SNAKE-LIKE ROBOT
(MECHANICAL PART)

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A project report submitted in partial fulfilment of the requirements for the award of the degree of Bachelor (Hons.) of Mechatronics Engineering

Faculty of Engineering and Science
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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

Signature : _________________________

Name : _________________________

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Date : _________________________

APPROVAL FOR SUBMISSION

I certify that this project report entitled **"SNAKE-LIKE ROBOT"** was prepared by **LEE YIT FUNG** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Science (Hons.) Mechatronics Engineering at Universiti Tunku Abdul Rahman.

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Date : _____________________________

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Throughout this final year project, I want to give thanks for the guidance and encouragement from Dr. Wang Xin as my mentor that gave me a lot of sources of successful-made snake-like robot. Besides, I would like to thank for my two teammates who help me for fabrication process and report writing.

SNAKE-LIKE ROBOT

ABSTRACT

This report describes the mechanical works and analysis being conducted in development of snake-like robot technology which suitable for conducting inspections and undergoing dangerous tasks. In this project a snake-like robot is modeled that can provide the locomotion as the real biological snake, and possesses with abilities in meeting the objectives set such as in the forest, going up stairs and each others. The snake-like robot constructed having 8 segments which having 16 DOF giving it the ability to flex, reach and approach a huge volume in its workspace with infinite number of configurations to overcome obstacles.

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CHAPTER 1

INTRODUCTION

1.1 Background

According to archaeologists, wheel was probably invented in around 8,000 B.C. in Asia and was believed to have been made by the Sumerians. Wheeled mechanisms constitute the backbone of most ground-based means of transportation in the past used in transportation, war, agriculture such as spinning pottery and else. On relatively smooth surfaces, such mechanisms can achieve high speeds and have good steering ability. The wheel is an amazing invention, but it does not roll everywhere. Unfortunately, rougher terrain makes it harder, if not impossible, for such mechanisms to move.

In nature, the snake is one of the creatures that exhibit excellent mobility in various types of terrain. It is able to move through narrow passages and climb on rough ground. This property of mobility is attempted to be recreated in robots that look and move like snakes. Snake-like robots usually have a high number of degrees of freedom (DOF) and they are able to move without using active wheels or legs.

Throughout the world, earthquakes are tremendously frightening to all the people whom living at the place like China, Japan, Philipines, Indonesia, and others. As we get a closer look to the place, Haiti, situated in the largest population country in the world, China, in January 12, 2010, it happened for the worst quake in region in 200 years with the death toll at estimated 230,000. (Wikipedia) In this situation, deep searching for survivors that trapped in the collapsed buildings must be carried on. Thus, snake-like robots provide a means to replace human by exploring to all hidden and unreachable areas of the incident happened. The advantages of automating snake-like robot will be discussed.

This report presents the prototype snake-like robot and outlines expectations for future development. Snake-like robots may one day play a crucial role in search and rescue operations, firefighting, and inspection and maintenance. The highly articulated body allows the snake-like robot to traverse difficult terrains such as collapsed buildings or the chaotic environment caused by a car collision in a tunnel. The snake-like robot could crawl through destroyed buildings looking for people, while simultaneously bringing communication equipment together with small amounts of food and water to anyone trapped in the shattered building. A rescue operation involving a snake-like robot has been envisioned. Moreover, the snake-like robot can be used for surveillance and maintenance of complex and possibly hazardous areas of industrial plants even inspecting the sewerage system looking for leaks or aiding firefighters. Also, snake-like robots with one end fixed to a base can be used as a robot manipulator which can reach hard-to-get-to places.

1.2 Aims and Objectives

For our aims and objectives of this project, we had divided it into three parts, which are the:-

- Mechanical part

  For mechanical part, the body or other mechanical parts is to be sure that can suit to the locomotion of the snake-like robot, which can move in 2-axis (the xy-plane), able to overcome the obstacle and move on uneven surface, and the weight of the chosen material is important for the locomotion as well.

- Electronics part

For electronics part, is to demonstrate that the effective voltage regulator for supplying efficient power to the motor and microprocessor, and solving the battery life issue being considered inefficient when supplying different power ratings by using linear voltage regulator.

- Programming part

  For programming part, is to program the snake-like movement for the snake-like robot, and with the vision assist of the camera, the snake-like robot will able to decide the possible solutions to overcome the obstacle that it face, and also able to respond to the feedback of the controlling sensors like angle sensor.

In this report of the snake-like robot project, the focus point is on the mechanical part. The objectives of the mechanical part in the report are:

a. To understand the difference between snake robot and snake-like robot
b. Perform literature review on understanding the locomotion of snakes
c. Understand the mechanism of snake-like robot and the way of implementing wheels or others into snake-like robot
d. To come out with design of prototype to be fabricated in the future
e. To know the improvements that can be made into the prototype design
f. To build the prototype and worked
g. Accomplished the objectives of overcome obstacles like slopes, rocks, and others.

CHAPTER 2

LITERATURE REVIEW

2.1 General Description of Snake-Like Robot

According to the timeline found, it shows us that the earlier snake-like robot was introduced on May 1999. The snake-like robot is known as GMD-Snake 2 with its description of a snake-like robot driven by wheels and a method for motion control by Bernhard Klaassen, Karl L. Paap. The snake-like robot was introduced at IEEE International Conference on Robotics & Automation, Detroit. (IEEE Robotics and Automation Society 1999, Volume 4)

However, the snake-like robot is improvised and implemented with different kinds of sensors, actuator and abilities. In search and rescue operation, snake-like robot is being installed for high infrared sensor and flex-sensor whiskers which introduced by Gavin S.P. Milner. (Joseph Ayers etc, 2002)

Besides that, Japanese government has works hard for this snake-like robot application especially the search and rescue snake-like robot by providing funding and promoting research. (S. Hirose etc, 2004) This implementation and researching of snake-like robot can be seen since mid 70’s shows how much efforts and benefits can be resulted through snake-like robot. (Michele Guarnieri etc, 2008)

2.2 Snake Locomotion

It is very important to know what locomotion to be applied to the snake-like robot beforehand. Therefore, the theory behind the possible locomotion must be clearly understood so that will ease troubleshooting and brainstorming time for a better design.

The first qualitative research is done by J.Gray in The Mechanism of Locomotion in Snakes. According to J.Gray from Department of Zoology, University of Cambridge, explaining about the locomotion have on a snake such as serpentine locomotion, side-winding locomotion, concertina locomotion and rectilinear locomotion. (*J Exp Biol*, 1946) In the other hand, the most natural way of snake's movement is known as lateral undulation. Sinus lifting is introduced in the snake-like robot designation.

2.2.1 Lateral Undulation

Lateral undulation describes that the body of snake alternately flexes to the left and right which results like a wave. [7] For lateral undulation locomotion, it is naturally to build the snake-like robot to have the same movement when moving in regular surfaces.Below is the figure of lateral undulation:

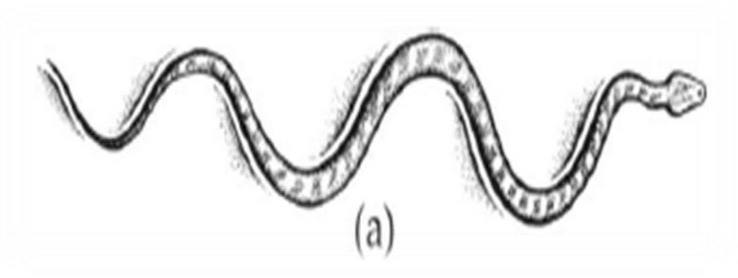


Figure 2.1: Lateral Undulation

2.2.2 Serpentine Locomotion

In serpentine locomotion can be described as the snake move through the grass or substratum of irregular surfaces. It is says that the snake’s body is thrown into a series of more or less sinusoidal curves, and during movement 'every part of the snake's body and tail faithfully follows the path taken by the head and neck, so that the snake seems to flow gracefully through grass and scrub like a water course in its narrow winding bed.

In engineering term, the whole serpentine locomotion can be represents by crank-slider which using push and pull mechanism. As the slider (head part of the snake-like robot) will act as the pulling actuator, the crank (body of the snake-like robot) will push upwards to move forward. Below is the figure of serpentine locomotion:

Figure 2.2: Serpentine Locomotion

2.2.3 Concertina Locomotion

A concertina is a small accordion instrument. The name is used in snake locomotion to indicate that a snake stretches and folds its body to move forward. The folded part is kept in a fixed position while the rest of the body is either pushed or pulled. Then, the two parts switch roles. Forward motion is obtained when the force needed to push back the fixed part of the snake body is higher than the friction forces on the moving part of the body.

Concertina locomotion is employed when a snake moves through narrow passages such as pipes or along branches. If the path is too narrow compared to the diameter and curving capacity of a snake, the snake is unable to progress by this motion pattern. Below is the figure of concertina locomotion:

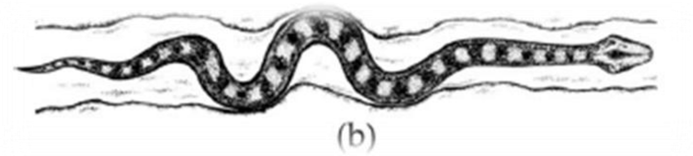


Figure 2.3: Concertina Locomotion

2.2.4 Rectilinear Locomotion

In rectilinear locomotion, the belly scales are alternately lifted slightly from the ground and pulled forward, and then pulled downward and backward. But because the scales "stick" against the ground, the body is actually pulled forward over them. Once the body has moved far enough forward to stretch the scales, the cycle repeats. This cycle occurs simultaneously at several points along the body. Static friction is the dominant type of friction involved in rectilinear locomotion.

Unlike lateral undulation and side-winding locomotion, which involve unilateral muscle activity that alternates from one side of the body to the other, rectilinear locomotion involves bilateral activity of the muscles that connect the skin to the skeleton. One set of these muscles lifts the belly scales up and pulls them forward and another set of muscles pulls downward and backward. Below is the figure of rectilinear locomotion done by real snake: [6]

Figure 2.4: Rectilinear Locomotion

2.2.5 Side-winding Locomotion

Sidewinding is probably the most astonishing gait to observe and is mostly used by snakes in the desert. The snake lifts and curves its body leaving short, parallel marks on the ground while moving at an inclined angle as shown in figure below:

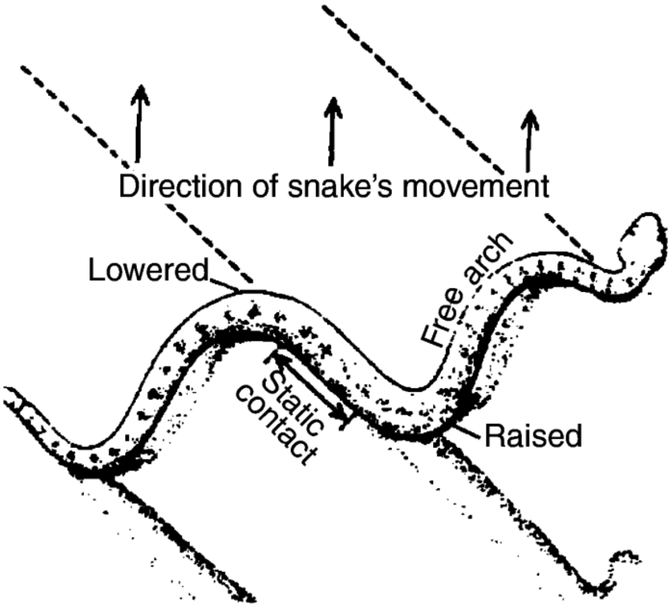


Figure 2.5: Side-winding Locomotion

Unlike lateral undulation, there is a brief static contact between the body of the snake and the ground. Sidewinding is usually employed on surfaces with low shear such as sand.

2.2.6 Sinus Lifting

Sinus-lifting is a modification of lateral undulation where parts of the trunk are lifted to avoid lateral slippage and to optimize propulsive force. This means that the snake-like robot will lift its body up from the surface and overcome obstacles such as big stones, branches, and others. [8] Sinus lifting is very important for this project as one of the objectives is to climb the stairs.

2.3 Summary of Review

Numbers of journals have been reviewed throughout this project. Therefore, a table is built to illustrate the comparison and improvising actions being done all these years and applied the methods to the snake-like robot.

Table 2.1: Summary of Reviews

Published Date:	Name of Author / Journal:	Review:	Analysis:
1946	J.Gray; The mechanism of locomotion in snake	• Describe in details of the mechanism of locomotion such as serpentine, side-winding, rectilinear, and other locomotion in snake that help snakes in their movement • Illustrate the movements in diagrams that ease the understanding	• Serpentine movement is very important mechanism in snake to ensure its stability
1999	Gavin S.P. Miller; Neurotechnology for biomimetic robots	• Explain the application of snake robot in future search and rescue operation • Explain snake robot with wheels and without wheels	• Give an idea of the advantages and disadvantages of using wheels and not using

			wheels in prototype
2004	Alessandro Crespi, Andre Badertscher, Andre Guignard, Auke Jan Ijspeert; AmphiBot II: An Amphibious Snake Robot that Crawls and Swims using a Central Pattern Generator	• Explain the process and mechanism in Amphibot II compares to Amphibot I • Introduces the snake-like robot that runs in Central Pattern Generator (CPG) that produce travelling waves that can perform crawling and swimming	• The speed of locomotion depends on the parameters determining the frequency, amplitude and wavelength of the body undulation • New technology known as CPG
2005	Grzegorz Granosik, Malik G. Hansen, Johann Borenstein; The OmniTread Serpentine Robot for Industrial Inspection and Surveillance	• Introducing University Michigan's OmniTread serpentine robot • Able to crawl and move in gaps, tracks, and rugged terrain • Uses Able to climb over high places, move in small gaps, and travel in pipes	• A starting of idea for implementing wheels on snake-like robot where OmniTread uses wheels mechanism like tank (having link, road wheel, and drive sprocket)
2007	Juan Gonzalez-Gomez, Javier Gonzalez-Quijano, Houxiang Zhang, Mohamed Abderrahim; Toward the sense	• Describe snake robot search and rescue operation by illustrating through a scenario • Introduces the touch rings approach for the implementation of the sense of touch in snake robots	• Starting idea to implement touch rings into snake-like robot prototype that suits the objective of search and rescue by placing

	of touch in snake modular robots for search and rescue operations		touch strips around the snake section, forming touch rings with embedded capacitive sensors
2007	Vipul Mehta; Optimal Gait Analysis of Snake Robot Dynamics	• Describe the dynamics calculation of snake-like robot • Perform analysis using a multi-objective evolution algorithm, NSGA-II	• Hard to understand the terms and variables
2007	Seif Dalilsafaei; Dynamic Analyze of Snake Robot	• Dynamics Analysis on measurement of the force exerting on snake body with spiral paradigm • Perform kinematics of regular crawling motion	• Need a lot of time to understand for the analysis performed
2008	Richard Anthony Primerano; A Serpentine Robot Designed for Efficient Rectilinear Motion	• Trajectory followed in planar movement test • Show how snake-like robot crossing a seven inch gap • Shows mechanical components of snake-like robot	• Details in showing the snake-like robot description
2009	Aksel Andreas Transeth, Kristin Ytterstad Pettersen and Pal Liljeback; A survey on snake robot modeling and locomotion	• Explain the locomotion in snake robot • Presents kinematics and dynamics analysis for snake robot • Perform Denavit-Hartenberg analysis on snake robot • Discuss future improvement needed in snake robot	• Get to know improvements that can enhance the capability of snake robot • Learn of performing analysis to snake-like robot model

2010	Raisuddin Khan, M. Watanabe and A.A. Shafie; Kinematics Model of Snake Robot Considering Snake Scale	• Shows mathematical model for the solution of forward and inverse kinematics considering friction effects of snake scales	• Understand some important criteria in performing mathematical model in snake-like robot
2010	T'Jae Gibson; Army Technology expands Snake-robotics	• Knowing the reasons of army for researching on snake robot • Army team using multiple parts of their bodies to manipulate an object, scan a room or handle improvised explosive devices	• Found that there is a drawback from snake robot in military area which can't solve the "opening a door" problem, which has been a consistent obstacle in robotics • High levels of articulation in the manipulator could prove to be effective for grasping and rotating different types of door handles using knobs, handles, levers and bars

CHAPTER 3

METHODOLOGY

3.1 Project Overview

The snake-like robot is separated into three different parts of tasks which are the mechanical, electronics and electrical and the programming part. Thus, team of three people with each person takes a part.

Below are the flow graph of the tasks and the project overview of the snake-like robot design project:

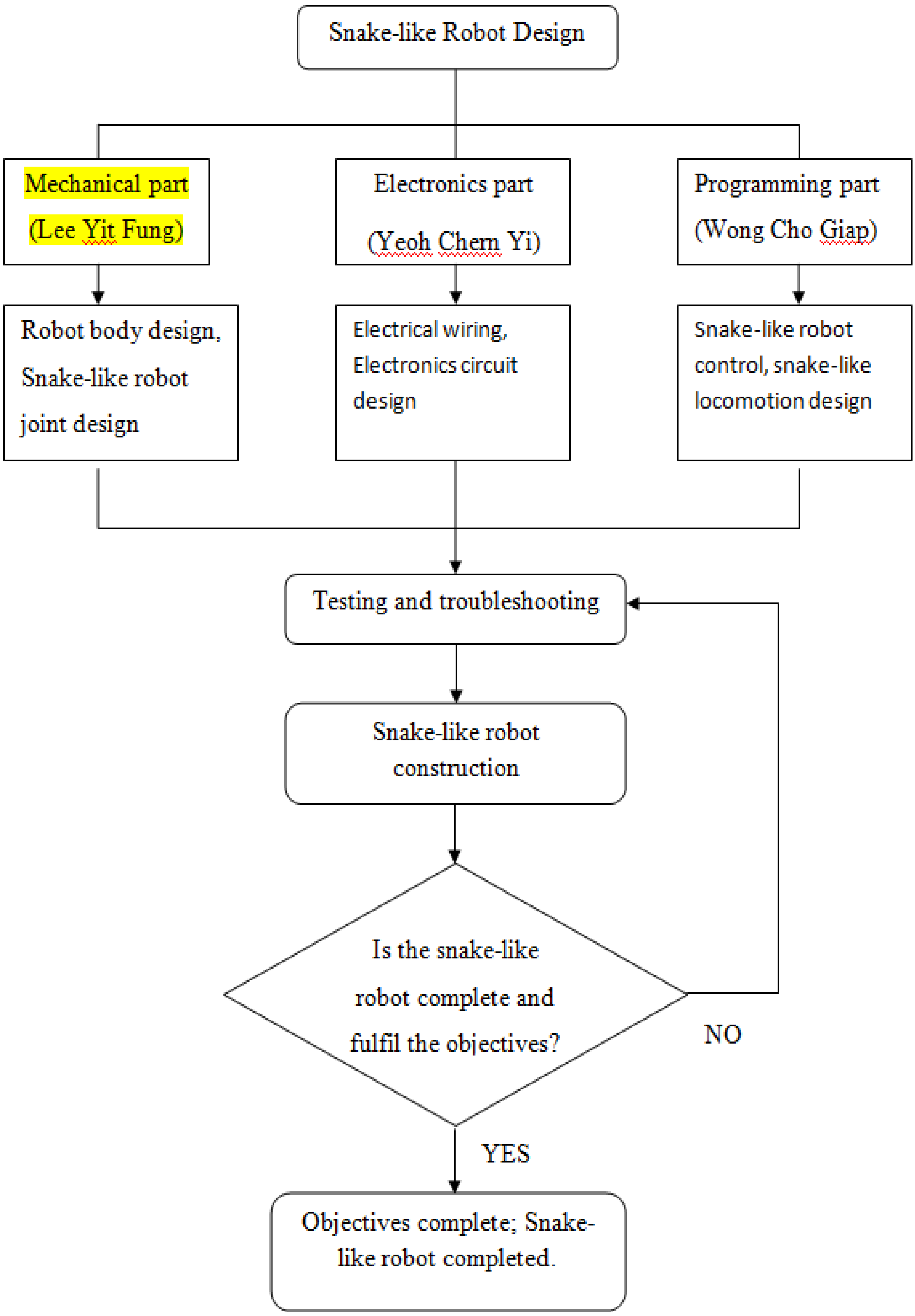


Figure 3.1: The flow graph for the snake-like robot design project.

There are some stages performed for accomplished the mechanical part of snake-like robot.

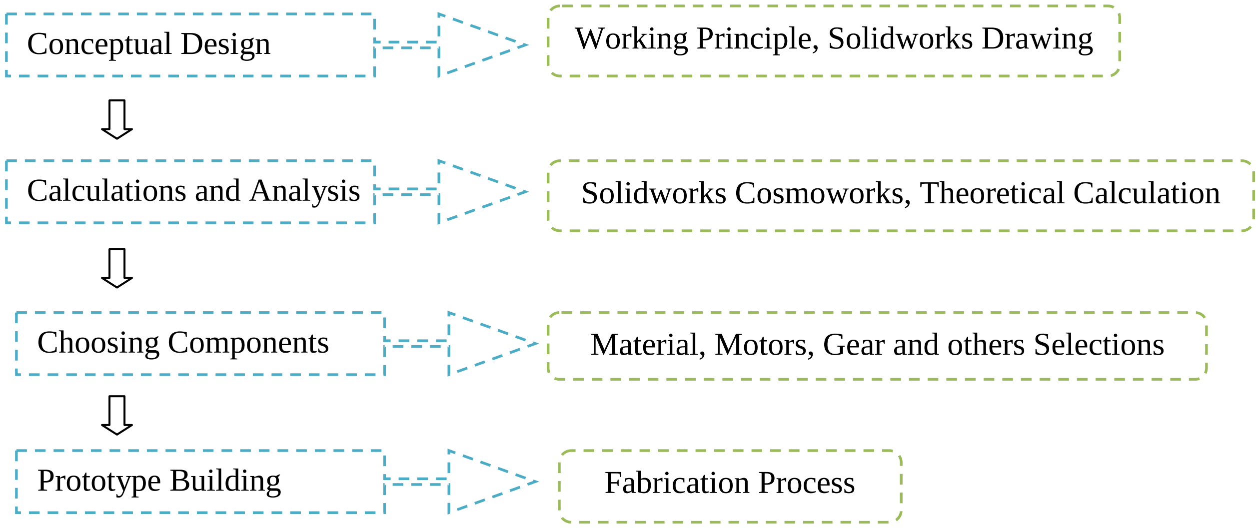


Figure 3.2: Flow Chart of Snake-Like Robot Stages

3.2 Working Principle

3.2.1 Locomotion

It is very important to decide which locomotion that can be achieved in the snake-like robot project to ensure that the robot can meets the requirement and be able to do some critical movements. From the literature review, based on 5 types of possible locomotion, the more related locomotion to be used are lateral undulation and sinus lifting locomotion.

3.2.2 How does it work?

Lateral locomotion works when the snake-like robot crawls on the even surfaces which moves forward, and to the left or right. It works by servomotor on each segment rotate to left and right causing the joints to move left and right. For moving forward direction, the motors placed on the head part will play an important role in moving the snake-like robot.

One of the objectives of snake-like robot is to accomplish the climbing stairs task. This can be overcome by using sinus lifting locomotion, snake-like robot will lift its head part with the supports from the high torque motor to sustain its position and move forward to climb for the stairs.

3.3 Snake-Like Robot Segments

3.3.1 Numbers of Segments

Before design for the snake-like robot model, numbers of segments are to be determined and set to ease the process of drawing and analysis. As decided, the numbers of segments are to be 8 segments which consist of 1 head part, 1 tail part, and 6 body parts as it is long enough to looks like a snake.

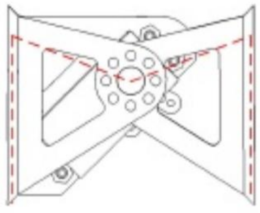
3.4 Comparison between Concept Model

There are few concepts found before developing the model. In modelling snake-like robot, joints play the most important elements and must take good consideration before fabrication process to ease improvements in the future. Below is the comparison and diagram of models and joints:

Table 3.1: Comparison of Concepts

(Source: http://www.scribd.com/doc/17645063/Development-of-a-Lowcost-Flexible-Modular-Robot-GZI)

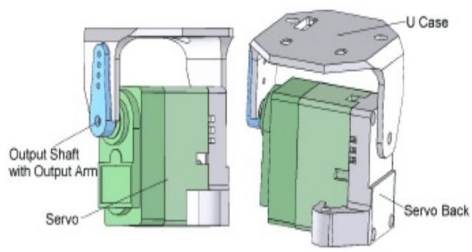
Model 1:



Description:	Cube- M Joint
Locomotion:	As model, the Cube-M will be moving like a caterpillar instead of moving like snake-like robot
Advantages:	1. Lesser of DOF which having 1DOF per segment 2. Easier to control for the movement 3. Easy to meet the one of the objectives – climb the stairs 4. Easy fabrication process
Disadvantages:	Does not meet the title of snake-like robot
Comments:	Utilize and learn the concept of configuring the joints and apply it into a better design

(Source: http://www.scribd.com/doc/14253627/Design-of-Modular-Snake-Robot)

Model 2:



Description:	U-Case Joint
Locomotion:	As model, the joint is power by a high torque servo linked with a U-case. It can perform serpentine locomotion as snake does
Advantages:	1. Can climb up stairs and pipes (more advance)

	2. Can be purchased easily from Cytron Technologies company 3. Easy fabrication process
Disadvantages:	1. High torque servomotor needed 2. Increase budget plan 3. Not suitable to add more features in the future
Comments:	Learn the way of powering the joint with servomotors and apply it to a more suitable design

(Source: http://www.sintef.no/Home/Information-and-Communication-Technology-ICT/Applied-Cybernetics/Projects/Our-snake-robots/Anna-Konda--The-fire-fighting-snake-robot/)

Model 3:

Description:	Hyper redundant manipulator with new joint
Locomotion:	As model, the joint is using the concept of a ring connected to 4 joints
Advantages:	1. Low budget needed as the model being fabricated from raw material 2. Can move in 2 directions which is up and down and left and right – fulfilled the requirements of a snake-like robot should behave 3. Easy to fabricate the model 4. Can add more features in the future such as sensors 5. Concept of modelling easy to be understood
Disadvantages:	Many segments resulting in many DOF
Comments:	This model can be used as the final concept of preparing the prototype

3.5 Prototype Modelling

3.5.1 Earlier Model

In figuring out the model of the snake-like robot, Solidworks software is being used for model out the prototype. The earlier model is having two rectangular shapes in different width which looks like the diagram below:

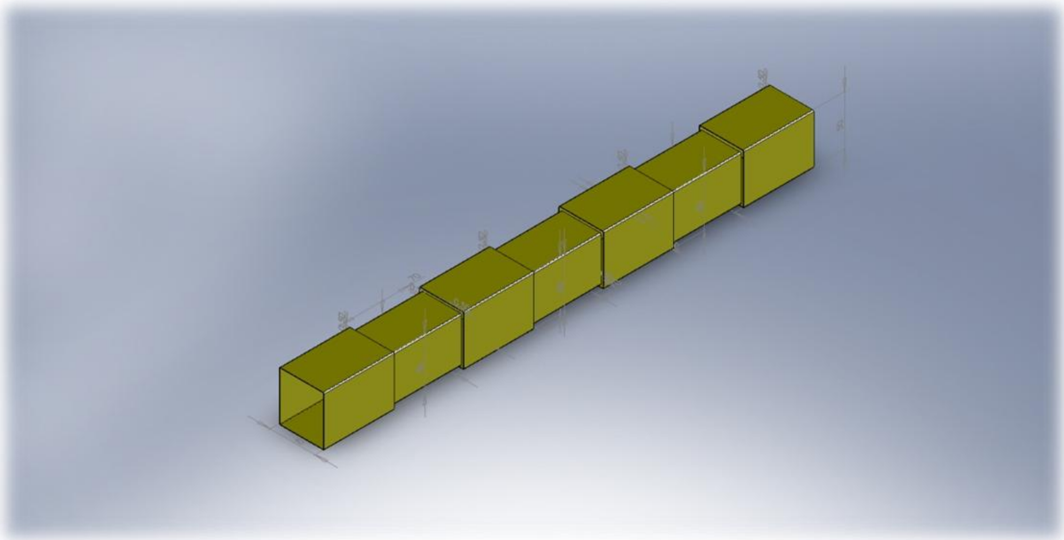


Figure 3.3: First Proposed Solidworks Design

The model is improvised by utilizing push-and pull mechanism or known as Crank slider movement or serpentine locomotion where the front part will be pulling the body parts to move forward with the wheels installed beneath the body. However, this model is rejected as it only moving in front and backwards.

3.5.2 Second Improves Model

In the second design, the model is improved by putting some joints between each segment to enable it to move left and right like a snake. From the previous idea of using Crank slider mechanism is rejected due to the joints will not able to perform the mechanism. The model is looks like the diagram below:

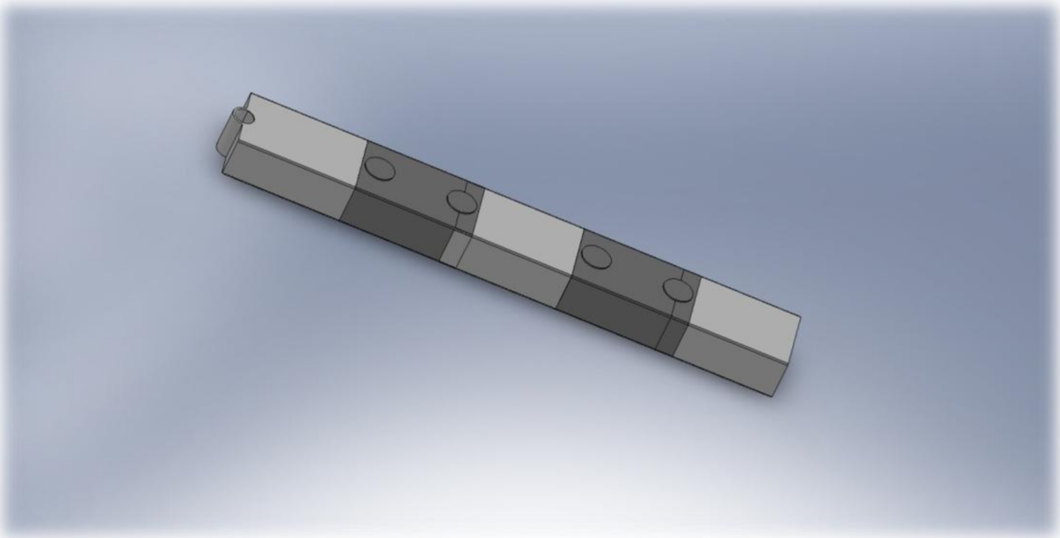


Figure 3.4: Second Proposed Solidworks Design with Joints in Between

3.5.3 Third Improves Model

Third model is to think of how to let the joints can be moving in two directions which are left to right and also up and down. As the snake-like robot needs to fulfil its objectives to climb up the stairs, it must possible to move upwards and downwards. Therefore, the model for designing the joints is very critical in this moment and the figure below shows how the joint that has been designed is:

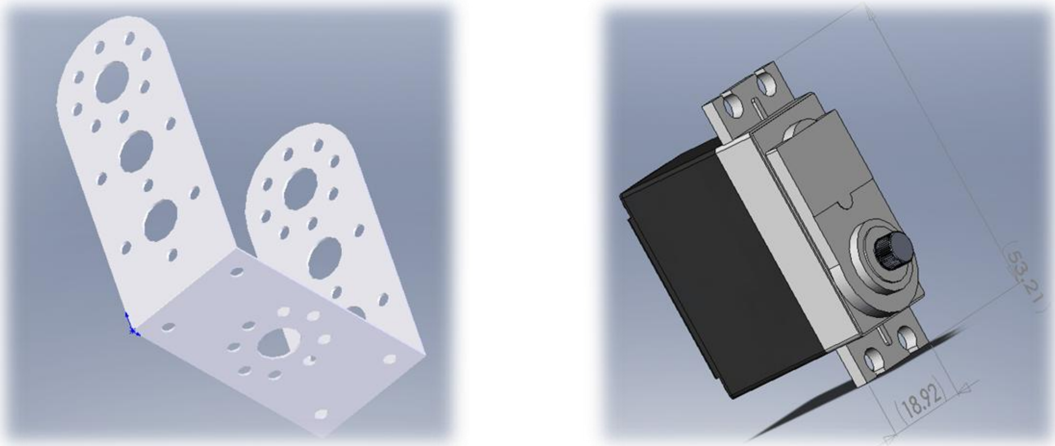


Figure 3.5: U Case and Servomotor that can be purchased from Cytron Technologies

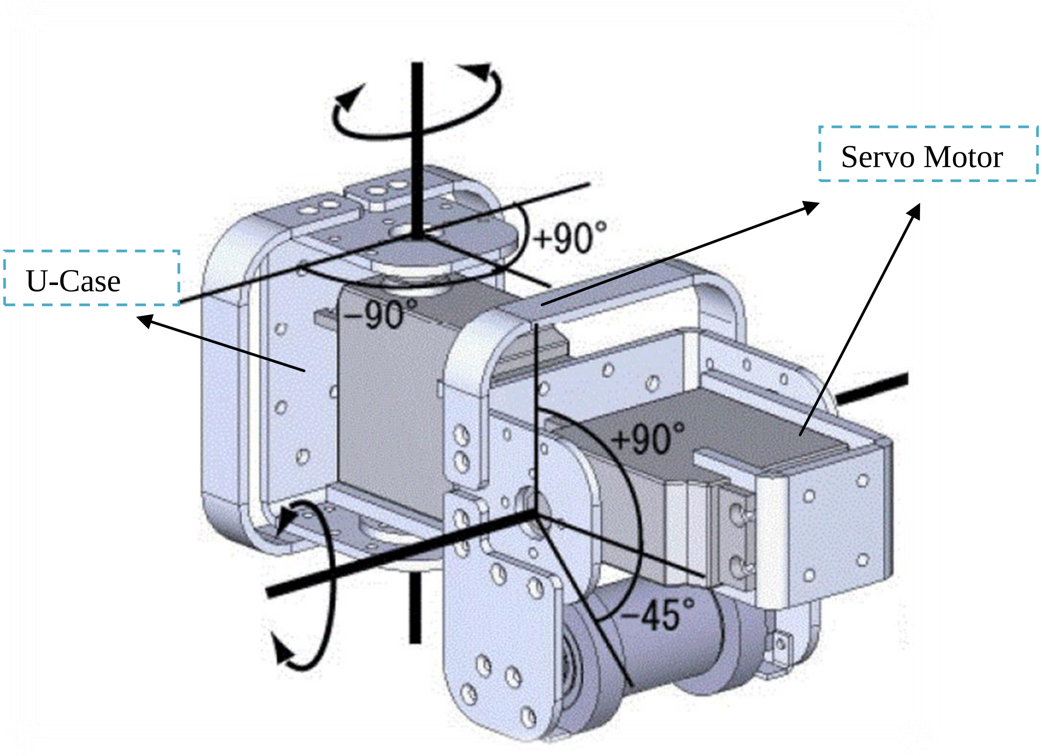


Figure 3.6: Assembly of Joint of Third Proposed Model

From the joints above, it is hard to build the U case as shown in the figure which is required to purchase it from the Cytron Technologies. As the budget given is limited, so the U case will not be purchase. Therefore, we are required to improvise the design so that the body and joints can be fabricated without purchasing it and use the money in purchasing the servomotors which are one of the most critical components needed in snake-like robot project.

3.5.4 Fourth Improves Model

After the outsourcing from the successful made snake-like robot articles, referring to the magazine, journals and else, the model is finalized by using the design shows in the assembly of Solidworks in the figure below:

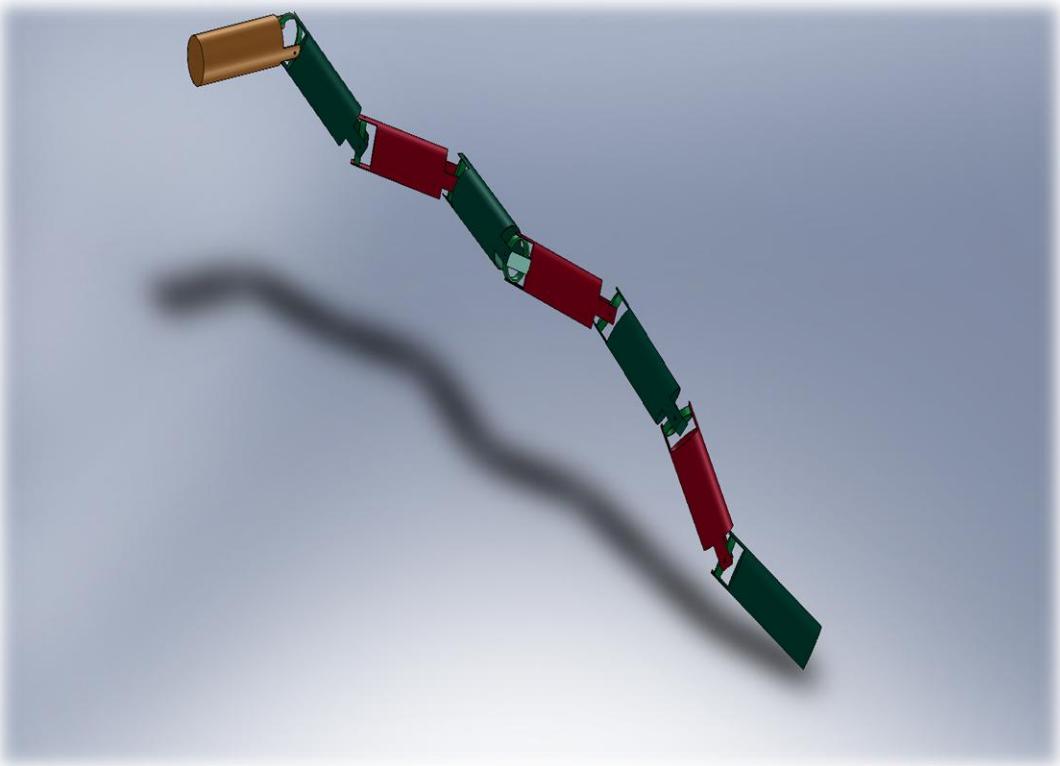


Figure 3.7: Final Model of Snake-Like Robot

Taking a closer look to the final model, the mechanical design will be separated into 3 main parts which consists of the special fabricated part with two joints at the end as the body of the snake-like robot, one joint at the end as the head and tail (end) of the snake-like robot, and the ring as the connector between the joints. Besides, the joints are using similar model as U case. The joints and ring are show in the figures below:

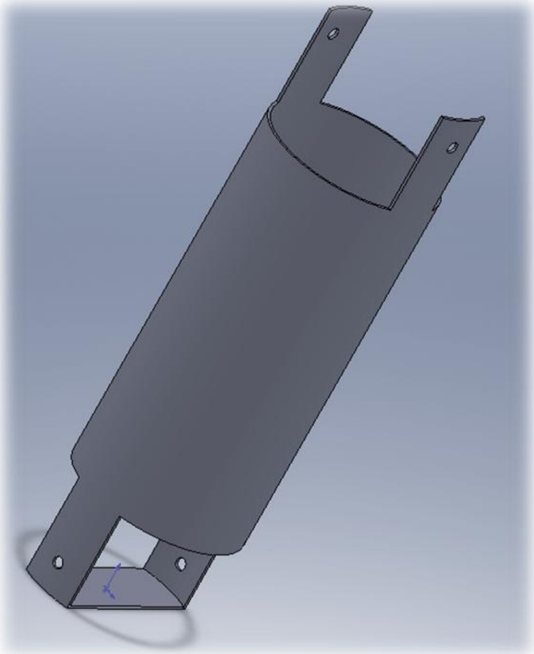


Figure 3.8: Joints of the snake-like robot body part

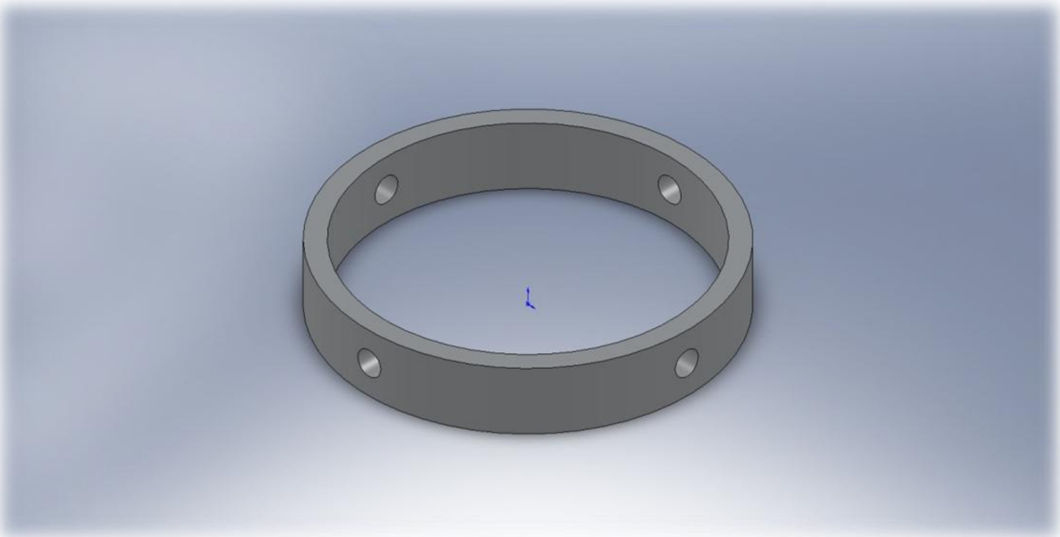


Figure 3.9: Ring that connects the joints of snake-like robot

Figure 3.10: Joints of the snake-like robot head and tail (end) part

3.5.5 Fabrication of Trial / Test Model

In the very beginning part, the final model is fabricated which to test for whether the model can results in moving in 2 directions as the snake-like robot required. The testing model is using a PVC pipe to fabricate for the body part and aluminium alloy is used for fabricate the ring part. As the result, the model is proven works and this is the diagram of the testing model:

Figure 3.11: Test Model

Figure 3.12: Test Model moving to left and right

Figure 3.13: Test Model moving to up and downwards

Figure 3.14: Close view of the joints and ring

3.5.6 Criteria For Choosing The Final Model

After the analysis, the fourth model is being choose for the snake-like robot prototype model. From the table below, it shows the comparison between the abilities and disadvantages between the proposed models:

Table 3.2: Comparison Between Models to Select The Best Design

Model		**1**	**2**	**3**	**4**
Mechanism	Serpentine	-	Yes	Yes	Yes
	Sinus Lifting	-	No	Yes	Yes
	Others	Crank-Slider	-		
Movement	Front and Back	Yes	Yes	Yes	Yes
	Left and Right	No	Yes	Yes	Yes
	Up and Down	No	No	Yes	Yes
Shape		Square	Square	Square	Round
Ease of Fabrication		Hard	Easy	Easy	Easy
Cost of Prototype		Moderate	Low	High	Moderate

Based on the comparison above, Model 4 is being chosen for the fabrication of the snake-like robot prototype as it can perform all the mechanism like a snake, it able to move left and right, up and down to avoid obstacles and easy for fabrication with moderate cost.

3.5.7 Materials of Segments

The material of segments is very important elements as it determine how much torque needed for lifting and moving the snake-like robot. As the material used is heavy will lead to high load while light material will leads to deformation or break when high force exerted.

In fabrication of snake-like robot, it requires a material that can sustain high force in stress and strain as the snake-like robot built must be robust in performing tasks. Beside, the material should be cheap and easy to get to ease the budget plan. The hardness of the materials should be moderate to ease fabrication process and lastly must be having the required dimension such as the diameter.

Materials are divided into two groups which are the metal and non-metal types. Analysis is performed in order to select the best materials to be used.

3.5.7.1 Metals

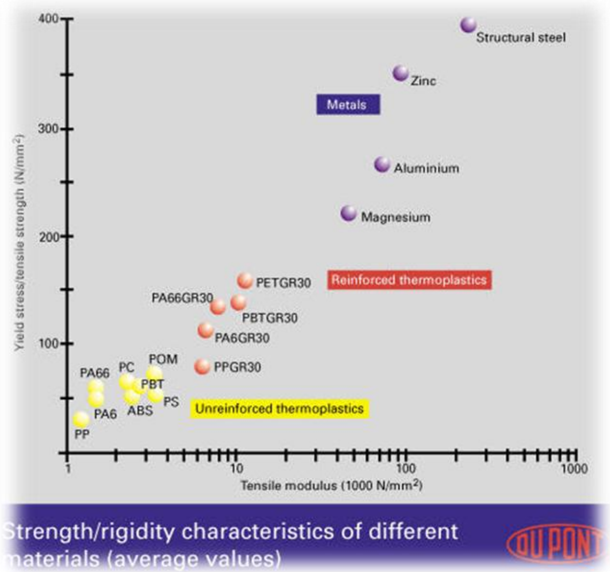


Figure 3.15: Strength and Rigidity Characteristics Supplied from DU POINT

(Source: http://www2.dupont.com/DuPont_Home/en_US/index.html)

From the diagram above, metals having a better stress and strength compares to other materials. Aluminium falls in between of the metals category having moderate strength and tensile modulus, easy to buy and the price is cheaper than other metals, hence aluminium is preferable.

Next, in comparison of types of aluminium, the comparison table obtained from Electrisola Malaysia shows plenty of aluminium available. In comparison of aluminium materials, pure aluminium has low tensile strength while aluminium magnesium alloy has moderate tensile strength. Copper clad aluminium is quite high in density which is hard for fabrication process.

Table 3.3: Comparison of Metal from Electrisola Malaysia

*(Source:*http://www.elektrisola.com/conductor-materials/comparison-of-metals.html*)*

	Density [kg/dm³]	Conductivity [S*m/mm²]	Resistance (IACS) [%]	Tensile strength [N/mm²]	Thermal coefficient of resistance [1E-6/K]
Copper					
Cu	8.9	58.5	100	220-270	3900-4000
Aluminum					
Al	2.7	36	62	120-140	3900-4100
Copper Clad Aluminum					
CCA10%	3.3	37.7	65	130-180	3900-4100
CCA15%	3.6	39.2	68	170-230	3900-4100
HTCCA	3.6	35	60	230-280	3600-3900
High Tension Wire					
HTW	8.9	54	93	350-400	3200-3600
XHTW	8.9	51	88	380-450	3100-3500
Copper Nickel Alloys					
CuNi1	8.9	40	69	220-350	2900-3100
CuNi2	8.9	20	34	290-370	1000-1600
CuNi6	8.9	10	17	310-380	500-900
CuNi10	8.9	6.7	11	320-380	350-400
CuNi23Mn	8.9	3.3	6	500-550	150-200
CuNi44	8.9	2	3	420-480	-80 - 40
Brass					
CuZn10	8.7	25.3	44	340-390	1300-1500
CuZn20	8.5	18.8	32	390-450	1300-1500
CuZn30	8.4	16	27	440-540	1300-1500
CuZn37	8.3	15	26	430-480	1300-1500
Silver					
AgCu1	10.5	57.5	99	220-320	3800-4000
Ag99.99	10.5	62.5	108	170-220	3800-4000
Gold					
Au	19.3	45.5	78	120-220	1400
Copper Tin Alloys					
CuSn6	8.8	7.5	13	470-530	550-750
Aluminum Magnesium Alloys					
AlMg5	2.7	17	29	200-300	3700-3900
Plated Wires					
Ms/Ag	8.5	16	27	440-540	1400-1600
Cu/Ag	8.9	58.5	100	220-270	3800-4200
Cu/Ni	8.9	55	94	250-300	3800-4200
Stainless Steel					
304	7.9	1.36	2	850-970	
316	7.9	1.36	2	740-840	

In conclusion, in metal, material that is most suitable to be used is aluminium alloy hollow bar where it can achieves the requirement needed to fabricate snake-like robot.

3.5.7.2 Non-Metal

In non-metal material world, the most popular are the PVC, plastic, silicone, Acrylonitrile butadiene styrene (ABS), Cold Casting (Epoxy) and others. However, the non-metal material that is most suitable in snake-like robot design is PVC as it is built in round shape and most easy to be obtained.

The properties for PVC are usually categorized based on rigid and flexible PVCs.

Table 3.4: Properties of PVC

(Source: http://en.wikipedia.org/wiki/Polyvinyl_chloride*)*

Property	Rigid PVC	Flexible PVC
Density [g/cm^3]	1.3–1.45	1.1–1.35
Thermal conductivity [W/(m·K)]	0.14–0.28	0.14–0.17
Yield strength [MPa]	31–60	10–25
Young's modulus [psi]	490,000	-
Flexural strength (yield) [psi]	10,500	-

Compression strength [psi]	9500	-
Coefficient of thermal expansion (linear) [mm/(mm °C)]	$5×10^{−5}$	-
Vicat B [°C]	65–100	Not recommended
Resistivity [Ω m]	10^{16}	10^{12}–10^{15}
Surface resistivity [Ω]	10^{13}–10^{14}	10^{11}–10^{12}

From the properties in the table, rigid PVC having better yield strength proven that it can sustain better force when fabrication process. In this, one of the example of rigid PVC is the Unplasticized Polyvinyl Chloride (UPVC).

3.5.7.3 Finalizing Material

Table 3.5: Material Selected from Metal and Non-Metal

Metal	Non-Metal
Aluminium Alloy Hollow Bar	Unplasticized Polyvinyl Chloride (UPVC)

In conclusion, UPVC is chosen as the final material to be used for fabricating the prototype. This is due to several reasons:

a) Cost of the material:
Aluminum alloy hollow bar is very expensive which costs RM450 for 10 meter while UPVC only costs RM30 for 10 meter

b) Material Properties:

Table 3.6: UPVC Properties

(Source: http://omraniyadubai.com/pdf/drainage_pipes.pdf)

Properties	Value
Density	1.42kg/m^3
Modulus of Elasticity	300N/mm^2
Tensile Strength	Min 45N/mm^2
Elongation at Break	Min 80%

Table 3.7: Aluminum Magnesium Alloy Properties

(Source:http://www.elektrisola.com/conductor-materials/comparison-of-metals.html)

	Density [kg/dm³]	Conductivity [S*m/mm²]	Resistance (IACS) [%]	Tensile strength [N/mm²]	Thermal coefficient of resistance [1E-6/K]
Aluminum Magnesium Alloys AlMg5	2.7	17	29	200-300	3700-3900

From the comparison above, the density of the UPVC is smaller which gives better weight. As the weight of the material decreases, the torque needed for lifting up the joint will decreases as well.

By comparing the tensile strength from both tables, UPVC is having relatively smaller value compare to aluminium. High tensile strength of the material is important when force placed on the material is high and will cause deformation. However, in the snake-like robot, the force that occurred is not at the joint but at the links. Therefore, smaller tensile strength is acceptable.

Besides, UPVC having some advantages comparing to aluminium because of:

a) Ease of installation and handling during fabrication as the UPVC having good elasticity

b) Resistance to rust and scratches

c) Easy to be obtained

d) Material not easy to deformation

3.6 Analysis of the Snake-Like Robot

3.6.1 Analysis of Kinematics of Snake-Like Robot

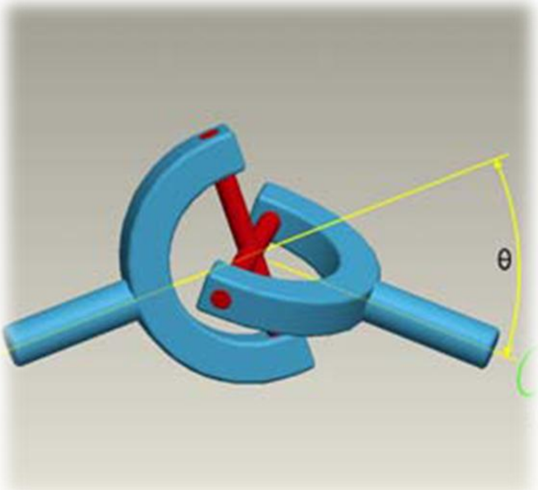


Figure 3.16: Joints on Snake-Like Robot Ring

From the diagram above shows the analysis on the ring of the snake-like robot. The degree of rotation for the snake-like robot is 45º. In this configuration, the input and output shafts rotate at the same velocity, while the linkage between the two shafts exhibits a non-constant velocity behavior. In order for the non-ideal behavior of the two u-joints to exactly cancel each other, the bending angle of each joint in figure below must be equal.

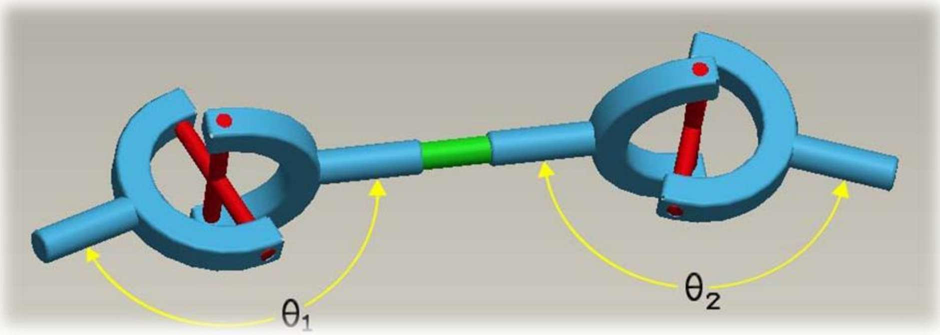


Figure 3.17: 2 Joints on Snake-Like Robot Ring

(Source: http://idea.library.drexel.edu/bitstream/1860/2917/1/Primerano_Richard.pdf)

3.6.2 Calculation of Components in the Snake-Like Robot

There are few components that will exerts certain weight which are the UPVC, rings, castor balls, gears, motors, screws, nuts, and others. The weight is important in order to determine the motors to be used whether it is sufficient to lift up the snake-like robot and perform some movements.

3.6.2.1 UPVC

Calculation:

Based on the material properties of UPVC, it is having a density of 1.42kg/m^3. Assuming the each segments of the snake-like robot having a length of 200mm, diameter of 100mm and thickness of 1mm;

Volume: (0.2 x 0.1 x 0.01) m^3 = 0.0002 m^3

The weight of the snake-like robot per segment (UPVC) = 1.42kg/m^3 x 0.0002 m^3

= 0.000284kg x 9.81m/s^2

= <u>0.00278604 N</u>

Total Force exerted by the snake-like robot (UPVC) = 0.00278604 N x 4

= 0.0112N

3.6.2.2 Rings

There are 3 rings that going to be used in 4 segments. The rings are made of stainless steel and are bended and welded. Below are the readings of the measured mass of the rings:

Table 3.8: Weight of the Rings

Rings	Reading 1(gram)	Reading 2(gram)	Average (gram)
1	3.20	3.15	3.18
2	3.24	3.18	3.20
3	3.17	3.15	3.16

Total Force exerted by the rings: (3.18 + 3.20 + 3.16) g

= 9.54g = 0.00954kg x 9.81m/s^2

= 0.09359N

3.6.2.3 Castor

Castor is installed at the second segment of the snake-like robot as the moving mechanism. The castor looks like the diagram below:

Figure 3.18: Castor

Force exerted by the castor: 100g = 0.1kg x 9.81m/s^s

= <u>0.981N</u>

Function: The castor act like a free wheel where enable it to roll anywhere according to the movement of servomotors on the links. With the aid of the castor, the snake-like robot is able to move to any directions with lesser friction force.

3.6.2.4 DC Motor Mount

For the DC motor, it has to mount on the last segment of the snake-like robot in order to power the wheels that for the forward movement.

Force exerted by the Mount = 754 gram = 0.754kg x 9.81m/s^2

= <u>7.3967N</u>

The shape of the mount is like the diagram below:

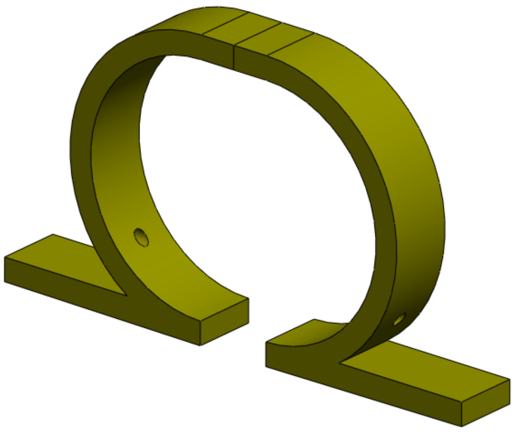


Figure 3.19: DC Motor Mount

Function: DC motor mount is to hold the DC motor at the end of the segment to drive the gears. The DC motor mount is fabricated using mild steel as it is easy to be shaped to hold properly for the DC motor.

3.6.2.5 Batteries

For the power up the DC motor, batteries are required to be connected. From the calculation done and retrieved from Snake-like robot electronics part required battery with the rating of maximum voltage of 11.1V and to be used down to 10V and the desired output is 7V to ensure the circuits and motors will meet the maximum performance. Therefore, LiPo (lithium polymer) battery is selected.

The force exerted by the battery = 280g = 0.28kg x 9.81m/s^2

= 2.7468N x 2 piece

= 5.4936N

3.6.2.6 Motors

Before building the outer part of the snake-like robot, motors play a crucial role in driving the joint to left and right to perform the locomotion movement as well as up and down movement for climbing slope purposes. Besides, to ensure the snake-like robot to move smoothly in uneven surfaces, motor is required for the forward movement just like an engine in a car.

3.6.2.6.1 Analysis:

Left and Right and Up and Down Movement

In order to perform lift up and down movement, high torque type motor is to be considered as it can support the joint which is loaded with motors, circuits, batteries, and others. By comparing the types of motor in the industry, there are few motors that are high torque and able to move in two directions (left and right):

1. Servomotors
2. Stepping Motors
3. Brushless Motors

Table 3.9: Comparison of Three Types of Motors

(Source: http://en.wikipedia.org/wiki/Electric_motor)

Type	Advantages	Disadvantages	Application	Typical Drive
Stepper DC	- Precision positioning - High holding	- High initial cost - Requires a controller	- Positioning in printers and floppy drives	DC

	torque			
Brushless DC	- Long lifespan - Low maintenance - High efficiency	- High initial cost - Requires a controller	- Hard drives CD/DVD players electric vehicles	DC
Brushed DC	- Simple speed control	- Maintenance (brushes) - Medium lifespan - Costly commutator and brushes	- Steel mills Paper making machines automotive accessories	Direct DC or PWM
Servomotor	- Able to control the rotation angle precisely - Low inertia of rotating components - High	- Required encoder - Might damage when sustained overload - Brush will wear out in time which required	- Aircraft actuators, instruments, computer printers, machine tools	AC or DC

	torque - Low starting cost	service		

From the comparison, servomotors are chosen to control the joint movement whether up down or left right direction. This is because to fulfill the objectives of our snake-like robot which is to climb for a stairs or blockage. In this, snake-like robot should be lifted up for several angles where the angles are controllable by the user set in the programming part according to the height to avoid or climb for the stairs. Servomotors are high torque motors which enable to lift heavy load as the snake-like robot having few segments. The costs of the servomotors are low compare to other motors.

Meanwhile, the DC motor is to be used as the motor that drive the snake-like robot in moving forward. This is because of its simple speed control and able to be powered by DC source such as batteries. Besides, as the DC motor is required to drive the whole snake-like robot, high torque is most important element in selecting it.

3.6.2.6.2 Selecting Servomotors:

In selecting servomotors, several calculations and criteria are performed and met in order to determine the most suitable servomotors to be used and purchased. Weight and torque are the most important elements in performing the calculation. The calculation below are mostly based on assumptions.

Calculation:

Table 3.10: Weight of Components

Components	Weight (N) Per Piece
UPVC	0.0112

Rings	0.09359
DC mount	7.3967
Battery	5.4936N
Castor	0.981

Assumptions made before analysis:

Assuming the one servomotors = 70g = 0.07kg x 9.81m/s^2

= 0.6867N

Assuming the force is distributed at the center point of the segments:

Length for one segment = 250mm = 0.25m

Center point = 0.25m/2 = 0.125m

Assuming each joint having 3 servomotors placed on the rings

1st Segment Analysis:

Weight of UPVC + 20% of Tolerance of Force from a servomotor weight

= 0.0112N + (0.6867 x 20%)

= 0.1486N

Torque required to drive 1st segment:

Torque = Force x Distance (Center Point)

= 0.1486N x 0.125m

= 0.0186 Nm

2^{nd} Segment Analysis:

= Weight of 2 UPVC + Rings + Castor + 3 Servomotors + 20% of Tolerance of a servomotor weight

= (2 x 0.0112N) + 0.09359N + 0.981N + (3 x 0.6867N) + (0.6867N x 20%)

= 3.294N

Torque required to drive 2nd segment:

= 3.294N x (0.125m x 2)

= 0.824 Nm

3^{rd} Segment and last segment Analysis:

Weight of 3 UPVC + 2 Rings + Castor + 6 Servomotors + DC mount + Battery + 20% Tolerance of a servomotor weight

= (3 x 0.0112N) + (2 x 0.0935N) + 0.981N + (6 x 0.6867N) + 7.3967N + 5.4936N + (0.6867N x 20%)

= 14.229N

Torque required to drive 3^{rd} and last Segment:

14.229N x (0.125m x 4)

= <u>7.115 Nm</u>

Adding up the torque required and getting the average torque:

= [(0.0186 + 0.824 + 7.115) / 3] Nm

= <u>2.6525Nm</u>

Converting to kg-cm: 2.6525 x 10 / 9.81m/s^2

= <u>2.704kg-cm</u>

In the servomotors of Cytron Technologies, C55S Servomotors can sustain from 9 – 13kg-cm torque by referring to the specification given and the servomotors can sustain the calculated torque. So, C55S servomotors are being chosen to be used in the snake-like robot.

Figure 3.20: Specification Sheet of Servomotors C55R

3.6.2.6.3 Selecting DC Motors:

For selecting the DC motors, it must be able to sustain the whole weight of the snake-like robot prototype in order to push the robot forward. Based on the calculation in servomotors:

Calculation:

Assumptions:

Weight of a DC motor: 220gran = 0.22kg * 9.81m/s^2

= 2.1582N

Assuming the force is distributed on the center of the wheels:

Center of the wheel: 35mm = 0.035m

Estimated total weight of snake-like robot:

9 Servomotors + 4 UPVC + 3 Rings + Castor + DC mount + Battery + DC motor + 20% Tolerance of a DC motor weight

= (9 x 0.6867N) + (4 x 0.0112N) + (3 x 0.09359N) + 0.981N + 7.3967N + 5.4936N + 2.1582N + (2.1582N x 20%)

= 29.7465N

Torque required to drive the snake-like robot:

= 29.7465 x 0.035m

= <u>1041mNm</u>

In the DC motor of Cytron Technologies, SPG30-300K can sustain 1176mNm torque by referring to the specification given and the DC motor can drive the whole snake-like robot. So, SPG30-300K DC geared motor is being chosen to be used in the snake-like robot.

Figure 3.21: Specification Sheet of DC motor model SPG30-300K

3.6.2.7 Dimension of Model

From the proposed design previously, the dimension of the each body segment of the snake-like robot is set to be 20mm x 6mm x 0.1mm. However, the real prototype dimension of the segment is 250mm x 110mm x 1mm. From the dimension, length and diameter of the design scaled up which is bigger in length and diameter than proposed design while maintaining the thickness. This is due to some factors:

a) To suit the dimension of the servomotors that are being connected to the ring placed side by side

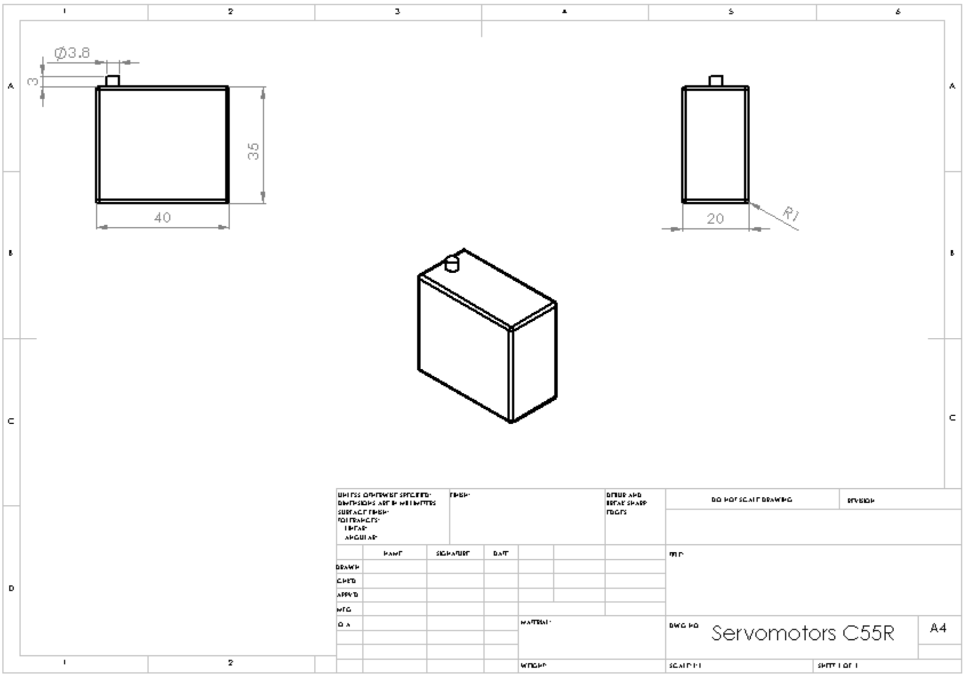


Figure 3.22: Dimension of Servomotors C55R

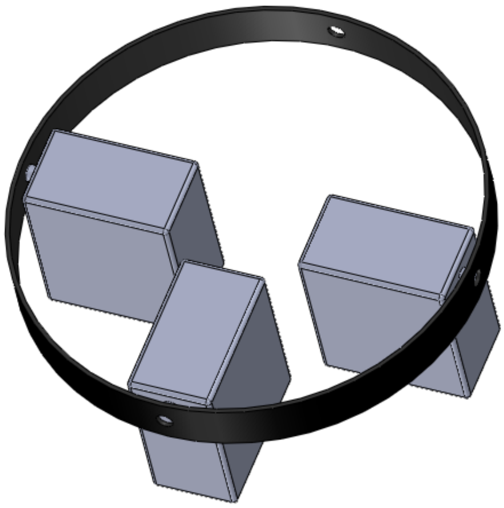


Figure 3.23: Servomotors mounted on the ring

b) To suit the dimension of the dc motors and gear to power up at the end part of the snake-like robot
c) To provide bigger space for the circuits and controller to be placed inside the snake-like robot

Therefore, the resulted designs are draw in Solidworks and show below:

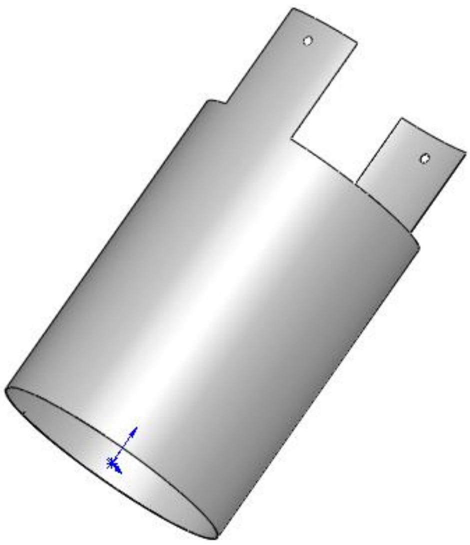


Figure 3.24: Head Part of Snake-Like Robot

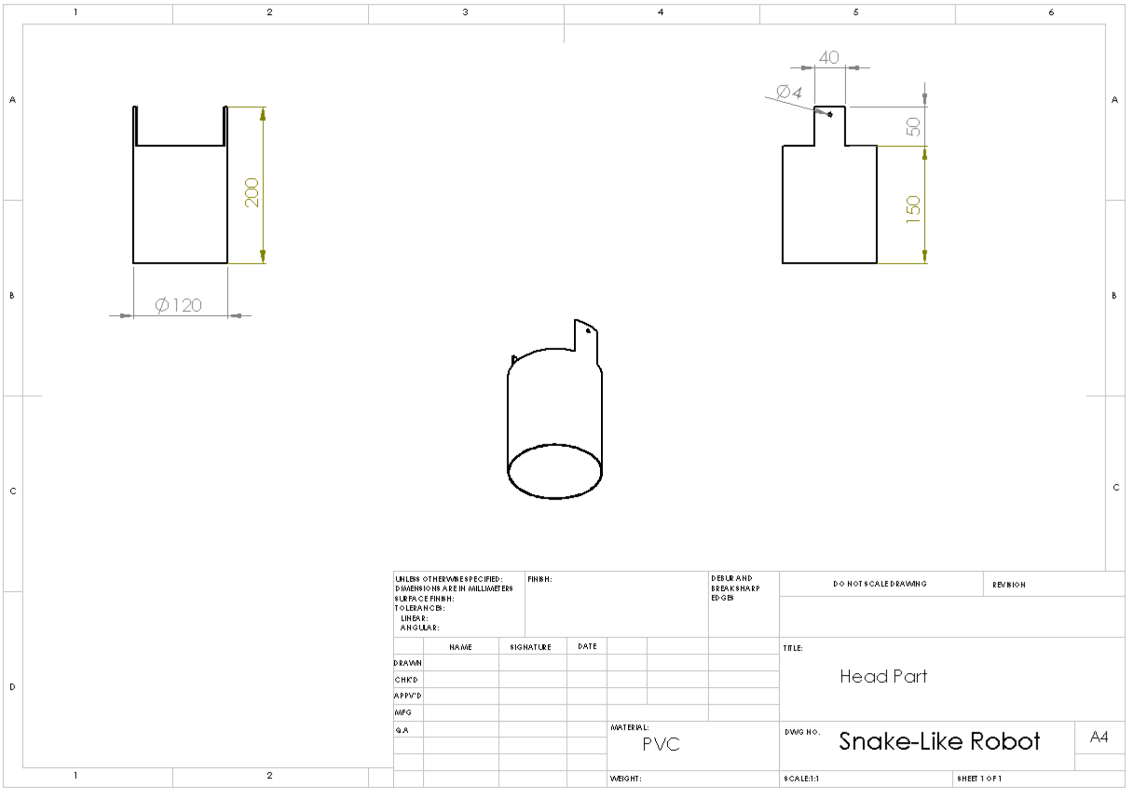


Figure 3.25: Dimension of the Part in Drawing Mode

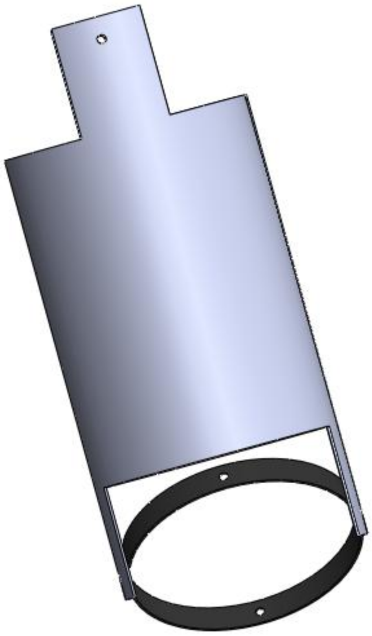


Figure 3.26: Body and Ring Part of Snake-Like Robot

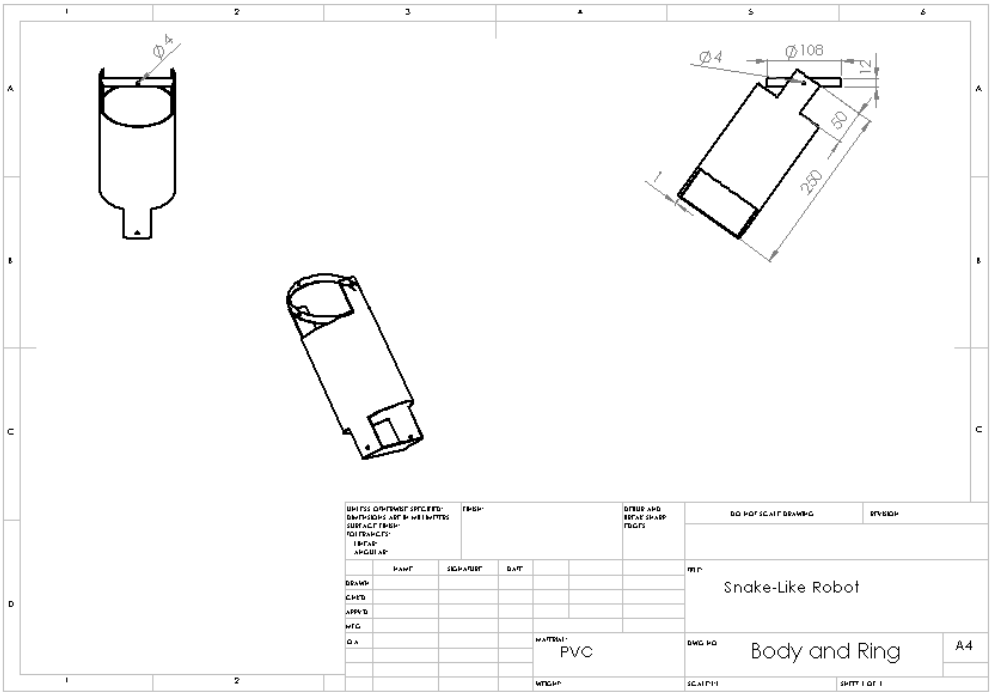


Figure 3.27: Dimension of Body and Ring Part in Drawing Mode

By comparing to proposed design, there will be 6 segments in the snake-like robot. However, the length of the segment is increased. The number of segments are reduced to 4 segments for better controlling.

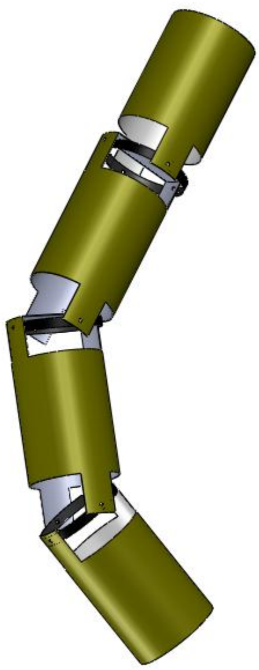


Figure 3.28: Assembly of 4 Segments of Snake-Like Robot (Outer Part)

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Prototype Fabrication

There are several stages in fabricating the snake-like robot. In between the stages, there are many problems or hardship that were encountered and will be discussed in this chapter. Below is the chart of the fabrication stages:

Cutting process into shapes

⇩

Assembly the servomotors on the joints

⇩

Gears, wheels and shaft fabrication and installation with DC Motor

⇩

Circuits Installation

⇩

Finalizing and Testing with the programme

Figure 4.1: Flow Chart of Prototype Fabrication

4.1.1 Cutting Process

In the cutting process, there are two materials to be cut into desired shape. First, is to cut the UPVC. The figures below show the cutting process:

Figure 4.2: Marking on the UPVC before cutting

Figure 4.3: Head, End and Body of the Snake-Like Robot Marking

Figure 4.4: UPVC after cutting process

Second, is to cut the stainless steels into dimension, make it to be round shape and lastly welded it to maintain the shape which is known as the rings. The diagram shows the ring which is connected to the joint:

Figure 4.5: Ring with the Joint

Figure 4.6: Ring with the Joint close view

Lastly is to assemble the rings into the joints and form the snake-like robot. Below are the after assembly snake-like robot diagram:

Figure 4.7: Assembly of Snake-like robot with 6 joints

Figure 4.8: Second view of the assembly parts

4.1.2 Assembly of the Servomotors

Next, the motors are connected to the joint. In this part, the servomotors are linked to the rings with a method to ensure that it works properly and able to rotate the joint.

First, 3 holes of the rings were enlarged to fit the connector of the servomotors while one hole maintain its original diameter. The holes on the connector are being enlarged by drilling with drill bit of Ø3 and tapped so that M3 screws can be inserted. This is to link the connector and rings. The solidworks diagram below shows how the servomotors are joined to the rings and the connector with the ring.

Figure 4.9: Servomotors are joined to the rings in Solidworks

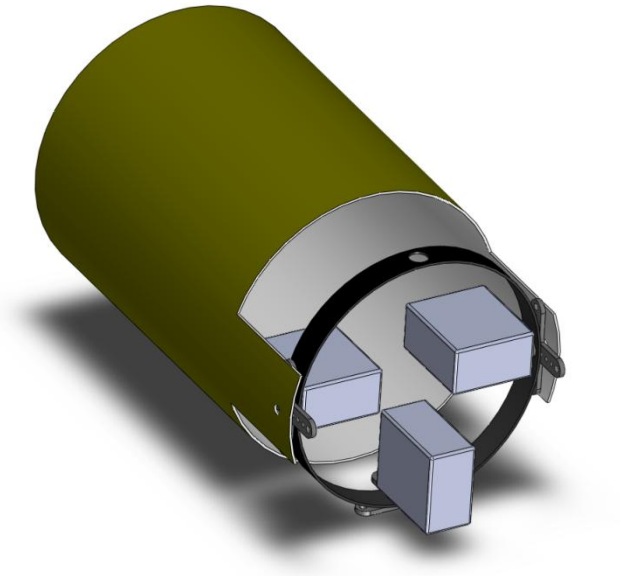


Figure 4.10: Head Part and Servomotors attached with Connecters and Rings

Figure 4.11: The fabricated and close view of the assembly between servomotor, ring and UPVC:

4.1.3 Shaft, Wheels and Gear Fabrication and Installation with DC Motor

4.1.3.1 Shaft:

The shaft is fabricated by using mild steel rod, cut and being tapped into M5 tapping. Below shows the Solidworks drawing, dimension and actual fabricated shaft.

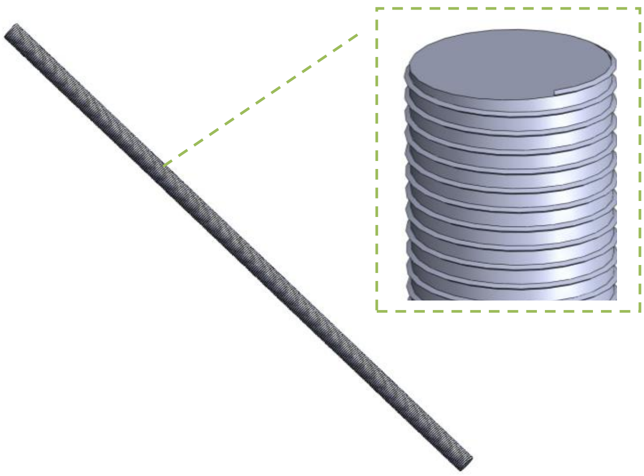


Figure 4.12: Shaft in Solidworks Drawing

Dimension of the shaft:

Length – 170mm Diameter – 5mm

Figure 4.13: Shaft Placed on the Last Segment of Snake-like robot

4.1.3.2 Wheels:

The wheels that are used in the snake-like robot are the Sherperd High Performance Racing Tyres. It is high quality standard and best raw materials to ensure excellent performance combined with low tyre wear. The tyre is made with harsh material that highly gripped and having high friction force when climbing the slopes.

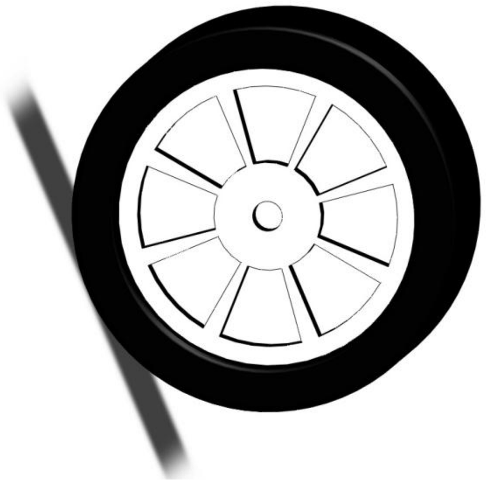


Figure 4.14: Wheels in Solidworks Drawing

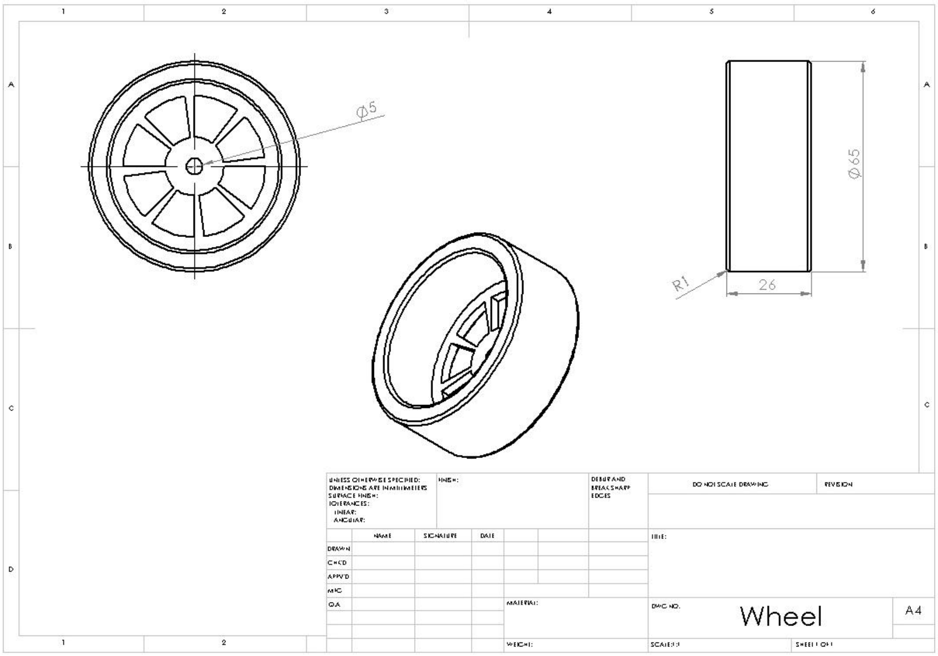


Figure 4.15: Dimension of the Wheels

4.1.3.3 DC Motor

The DC motor used in the snake-like robot is from Cytron Technologies. The model is SPG30-300K which having 12RPM and 1176mNm. It is a DC geared motor which having a high torque. Pinion is connected to the shaft of the motor to provide rotation to the gear to drive the shaft of the wheels. Below is the Solidworks drawing and dimension of the DC Motor, pinion and gear.

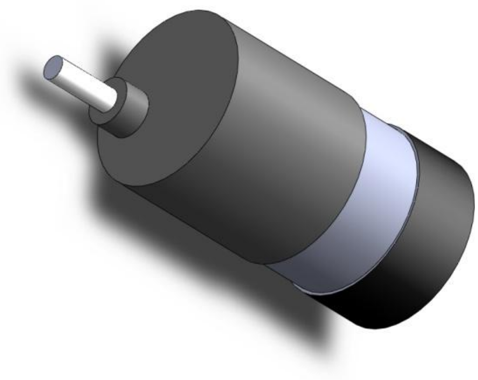


Figure 4.16: DC Motor of SPG30-300K

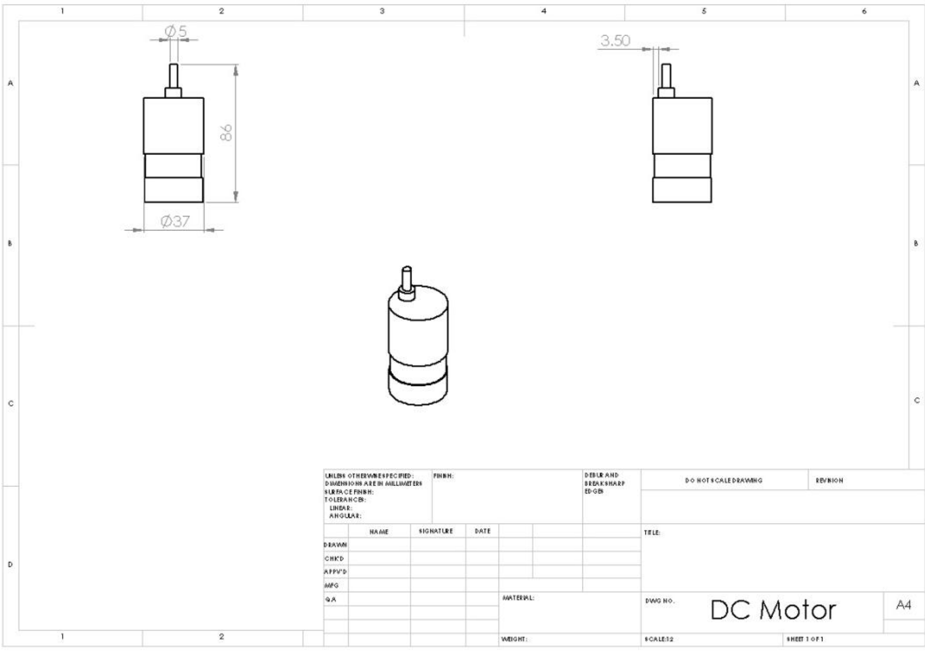


Figure 4.17: DC Motor of SPG30-300K dimension

The pinion model is 18T-pinion which having 18 teeth.

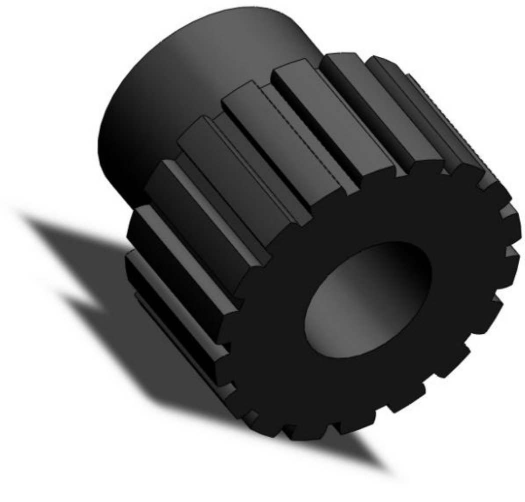


Figure 4.18: Pinion

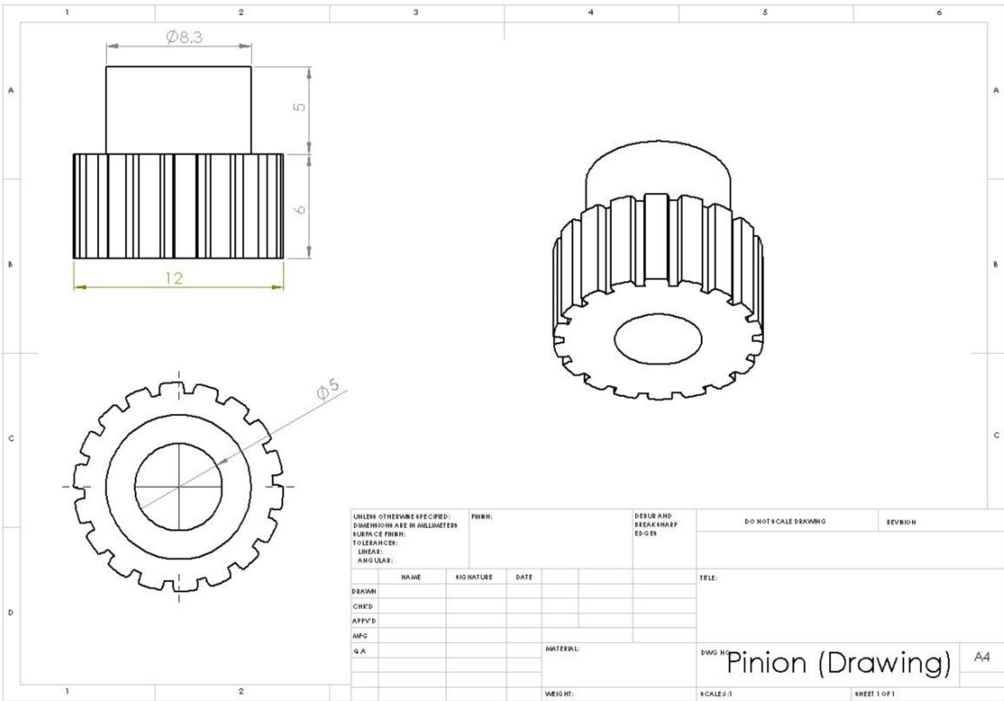


Figure 4.19: Dimension of Pinion

The gear used is fit to the pinion size and having 38 teeths.

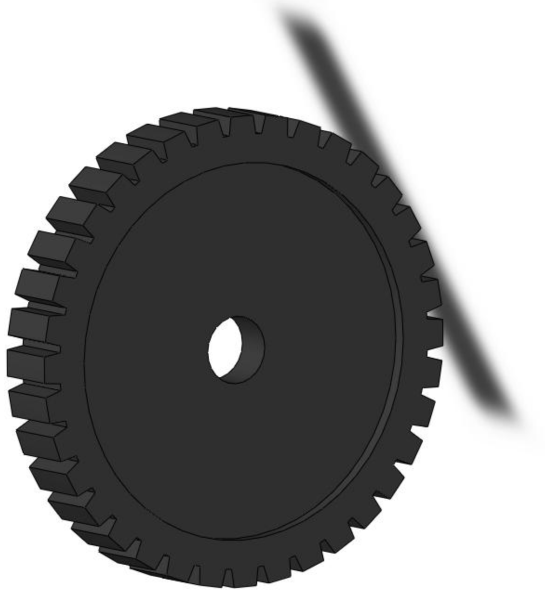


Figure 4.20: Gear

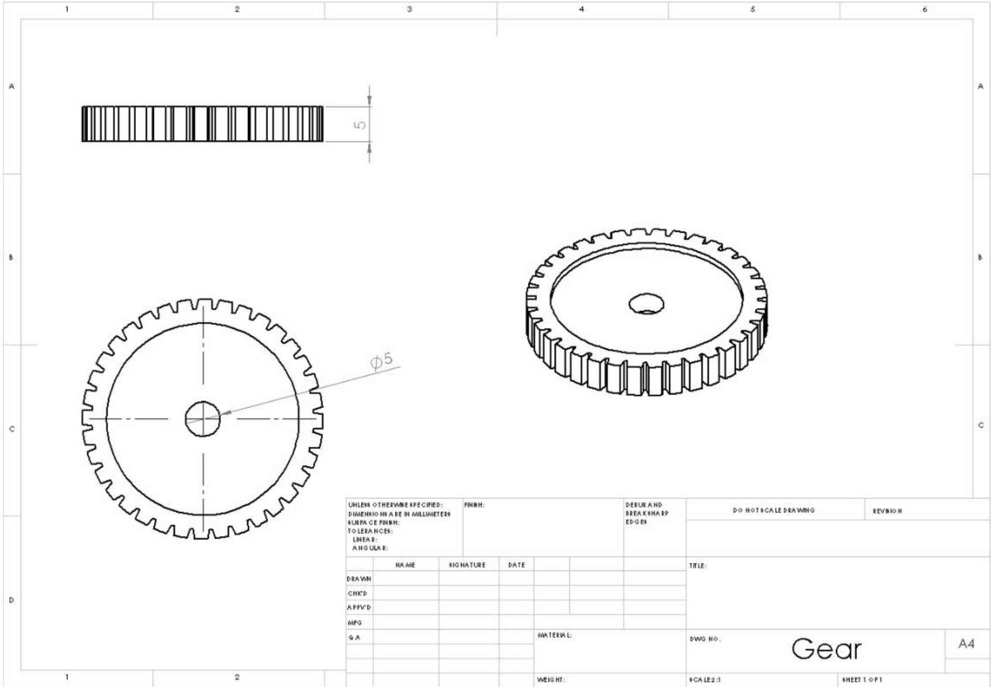


Figure 4.21: Dimension of Gear

4.1.4 Calculation of the Speed

This section is to calculate for the speed of the front movement exerted by the DC motor pinion to the gear which to drive the wheels of the snake-like robot. Below is the ratio of the pinion and gear:

Teeth of Pinion : Teeth of Gear

18 : 38

1: 2.11

From the ration, it means that when the pinion rotates one revolution, the gear will rotate for two revolutions. Thus, the speed of the snake-like robot will be:

Rated speed of the DC Motor x 2.11 rev

12 rpm x 2.11rev = <u>25.33rpm</u>

It is relatively move in a very slow speed but the torque exerted by the wheels is large which enable it to move in rough surface without any problem.

4.1.5 Assembly of Gears, Wheels, Shaft and DC Motor

For the assembly part of the gears, wheels, shaft and DC motor, there are a lot of concept being made for mounting the DC Motor on the right place, shaft and maintaining the stability of the snake-like robot. As the snake-like robot only required two wheels connected to a shaft and one motor to drive, therefore, single-stage drive is being used as the final concept. Below is the diagram of the single-stage drive:

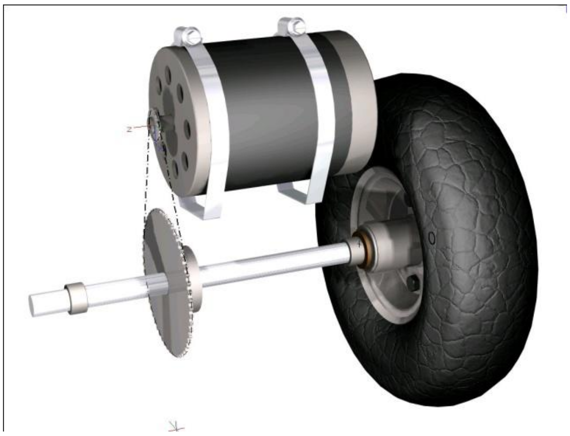


Figure 4.22: Single-Stage Drive

The assembly is show in the figure below:

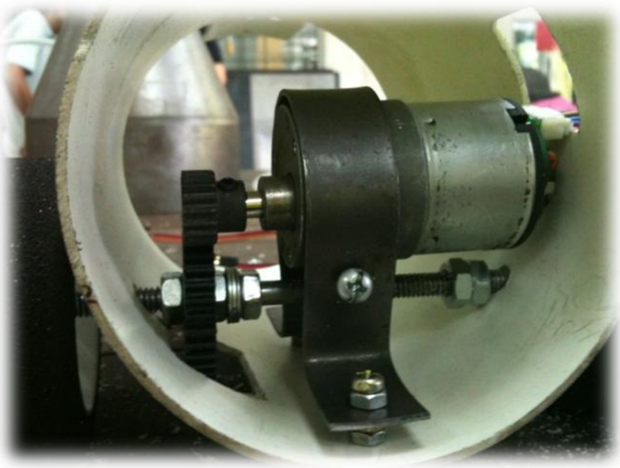


Figure 4.23: Full view of the Assembly

Figure 4.24: The DC mount connection

Figure 4.25: The Pinion and the Gear

Figure 4.26: Back view of the Assembly

From the figures above, it shows how the actual view of the DC Motor that fixed to the pinion and placed on top of the gear to function as the single-stage drive. The DC mount is holding the DC Motor and fixed to the last segments of the snake-like robot.

4.1.6 Castors

Castor is used in the snake-like robot prototype. Castor able to roll to anywhere according to the movement and direction controlled by the servomotors. The diagram below shows the castor in Solidworks drawing and dimensions. Besides, the castor is installed on the second segments of the snake-like robot.

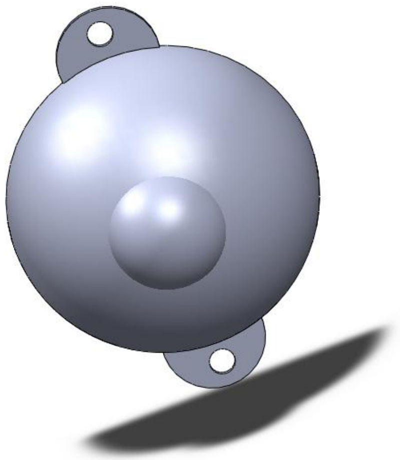


Figure 4.27: Castor on Solidworks Drawing

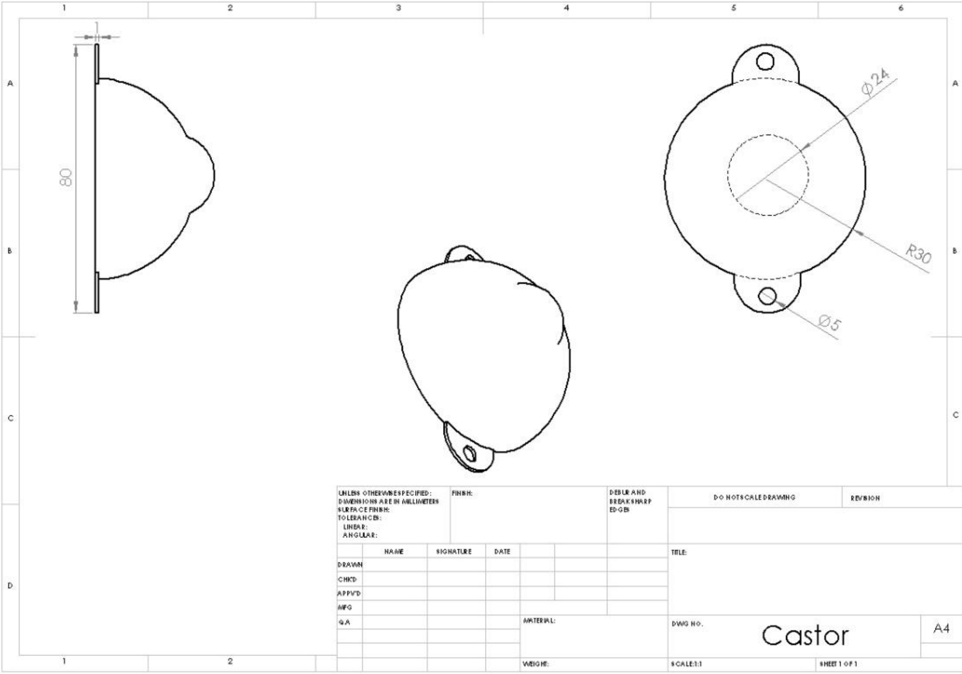


Figure 4.28: Dimension of the Castor

Figure 4.29: Placement of Castor on Second Segments

4.1.7 Internal Placement

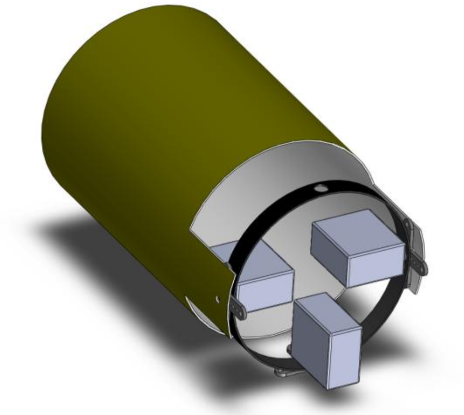
For the placement of the circuit boards, batteries, receiver and sensors, the placement is properly divided into the 4 segments of the snake-like robot.

Table 4.1: Placement of Components

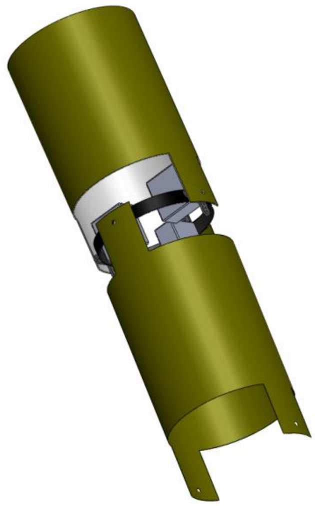
Components	Placement
Batteries	Batteries are mount at the third and fourth segment of the snake-like robot as it is quite heavy, therefore the batteries are put at the last segment as the base.
Circuit Boards	Circuit boards are mount on the second segment of the snake-like robot as easier connection to the receiver and sensor on the head part.
Receiver and Sensors	Receiver and sensors are mount on the head part which is the first segment of the snake-like robot. This is to ensure that the sensor able to sense the blockage in front to stop the movement of the snake-like robot.

4.1.8 Full Assembly

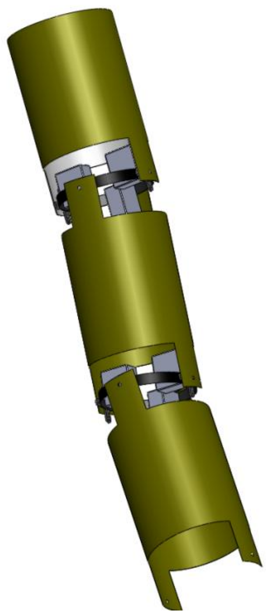
This stage shows how are the full assembly is done in Solidworks and the fabricated full assembly of the snake-like robot being done.



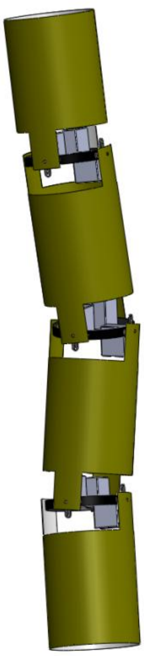
First segment (Head part) connected to the rings and Servomotors attached by connectors



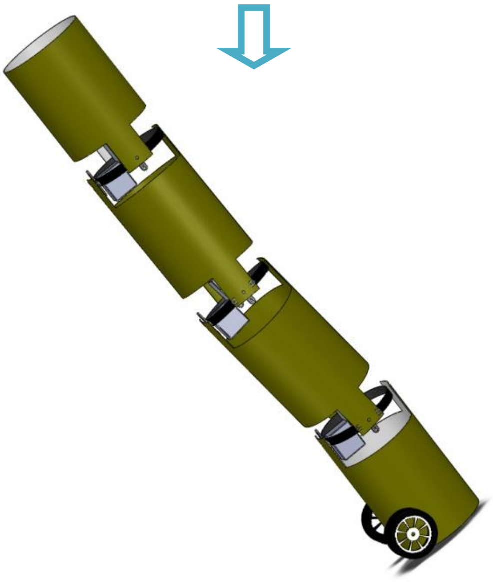
Second segments is joined to the first segment



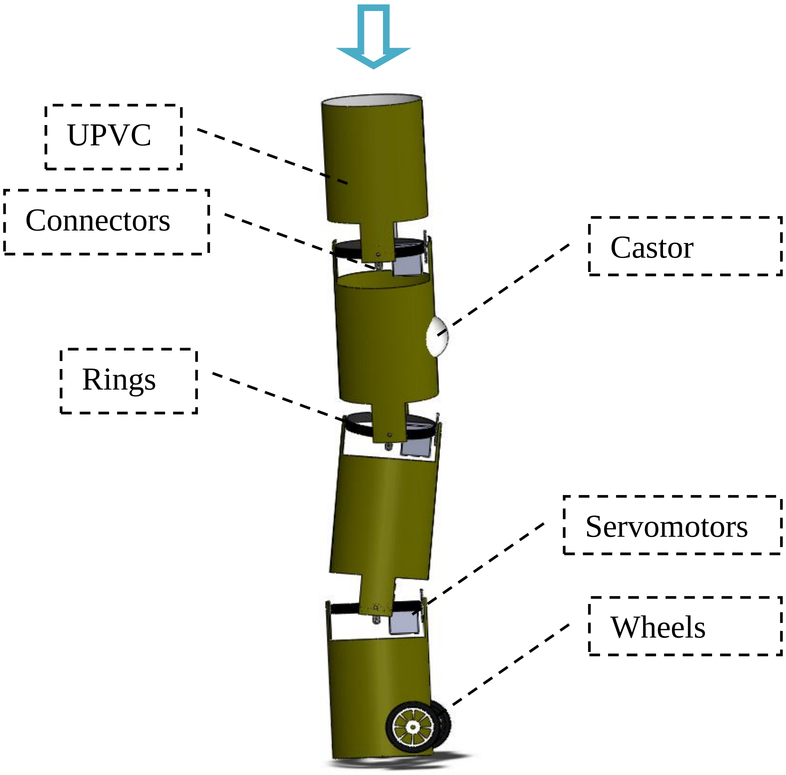
Third segments is joined to the second segment



Fourth segments (Tail Part) is joined to the third segment



Wheels are installed in the last segment with motors and shaft inside



Full assembly with the last installation of the castor on the second segments

Figure 4.30: Steps of Full Assembly in Solidworks

Figure 4.31: The End Product of Snake-Like Robot

Figure 4.32: Up view of the Snake-Like Robot

4.1.9 Problems Encountered

In the buidling the prototype, there are some problem that were encountered and being solved by applying knowledge of engineering. Below is the problems and the solutions being made.

4.1.9.1 Size of UPVC

Diameter of the UPVC obtained from the shop is Ø110mm which is 10mm difference between the designed or exact required dimension.

Solution: The UPVC is put to be experienced little expansion between the ring and the UPVC itself. This is work because UPVC having good characteristics which are flexibility and can sustain stress and strain.

4.1.9.2 Collision of Servomotors

The servomotors dimension is relatively bigger which causes the servomotors having some collision on the wires.

4.1.9.3 Weight of the Castor

The castor used in the snake-like robot is made by steel and having a weight of 100gram which is considered a high force exerted on the servomotors to drive it and lift the segments up to avoid obstacles.

4.1.9.4 Hole Diameter of the Pinion

The pinion that connected to the DC motor shaft is 18T pinion. As the pinion having a smaller diameter compare to the shaft of the DC motor. As the pinion is made of a kind of hard steel, therefore, it cannot directly drill for a bigger size hole by using drilling machine. Therefore, some modification has done.

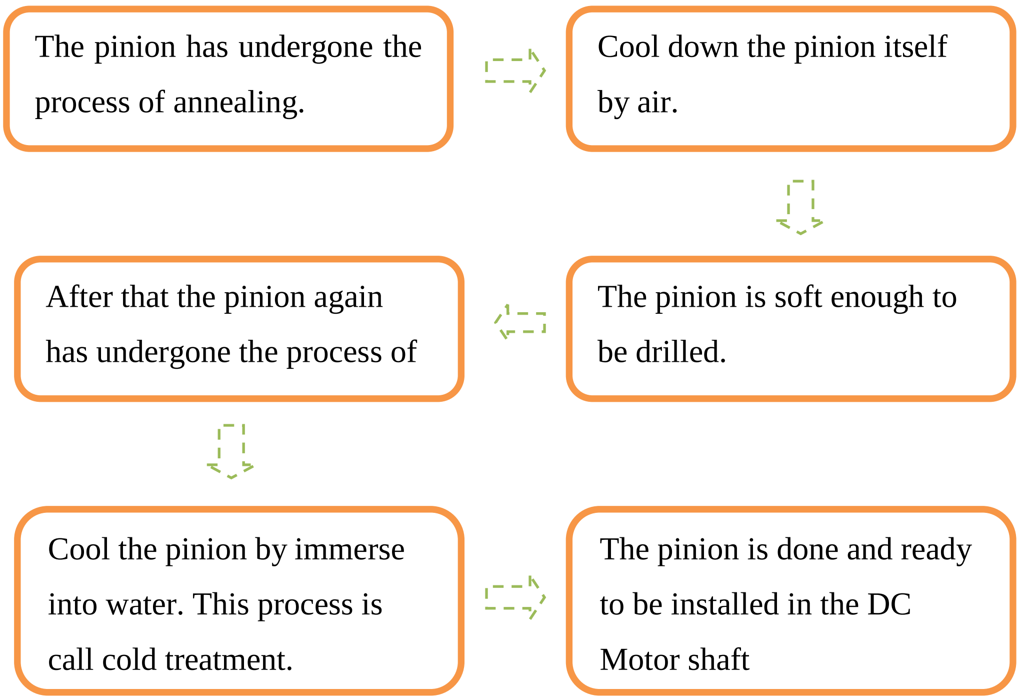


Figure 4.33: Flow Chart of Modifying Pinion Hole Diameter

4.1.10 Testing of Prototype

For the prototype, tests are being conducted to test for the stability of the snake-like robot.

1. Safety Testing

   For the safety testing, the snake-like robot cannot be undergo for the water surface. This is because the prototype is not covered for the electronics part and it will spoilt if contacted with water. Second, the wheels is made of some kind of materials which having a high grip and it is not suitable to be contacted with water which will spoilt the grip.

2. Lab Test

   For the last segment, after the fabrication and assembly of the DC Motor with other parts showed in the Figure 4.23 to 4.26, test is being conducted in the lab for whether the wheels are able to move properly. It is connect directly to the 12V source to drive the DC Motor. It shows that the pinion is able to drive the gear successfully.

3. Drop Test

   For the snake-like robot prototype, it is being dropped for a height of 1 meter and the prototype is still in a good condition. This proves that the prototype is built tough enough to sustain a light drop. Besides, for the hardware such as electronics part which placed inside the snake-like robot, the PC Board is placed and gum by using hot glue. The PC Board is glued for two times to ensure that it is properly stick so that when performing the drop test, the board will not come out.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In conclusion, the snake-like robot is able to be built and assemble together with the electronics and programming part.

In specific for mechanical part, the snake-like robot is fabricated from the best design among all the proposed designs with the abilities of moving in either smooth or rough surfaces. Besides, snake-like robot also able to avoid the obstacles and overcome by moving up and down or left and right.

5.2 Plan of Actions

5.2.1 Improvements to Snake-Like Robot in Future

There are few improvements that will be implemented in snake-like robot in future in order to produce high capabilities and meeting the objectives.

First, implement wheels or crawls on snake-like robot. As one of the objectives is to climb up the stairs, wheels or crawls are needed in assistance of snake-like robot to perform the action. As stated in the review, OmniTread is using the wheel-mechanism like the tank and proven that it can overcome obstacles like stones, stairs and others. Therefore, wheel-mechanism as mentioned will implement into test model. Below is the diagram to show the OmniTread wheel mechanism:

Figure 5.1: OmniTread Wheel Mechanism

(Source: http://www.ubergizmo.com/15/archives/2010/02/omnitread_snake_robot.html)

Second, in addition of the implementation in future, by considering implement crawls around the model will help to improve the capabilities of the snake-like robot in achieving objectives. The crawls may look like the diagram below:

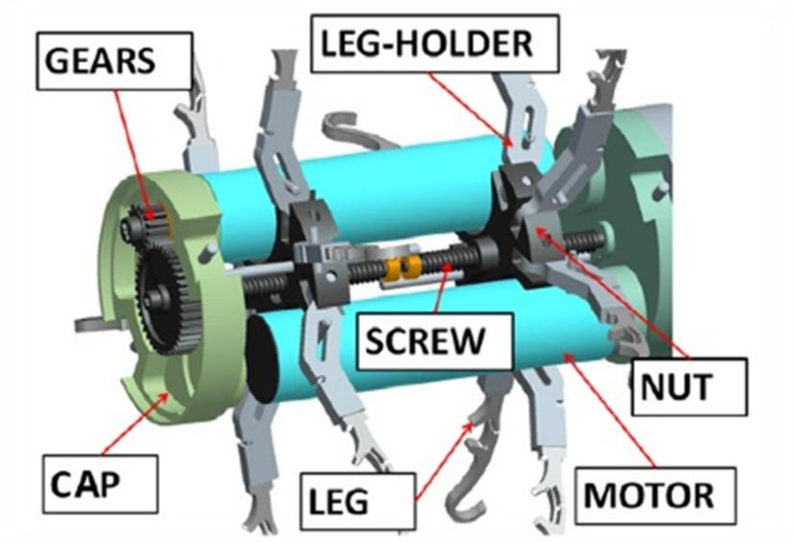


Figure 5.2: Crawls on Snake-like Robot

(*Source: http://www.smartplanet.com/business/blog/smart-takes/new-spider-pill-camera-robots-offer-comfortable-alternative-to-colonoscopy/1617/*)

Third, touch rings play an important role in searching process. As the touch rings will sense the surroundings for any obstacles, the snake-like robot are required to move it back to its original place. Below is the example diagram of the touch rings:

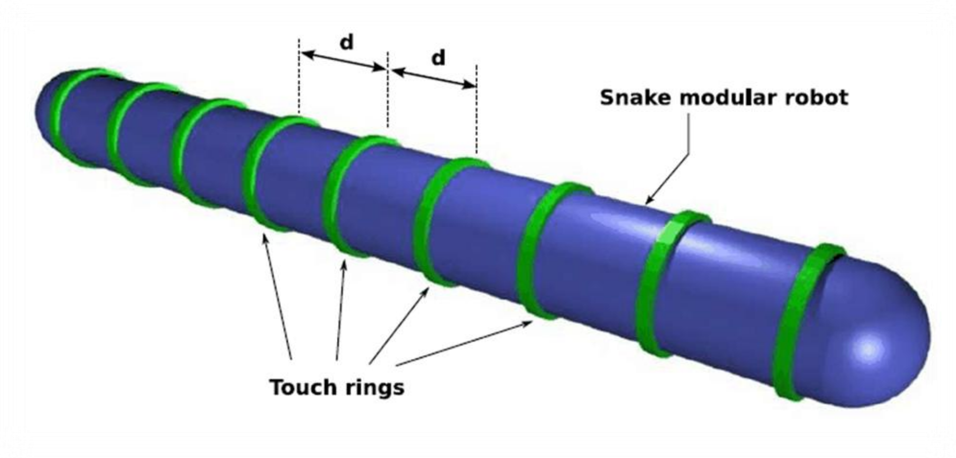


Figure 5.3: Touch Rings on Snake Robot

(Source: http://www.iearobotics.com/downloads/2010-05-03-ICRA-Workshop/Paper-ICRA-workshop-2010-snake-USAR.pdf)

Forth, the head part of the snake-like robot model will be installed with various type of sensor in order to be controlled for the movement in an environment as stated in the objective. The diagram below shows the head part of the snake-like robot will be modelled as this:

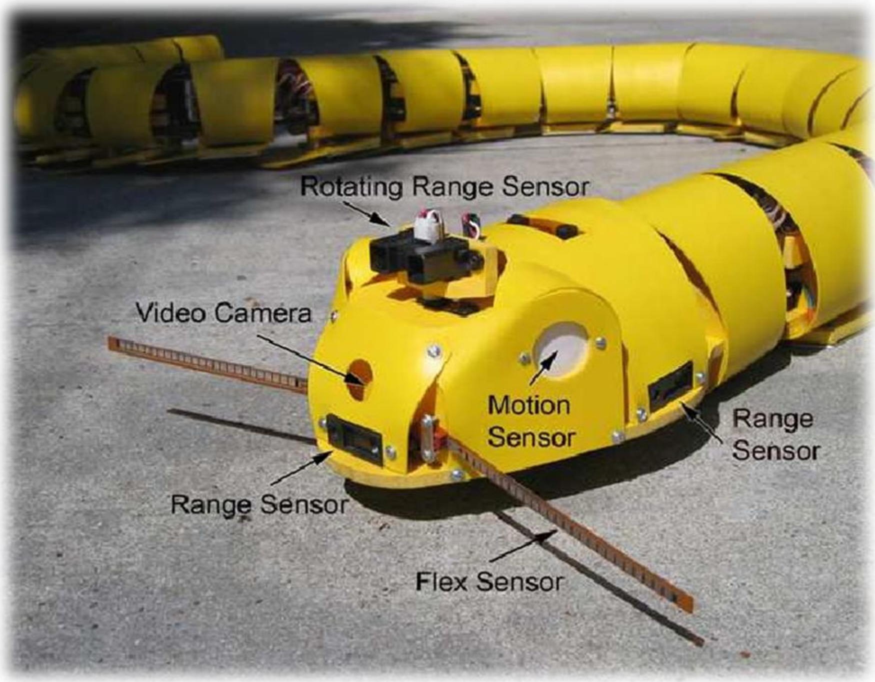


Figure 5.4: Head Part of Future Snake-Like Robot

(Source: http://www.engineeringpolymers.com/epbb/design1.html)

Fourth, the diameter of the fabricated snake-like robot can be reduced if the servomotors used are in smaller dimension. As the prototype goes smaller in size, it will be better when moving around as the friction force greatly reduced. It can also go into the holes if the hole is small.

Fifth, the snake-like robot also can be improved by replacing the back wheels by legs or without legs. The castor and wheels can be replaced by the omni-wheels which provide better movement and stability.

Figure 5.5: The Omni-Wheels

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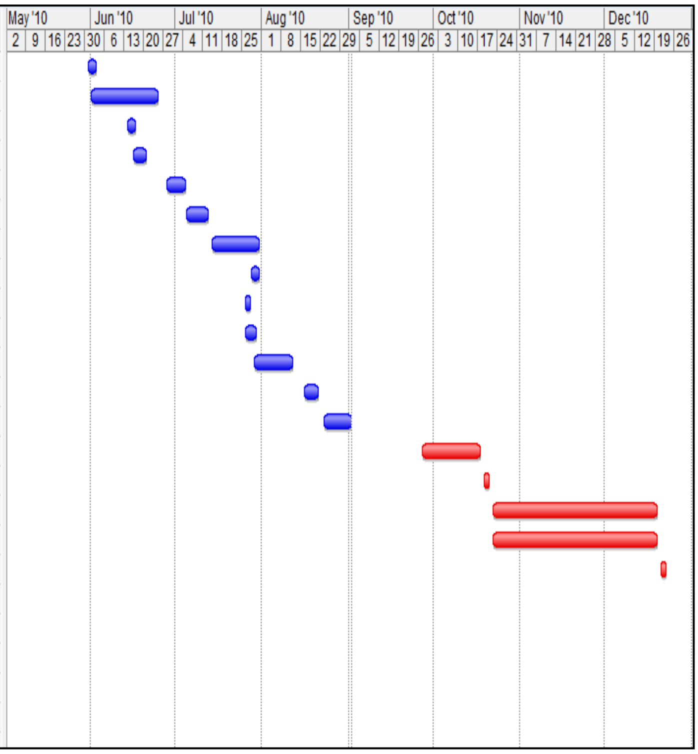
APPENDICES

APPENDIX A: Gantt Chart

	Task Name	Start	Finish	Duration
1	Project Introduction	Mon 5/31/10	Thu 6/3/10	3 days?
2	Project Planning	Tue 6/1/10	Fri 6/25/10	18 days?
3	Sourcing for Snake Robot Features	Mon 6/14/10	Thu 6/17/10	3 days?
4	Drafting on Project Objectives	Wed 6/16/10	Mon 6/21/10	3 days
5	Goal setting	Mon 6/28/10	Mon 7/5/10	5 days?
6	Literature review on Snake Locomotion	Mon 7/5/10	Tue 7/13/10	6 days?
7	Literature review on Joints and Design	Wed 7/14/10	Sat 7/31/10	13 days?
8	Literature review on Improvements on Snake-Like Robot	Wed 7/28/10	Sat 7/31/10	3 days?
9	Conceptual Design (Draft)	Mon 7/26/10	Wed 7/28/10	2 days?
10	Test Model	Mon 7/26/10	Fri 7/30/10	4 days?
11	Conceptual Design (Solidworks)	Thu 7/29/10	Thu 8/12/10	10 days?
12	Project report preperation	Mon 8/16/10	Sat 8/21/10	5 days?
13	Submission and presentation of project findings	Mon 8/23/10	Thu 9/2/10	8 days?
14	Improvise the Snake-like Robot Model	Mon 9/27/10	Mon 10/18/10	15 days?
15	Finalizing Model	Tue 10/19/10	Thu 10/21/10	2 days?
16	Building Up Final Prototype	Fri 10/22/10	Mon 12/20/10	41 days?
17	Troubleshooting	Fri 10/22/10	Mon 12/20/10	41 days?
18	Testing for The Prototype	Tue 12/21/10	Thu 12/23/10	2 days?



APPENDIX B: Test For Prototype

LIGO

Prototype Testing
Generalities

- ALL subsystems must perform prototype & final article testing to assure fit, function & performance (to a practical extent).
- Most subsystems will perform prototype testing for design optimization.
- Material or device development tests are of course required (e.g. sapphire absorption, detector characteristics, etc)
- QA tests on components (COC metrology, device testing, etc.) are also required
- Research tests are required for high development risk areas
- Subsystem Testing:
  What are the key component tests needed?
  (tests that may affect a design choice)
  - » Focus here is on prototype testing to resolve design issues which could influence major subsystem design choices, impact other subsystems or effect the system design or requirements trade-offs.

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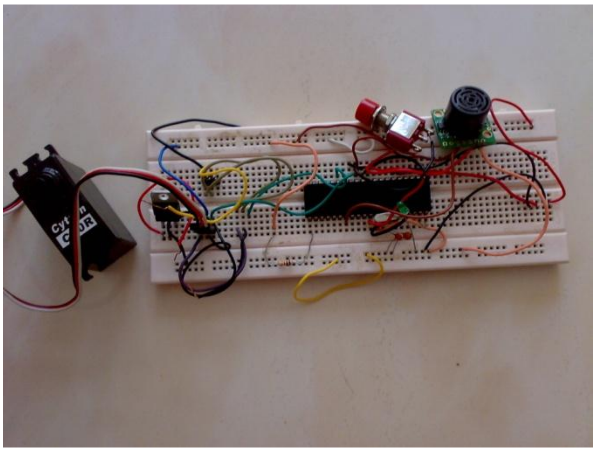
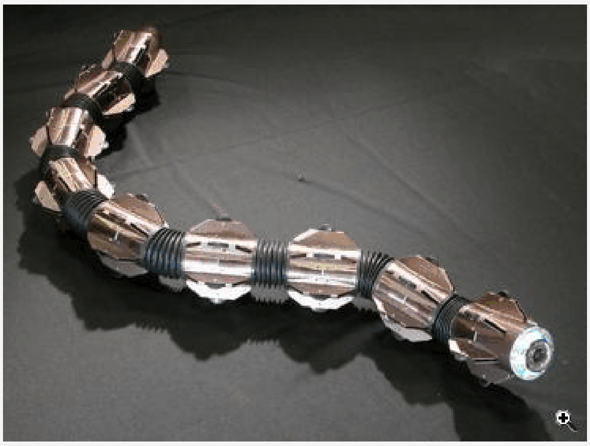
APPENDIX C:Pictures of Extra Components

LiPo battery 11.1 V 2200 mAh.

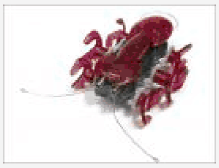


Microcontroller, ultrasonic sensor, and servo motor of electronics part

APPENDIX D: Articles on ACM-R5



Related Pictures



HEXBUG Micro Robotic Ant

Upward Mobility with REX

The Hirose-Fukushima Robotics Lab in Japan has invented an amphibious snake-like robot called "ACM-R5". The amphibious robot's form is quite similar to that of a living sea snake, as it allows both swimming and crawling. Like other snake-inspired robots, the ACM-R5 was developed for the purpose of performing search and rescue missions such as looking for people trapped in collapsed buildings and other tight spaces. The snake-bot could also help build underground optical fiber infrastructures, and inspect unreachable waterways and sewer systems.

Sea snakes live in water, and even terrestrial snakes sometimes show swimming abilities on the water's surface. The structure of ACM-R5 enables it to mimic quite successfully this amphibious movement thanks to its joints, which consist of a universal joint and flexible bellow (which can be seen in black in the image); it was developed on the basis of the previous model HELIX, which was designed for research of spirochete-like helical swimming.

A universal joint plays the role of bones, and bellows take the role of an integument. This joint structure gives ACM-R5 the ability to form a smooth shape, which is important for effective locomotion. To be precise, the universal joint has one passive twist joint at the intersection point of two bending axis, which help to prevent mechanical interference with the bellows.

One of the main challenges the researchers faced was creating a wavelike motion. In order to do so, they equipped the ACM-R5 with paddles and passive wheels around the body. To generate propulsive force by undulation, the robot needs resistance, since it glides freely in tangential directions but cannot in normal directions. Thanks to the paddles and passive wheels, ACM-R5 obtains that characteristic both in water and on ground, as can be seen in this video.

ACM-R5 has an advanced control system. Each joint unit has a CPU, a battery, and motors so it can operate independently. Through communication lines each unit exchanges signals and automatically recognizes its number from the head, as well as how many units join the arrangement. The system's dynamic structure gives operators the freedom to remove, add, and exchange units freely. Although ACM-R5 seems to have a promising future, its creators say that a large number of problems remain obstructing the realization of practical snake-like robots, both in software and hardware.

TFOT has also covered the OmniTread, a snake-like robot capable of climbing high vertical obstacles such as stairs, and the grasshopper inspired jumping robot, capable of jumping to a height of more than 27 times its body size. Another related TFOT story covers the Whegs series of robots, which use both wheels and legs to move at a relatively high speed and climb over obstacles.