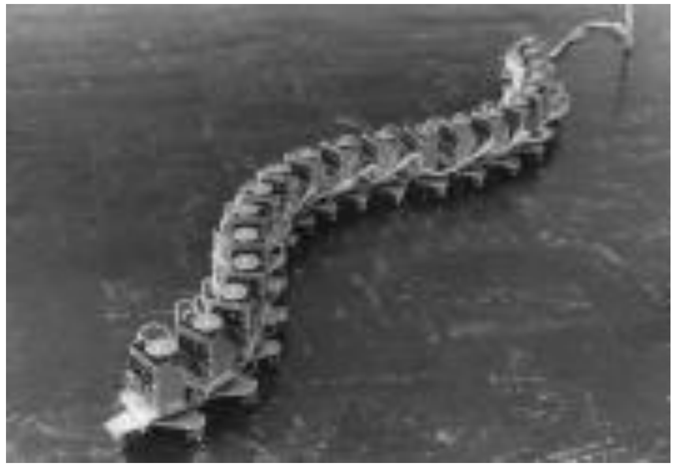


Figure 0.1. ACM III [2]

According to Transeth (2007), the first qualitative research on snake locomotion was presented by Gray (1946) while the first working biologically inspired snake-like robot was constructed by Hirose almost three decades later in 1972. He presented a two-meter long serpentine robot with twenty revolute 1 DOF joints called the Active Cord Mechanism model ACM III, which is shown in Figure 1.1. Passive casters were put on the underside of the robot so that forward planar motion was obtained by moving the joints from side to side in selected patterns [2].

Serpentine robot without a wheel also can achieve a high maneuverability on the smooth terrain. But the problem is how the serpentine robot can avoid the obstacles? Therefore this research will focus on designing a snake robot which can avoid an obstacle at front of it by rolling mechanism.

1.3 Objective

The objectives of this project are stated as bellow:

1. To design high mobility serpentine robot that can used efficiently in the real life situation.
2. To avoid the obstacle by switching the serpentine locomotion robot to the rolling robot.

1.4 Scope

The scope of this project is shown in the table below:

Table 1.1 Scope of the project

Scope	Task
Identify the problem statement	• Identify the problem faced by the robot in the real life situation
Study and analyze the existing design	• Benchmarking • Find out the limitation of the existing design • Brainstorming the improvement of the current design
Design the snake robot	• Sketch and create 3D model of the robot • Analyze the mathematical calculation needed
Fabricate the prototype	• Create the robot and do cost calculation
Result analysis and future work	• Analyze the result and identify future work

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

In this chapter, some of the existing design of snake robot will be discussed. This chapter includes the type of current snake robot, the locomotion, advantages and limitation of existing snake robot.

2.2 Snake robot

The founder of “biologically inspired” robot is Dr Hirose. His pioneering work in snake like robot began in 1970 with Umetani. He was studied and developed the snake in many aspect of locomotion and design. His first model accurately follows the serpentine locomotion and thus formulated his concept of the Active Chord Mechanism (ACM) based on his proposed equation for serpentine curve. His book on biologically inspired robots, which has now become a mainstay on the bookshelves of many researchers, presents an excellent overview of the research he has conducted over the years. All the prototypes developed by Hirose are remarkable [3].

2.3 Existing Design of Snake Robot

Few years ago, there are many type of snake robot have been created for inspection, spying and rescuing. Snake robots come in many shapes and sizes. Snake-like robots are researched in all over the world and various types of snake-like robots have been developed. During 1972, first of robot named ACM-Ill was built under Active Cord Mechanism (ACM) concept developed by S. Hirose. ACM is focused on how it along with differential friction helps in serpentine motion and control the motion with the help of controller to avoid the obstacles. The application of lag-lead compensator designed using graphical domain approach is the key concept for designing the controller which thus helps is giving fast response along with small steady state error at same time. Thus, providing a good control over the segmented snake robot [4].

ACM-R8 is one of the examples of snake-like robot which can climb stairs and reach doorknobs. The design of this robot incorporates several key features such as joints with parallel link mechanism, mono-tread wheels with internal structure, force sensors and 'swing-grousers' which were developed to improve step climb ability [12].

While, OmniTread serpentine robot is developed at University of Michigan. OmniTread serpentine robots are a new class of mobile robots which has the unique shape. Usually serpentine robots have multiple segments connected by joints. Some serpentine robots have legged, wheeled, or tracked propulsion, and actuation for the joints. Pneumatic Integrated Joint Actuators (IJA) invented and built especially for this OmniTread serpentine robots. The IJA combines advantages of pneumatic bellows-like actuators with our proportional position and stiffness (PPS) control algorithm. Controllable stiffness is of crucial importance in serpentine robots, which require stiff joints to cross gaps and compliant joints to conform to rough terrain for effective propulsion [5].

Other than that, University robotics research in Norway was started the research on swimming snake robot shown in Figure 2.1 over 9 years ago. It is designed to inspect structures in the sea area and carry out to repairs. The swimming snake robot is currently being tested on oil rigs. The design allows the swimming snake robot to work in the space that might be in accessible to other vehicles [13].

Figure 2.1. Swimming snake robot [13]

2.4 Snake locomotion

Snakes are able to adapt their movement to various environments. For instance, snakes can move across extreme environments such as sand, mud and water. Research has discovered there are four types of snake motion. These motions include serpentine movement, rectilinear movement, concertina movement and side-winding movement.

2.4.1 **Serpentine Locomotion**

Serpentine locomotion, known as lateral undulation, is the common form of locomotion used by snakes (Figure 2.2). All snakes are capable of serpentine locomotion, and they frequently use serpentine locomotion when moving through terrain such as grass, stones, and sand. The snake body moves laterally in a sinusoidal curve that propagates down the snake. In this form of locomotion, every part of the snake body follows the same path. The forward propulsion occurs due to forces pushing laterally (normal) against the snake body. These forces are mostly achieved by the snake pushing its body against obstacles located along its path. Obstacles can be large, such as a stick or rock, or small, such as small pebbles and sand. Studies have shown that snakes will alter the curvature of their serpentine waves dependent on the terrain that they are moving over and the location of obstacles in that terrain [6].

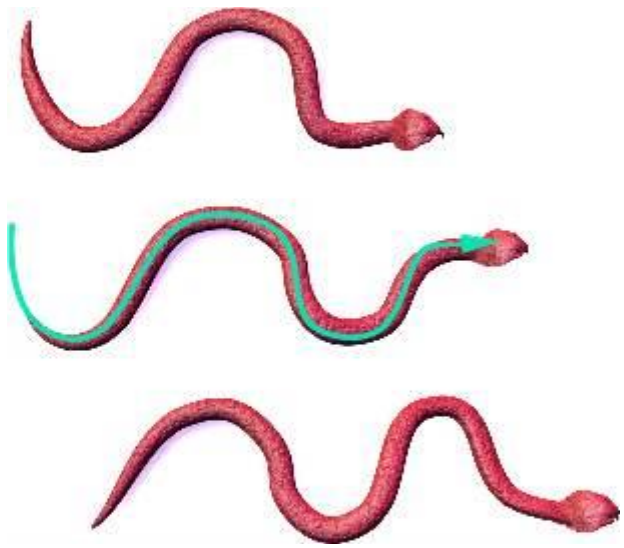


Figure 2.2. Serpentine Locomotion [14]

In order for snakes to successfully locomote using serpentine motion, the belly of the snake must have anisotropic coefficients of friction for the normal and tangential directions. Specifically, the normal friction must be greater than the tangential friction. As a result, when the snake exhibits a force on the ground, it will move in the tangential direction without slipping in the normal direction [8].

Real snake motion does not follow specified equations. However, research has proven that the serpentine motion of a snake can be modeled with the following equations :

$$x(s)=\int_0^s \cos(\zeta_\sigma)d\sigma$$

$$y(s)=\int_0^s \sin(\zeta_\sigma)d\sigma$$

$$\zeta_\sigma = a\cos(b\sigma) + c\sigma$$

Where the parameters a, b, and c determine the shape of the serpentine motion. The Figure 2.3 shows graph of how the parameters influence the serpentine curve. Basically, a changes the appearance of the curve, b changes the number of phases, and c changes the direction [7].

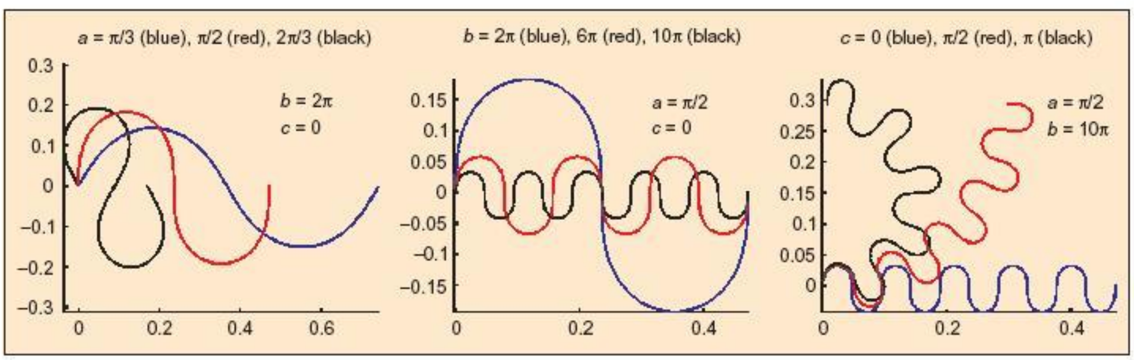


Figure 2.3. Serpentine curve [7]

The serpentine curve can be modeled with a snake like robot by changing the relative angles between the snake robot segments using the following formula with the number of segments (n):

$$\emptyset_i = \alpha \sin(\omega t + (i-1)\beta) + \gamma, (i = 1, \dots, n-1)$$

Where α , β , and γ are parameters used to characterize the serpentine curve and are dependent on a, b, and c as shown below:

$$\alpha = \alpha |\sin\left(\frac{\beta}{2}\right)|$$

$$\beta = \frac{b}{n}$$

$$\gamma = -\frac{c}{n}$$

2.4.2 **Concertina Locomotion**

Concertina locomotion involves pulling up the body into bends and then straightening out the body forward from the bends. As shown in Figure 2.4, the front part of the body then comes to rest on the surface and the back part of the body is pulled up into bends again, and so forth. The bends may push laterally against the sides of a tunnel or vertically against the ground to keep the body from slipping. Thus, static friction is critical to concertina locomotion. Concertina locomotion is used in crawling through tunnels or narrow passages and in climbing. In concertina locomotion, blocks of muscles are activated simultaneously, and unilaterally, in regions of bending and of static contact with the sides of a tunnel [8].

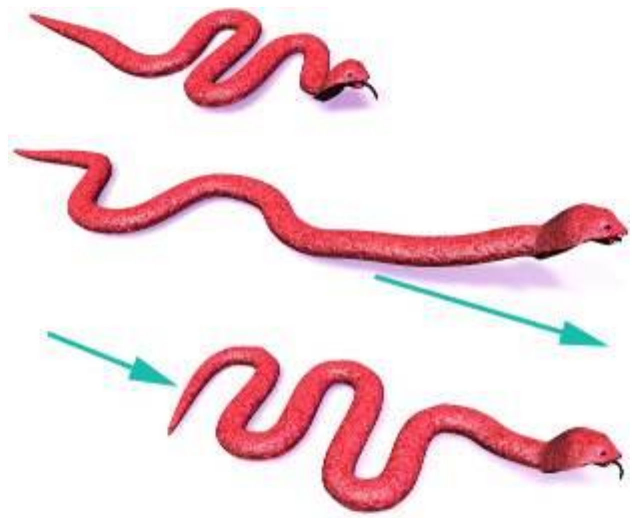


Figure 2.4. Concertina Locomotion [14]

2.4.3 Sidewinding (Crotaline) Locomotion

Very distinct form of snake locomotion is known as sidewinding. Sidewinding is a form of locomotion that is typical of a certain group of rattlesnakes that live in sandy deserts. Sidewinding is similar to serpentine locomotion in that the sidewinder propagates waves of curvature along the body. However, in sidewinding locomotion, the resultant movement of the snake is sideways with respect to the axis of the body. Figure 2.5 shows tracks that are produced by the sidewinding locomotion that point in the direction of the travel. The snake lifts and rolls its body between the tracks to achieve advancement, as the sections that lie within the tracks are in static contact with the surface. The weight is appropriately transferred to these points to ensure proper friction with the ground. Sidewinding can be considered a specialized gait that is only used on slippery surfaces such as sand [5].

Figure 2.5. Sidewinding Locomotion [14]

2.4.4 **Rectilinear Locomotion**

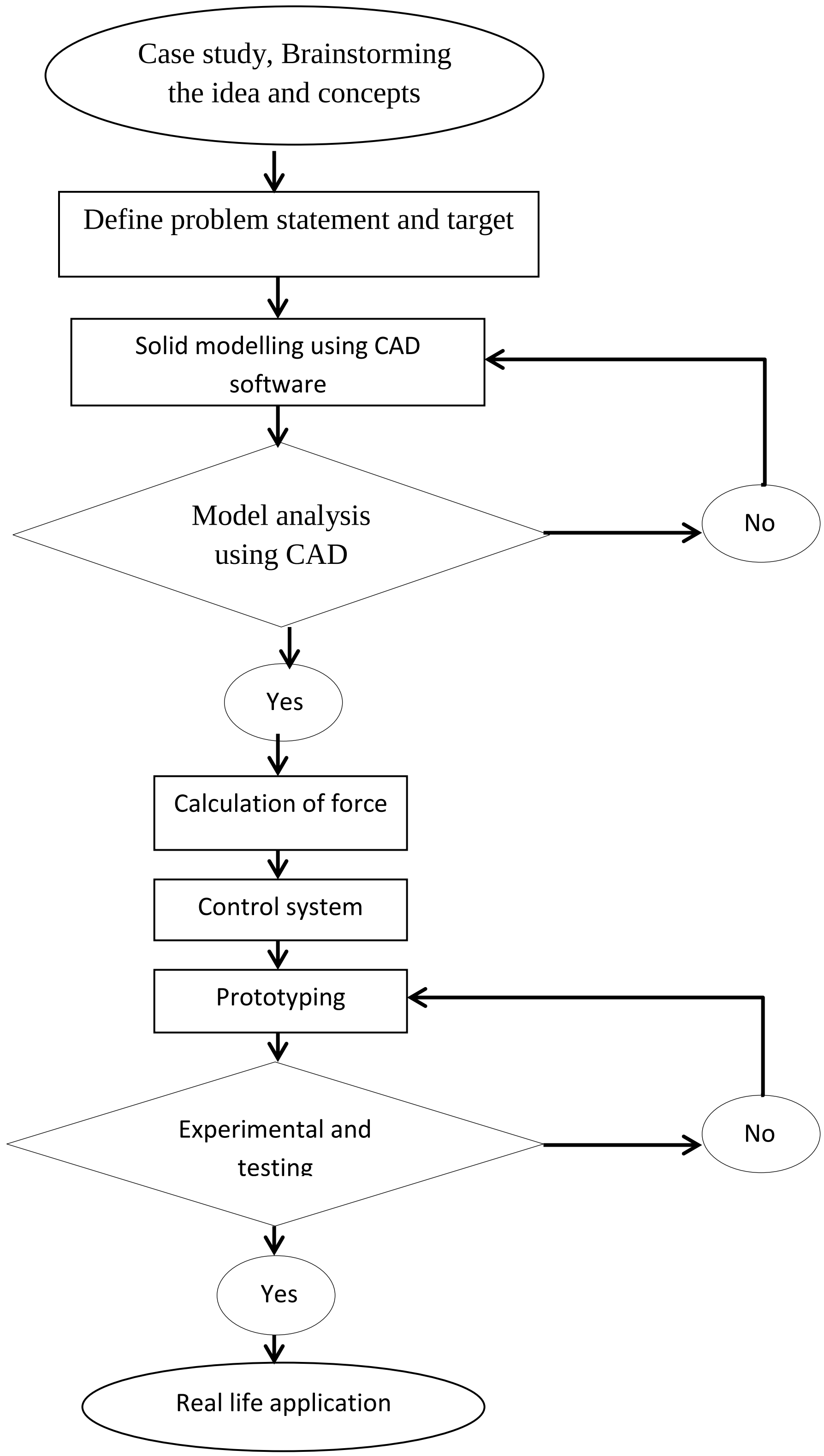
Rectilinear locomotion is the second basic motion pattern of snakes. It is differs from lateral undulation. This locomotion involves the application of force from contact points that are on the bottom of the body instead of on the side, and it is effective only if friction is established between the snake's "skin" and the ground. This motion enables a snake to advance in a straight line as it stalks prey or crosses a flat surface. In order to move in this mode, the snake fixes several points along the bottom of its body and moves the part of its body between them. These fixed point on the ground are called static points. The propelling force driving the snake is primarily the friction force between the snake and the ground [6]. Movement is achieved by waves of muscular contraction and expansion passing along the body of the snake. This form of locomotion is best understood by imagining two points located on the ventral (bottom) surface of the snake. With the waves of muscular contraction and expansion, the distance between the two points is oscillating. When the distance between the two points is at a minimum, that segment is at rest.

When the distance between the points is either increasing or decreasing, the moving point is moving forward. This is achieved by the frictional characteristics between the snake and the surface, and can be thought of as a “ratcheting” action. The points on the ventral surface move forward in discrete steps [5]. However, the top of the body moves continuously because of the changing geometry of the muscular segments. Figure 2.6 illustrates the muscular contraction and expansion that occurs during rectilinear motion.

Figure 2.6. Rectilinear locomotion [14]

CHAPTER 3 METHODOLOGY

3.1 Project methodology



3.2 Case study on existing robot

The locomotion and mechanism of snake robot is studied to compare their advantages and disadvantages. The simplest locomotion is lateral undulation, it also known as serpentine locomotion. The advantage of lateral undulation is whenever a snake pushes against multiple objects simultaneously; the lateral force vectors cancel each other and then leaving a resultant vector that propels the snake forward. In lateral undulation, the large dorsal muscles are activated sequentially along the body. The muscles are active unilaterally in each bend, from the convex part of a bend forward to the straight or concave part of the bend. Finally, every point along its body will follows the path established by the head and neck, like the cars of a train following the engine as it moves along the track [9].

Although many existing snake robots vary in design and size, there is one thing that all snake robots share. They can move into and maneuver through narrow space. Furthermore, many snake robots are constructed by chaining together many independent links. This redundancy makes them resistant to failure because they can continue operate even one parts of their body are destroyed.

3.3 Design of the SolidWorks

The idea of mechanical design and moving mechanism of the snake robot is created using SolidWorks CAD software. All parts were assembling to form 3D modelling of the snake robot using assembly function.

3.3.1 **SolidWorks modelling**

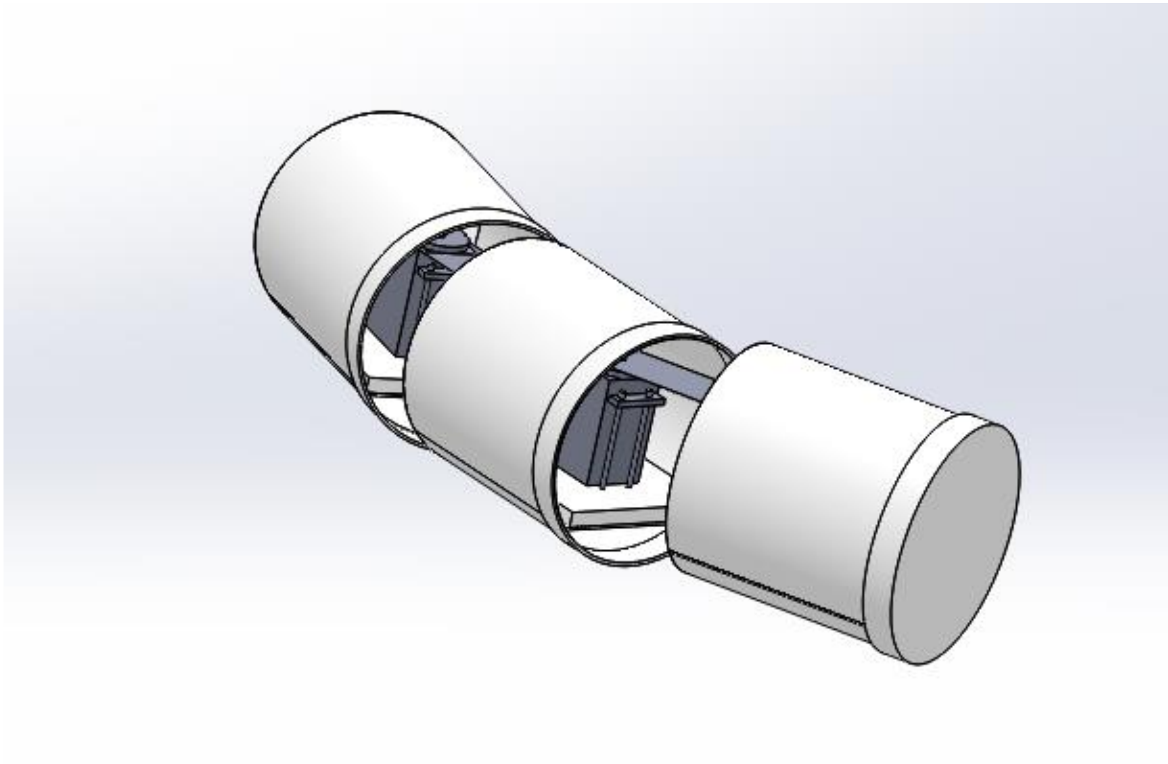


Figure 3.1. Overview of snake robot

Figure 3.1 shows overall design of snake robot. This snake robot has three units of the body segment. First and second unit of the body hold the servo motor to move in serpentine locomotion. While, the last unit has a servo motor to roll the wheel attached at the tail. Basically, each unit of the snake is connected to another unit by using a beam. Inside the body of snake robot also have the chassis to hold the servo motor from moving. Screws are used to fix the servo motor on the chassis.

3.4 Locomotion and moving mechanism

The main locomotion of this snake robot is lateral undulation. By using the servo motor, the body of snake robot can move in serpentine shape. Serpentine locomotion allows the body of snake robot moving forward because of the frictional force. Servo motor is embedded in a tail of snake robot so that the robot can roll in order to avoid the obstacle.

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3.5 Motor torque

In order to ensure the motor will rotate the tail of snake robot, the frictional force of the wheels against the ground must be strong enough to sustain its own weight.

3.5.1 Calculation of required torque

The frictional force between the wheel and the snake body is mainly affected by control of servo motor. Furthermore, in order to roll the body of snake robot, the motor torque must have enough strength to encounter the weight of it. The frictional force, F_s, between the wheels and the motor can be calculated from the formula

$$F_s = \mu R \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

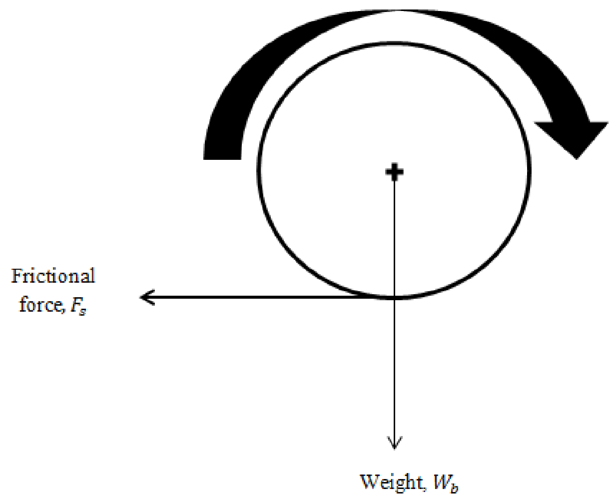


Figure 3.2. Free body diagram single unit robot.

Figure 3.2 shows the free body diagram of the snake robot. Static equation is equal to the weight of whole body of the robot. Since the robot have 3 unit of segment, therefore 3 identical frictional forces present on the snake robot. Hence, below is static equation for this snake robot

$$W_b = 3F_s \text{..........................} (2)$$

W_b is the weight of the whole body which is approximately 2.367 N. Hence the frictional force produced by each segment equal to 0.789N

While the torque equation is

$$T = FR \text{....................} (3)$$

R is the radius of the wheel, which is 0.0375 m from the equation 3, the minimum torque required to roll the wheel approximately 0.02959 N.m .

3.6 Component required

After the calculation of force and torque has been done in previous section, the components needed for serpentine robot were determined.

3.6.1 **Arduino UNO Board**

Arduino UNO as illustrated in Figure 3.3 is an open-source electronics platform based on easy-to-use hardware and software. The Arduino is a microcontroller board based on the ATmega328 (datasheet). It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. The Arduino Software (IDE) is easy-to-use for beginners, yet flexible enough for advanced users to take advantage of as well. The software is published as open source tools, available for extension by experienced programmers. The language can be expanded through C++ libraries, and people wanting to understand the technical details can make the leap from Arduino to the AVR C programming language on which it's based [9]. The Arduino board holds the chipsets and provides slot or ports for others components which enables facilitate programming and incorporation into other circuits.

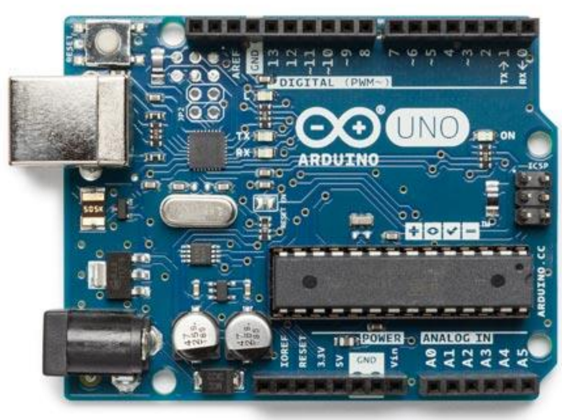


Figure 3.3. Arduino UNO [9]

3.6.2 **Servo motor**

Figure 3.4. Servo Motor [11]

A servomotor shows in Figure 3.4 is a rotary actuator or linear actuator that allows for precise control of angular or linear position velocity and acceleration. Servo is controlled by sending an electrical pulse of variable width or pulse width modulation (PWM), through the control wire. There is a minimum pulse, a maximum pulse, and a repetition rate. A servo motor can usually only turn 90° in either direction for a total of 180° movement. The motor's neutral position is defined as the position where the servo has the same amount of potential rotation in the both the clockwise or counter-clockwise direction. The PWM sent to the motor determines position of the shaft, and based on the duration of the pulse sent via the control wire; the rotor will turn to the desired position. The servo motor expects to see a pulse every 20 milliseconds (ms) and the length of the pulse will determine how far the motor turns. For example in Figure 3.5, a 1.5ms pulse will make the motor turn to the 90° position. Shorter than 1.5ms moves it in the counter clockwise direction toward the 0° position, and any longer than 1.5ms will turn the servo in a clockwise direction toward the 180° position [11].

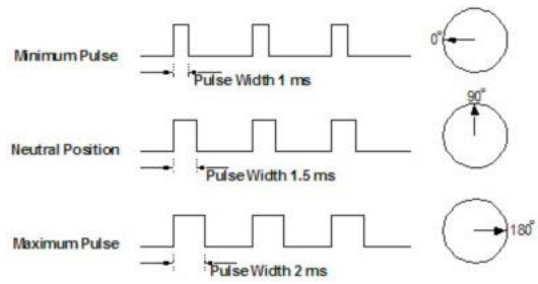


Figure 3.5. Variable Pulse width control servo position [11]

When these servos are commanded to move, they will move to the position and hold that position. If an external force pushes against the servo while the servo is holding a position, the servo will resist from moving out of that position. The maximum amount of force the servo can exert is called the torque rating of the servo.

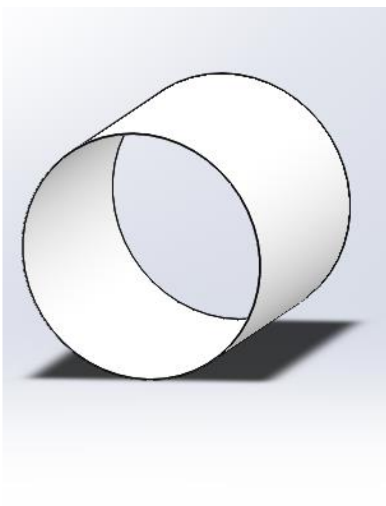
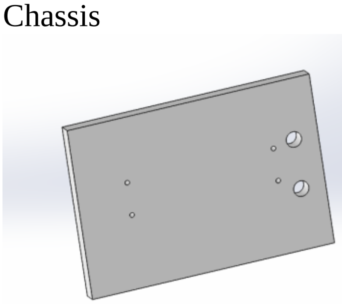
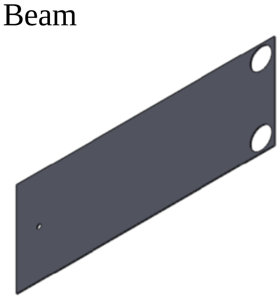
3.7 Fabrication of the prototype

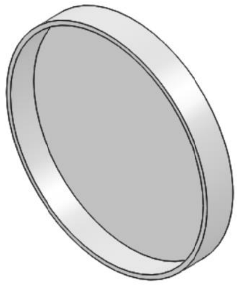
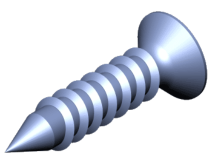
After all the design and engineering drawing have been finalized, the fabrication of the prototype of the snake robot is started.

3.7.1 **Execution of Fabrication**

All the machines, tools and fabrication process for non-standard parts have been listed and explained in the table below.

Table 3.1. List of part

Part Model (CAD file)	Detail Drawing	Material	Description Of Machining Process		
			Machine	Process	Tools
Body 	Appendix B	Cupboard	NA	NA	NA
Chassis 	Appendix C	Perspex	Milling and Drilling Machine	Milling Drilling	Drill bit
Beam 	Appendix D	Aluminum	Drilling and Hydraulic Cutter	Cutting Drilling	Drill bit

Roller 	Appendix E	NA	NA	NA	NA
Screw M5x7 		Screw M5x7	NA	NA	NA
		Screw M2x3	NA	NA	NA

3.7.2 Cost Estimation of the Prototype

The cost estimation for the prototype has been calculated as shown in the table below.

Table 3.2. Cost estimation

Parts	**Material Cost (RM)**	**Quantity**	**Total(RM)**
Body	RM 0.50	3	RM 1.50
Chassis	RM 1.00	3	RM 3.00
Beam	RM 1.00	2	RM 2.00
Screw	RM 0.60	12	RM 7.20
Screw	RM 0.10	4	RM 0.40
Roller	RM 0.10	3	RM 3.00
Total Cost			RM 17.10