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A Mechanism Concept and Design of Reconfigurable Robot for Rescue Operation

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Abstract- There seem to be a lot of robots that have been built up until today. Basically, the creation of robot is supposed to be a helper for a human. Robot will replace human whenever the task is really difficult or dangerous to be done by human. Recently, the robots that have been created were made reconfigurable. The purpose is to make the robot to function in more type of surroundings rather than only one surrounding. With this ability, the robot can be more useful to human, and less number of robot is required to complete a certain task. This report emphasizes on the reconfigurable robot project, where in this report, the robot that has been created is using the walking motion. It presents a description with pictures and construction drawings of a four-leg reconfigurable robot.

Keywords: robot, mechanism, reconfigurable, rescue, controller.

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A Mechanism Concept and Design of Reconfigurable Robot for Rescue Operation

Md. Nasir Uddin [α], Md Ahbabur Rahman [σ], M. M. Rashid [ρ], N A Nithe [ω] & JI Rony[¥]

Abstract- There seem to be a lot of robots that have been built up until today. Basically, the creation of robot is supposed to be a helper for a human. Robot will replace human whenever the task is really difficult or dangerous to be done by human. Recently, the robots that have been created were made reconfigurable. The purpose is to make the robot to function in more type of surroundings rather than only one surrounding. With this ability, the robot can be more useful to human, and less number of robot is required to complete a certain task. This report emphasizes on the reconfigurable robot project, where in this report, the robot that has been created is using the walking motion. It presents a description with pictures and construction drawings of a four-leg reconfigurable robot.

Keywords: robot, mechanism, reconfigurable, rescue, controller.

I. Overview

It is believed that a mechanism must be designed with a cosistent structure and invariant functions during operation. However, as the knowledge for mechanism design was surprisingly promoted in the past century and new design ideas are continuously evolutionary and born, people started to realize that a mechanism may be elegantly structured so that its configuration can be manipulated. The manipulation should be with multiple operation modes in order to collectively fulfil multiple tasks based on a sole mechanism. Because of the problem faced, people start to search to another alternatives, and the alternatives lead to creation of robot which can be reconfigured to adjust itself to suit to the environment. Such mechanism, which can change its configuration during operation, is normally so-called the reconfigurable mechanism.One of the objectives in the field of mobile robot is so that it can replace man to achieve a task whenever man are not capable of doing it. The building systems of a robot are created to operate in natural environment which are dramatic, unstructured and hazardous, which is very difficult for human. Nowadays, the reconfigurable mechanism have caught so many attention among people. It has also found excellent applications in various industries [1-3].

The study on reconfigurable mechanisms especially in structural design and kinematics has not been noticed even until the middle 1990s. From then on, some pioneering researches were started to surface.

After that, the attentions onto this topic gradually increase. Until today, the results of its relevant work have show progressing succesful work around this new mechanism concept.

Several new studies such as kinematotropic linkage, metamorphic mechanisms, mechanism with variable chains, and etc are leading the reconfigurable mechanism studies into a new level.

According to Merriam-Webster Dictionary, "configuration" is defined as "relative arrangement of parts or elements." Basically, the configuration looks at the relative arrangement. The relative arrangement that we discuss may be relative distance, relative angle, relative position, etc. The "parts or elements" are the links and joints of the mechanism and the "relative arrangement" are the relative positions, or further the relative motions, among the links and joints. Since the movement of the mechanism is depend not only by the arrangement of the joints but also their kinematic types, the configuration of the mechanism is described together by geometric arrangement and the kinematic types of its all kinematic joints [1-5].

a) Reconfigurable to robots

In our times today, we can see a lot of handful of commercially available mobile robots, wether used in industry factory, house, or for research in the laboratory. Most of all cases, the robot get around on wheels, or perhaps tracks. For example, the remote-controlled bomb disposal robot. It cannot be denied that the wheels are definitely the most sensible choice for the environments that these robots run in. Wheels are very easy to control since it act predictably given a flat surface to run on. Other than cheap in cost, the power systems behind the locomotion are very well developed and understood. Besides, the wheel's speed can be easily configured just by controlling the amount of torque applied to the shaft connected to the wheels. Thus, it can make the robot to run faster[3-6].

However, wheels may not fully function in some cases. There are environments in which wheels become useless such as getting up to stairs. Although today's large buildings that have uses for robot have uses lift to accomodate the robot, it is not practical to implement it to the outside world. Some estimates suggest that half

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of the earth's surface is presently inaccessible to wheeled vehicles[4-6].

Thus, engineers take the idea of using the walking leg as another alternatives to overcome this problem. Plus, the legs can be reconfigured to adjust itself to the environment. It is quiet difficult for a wheeled robot to suddenly change the tyres to a different direction compared to walking leg robot[5].

b) History

Starting from 1960's, most of legged machines have used a degree of computer control. Since its advent, this system technique has become greatly compacted and also be applied to the small machine.

Table 1 : Research issue concerning reconfigurable robot

Research issue concerning self reconfigurable robot	
The part and the whole diversity	Self-similar structure, boundary of a system, flexibility, multifunctionality; adaptable to change according to environment.
Morphogenesis	Logic of growth from homogeneity to heterogeneity; computational complexity
Robustness	Self-repair, graceful degradation, scalability
Self-reproduction evolution	Driving force of evolution, novel method of production co-evolution betweenmorphology and motion; acceleration of evolution
System architechture	Centralized/decentralized, homogeneous/heterogenous, local/global communication

The idea of building systems by homogeneous components comes from von Neumann's "Theory of self reproducing cellular automata". His model assumes complete homogeneity of initial modules. This is an analogy to biological systems. In the system, the cell division from a single cell after fertilization produce the differentiated cells. However, the biological system has it's own weakness as it need a large number of cells in order to form their bodies[4-7].

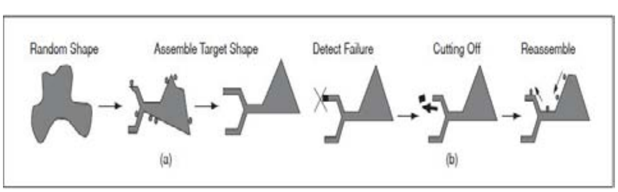


Figure 1.1 : shows self-assembly and self-repair. (N.Inou etal, 2003)

In 1988, a robot called CEBOT (Fukuda etal, 1990) was created and this is the first self-reconfigurable robot designed based on heterogenous components. It is composed of several different module. The module include transportation, rotational joint, telescopic arm, and grasping modules. Because of these modules combination, the CEBOT was able to perform a lot of different tasks[3].

Following the heterogeneous module, the study of reconfigurable robot with homogeneous module takes place. In the homogeneous system, all the modules are identical. A set of common rules should sufficiently describe the differentiation and behaviour of each module. Any module can be replaced with another module as soon as this is realized. This property makes the self-repair and self-reproduction schemes become easier.

c) Problem statement

People nowadays normally use a lot of help from the robot to do something that they cannot do by themselves. A lot of robot that we see in the market today have their own programme to do a task, but ufortunately every robot have their own limitation. As we can see today, the normal robot may be able to move into a certain direction only. Most of them cannot adapt to sudden change in environment. Whenever the surrounding change, such as from a floor to the staircase, the robot will become completely useless. In the end, people need to replace that robot with another robot that is built only for that task. This makes the time taken to complete the task become very slow. It such a waste of timeand a bit tiring.

d) Objectives

This paper approach four central challenges-

To develop a robot that will be able to reconfigure if it stuck in a changed environment. To design the mechanical system for the robot. To design the control system so that the robot can move efficiently without any problem. To test the performance of the robot.

II. Introduction

Reconfigurable robot is a robot where it can modify their shape and size in order to accomplish difficult mission. This capability is very desireble in many tasks. Such reconfigurable robot is very useful to overcome obstacles during doing the task. Reconfigurable robots offer a new approach in robotics.

The applications can be applied in many areas such as urban search and rescue, military reconnaisance and civil exploration [5-7].

This late few years, considerable progress has been made in the field of reconfigurable robotic systems. Normally, it would compromise with several segments that are connected with joint. The kinematic modes that we commonly see are multiple legs, wheeled and chain-track vehicle. According to study, the robot with multiple legs kinematic is less adapted compared to wheeled and chain-track vehicle robot. The multiple legs was said to be too complex since the structure has so many degree of freedom. Robots with wheeled and chain-track vehicle are usually portable since the adaptability to unstructured environment is high[6].

Usually for reconfigurable robot with multiple legs, the robots are facbricated based on modularity. Modularity consists of any number of identical interconnected units or modules. This system have advantages in term of manufacturing and robustness because of their homogeneity and redundancy. However in this type of kinematics, there are many degree of freedom (D.O.F) which make it complex and difficult to build. For example, a 14 degree of freedom (D.O.F) reconfigurable manipulator robot has been developed as a part of the Dockwelder EU project to perform in ship manufacturing industry.

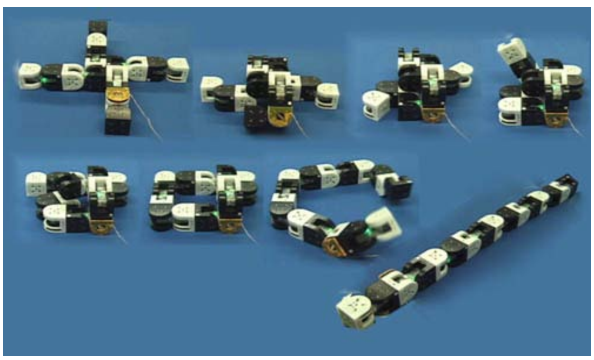
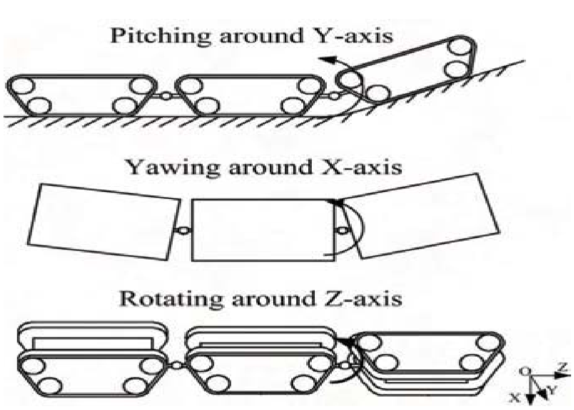


Figure 2.1: Picture of modular reconfigurable robot.



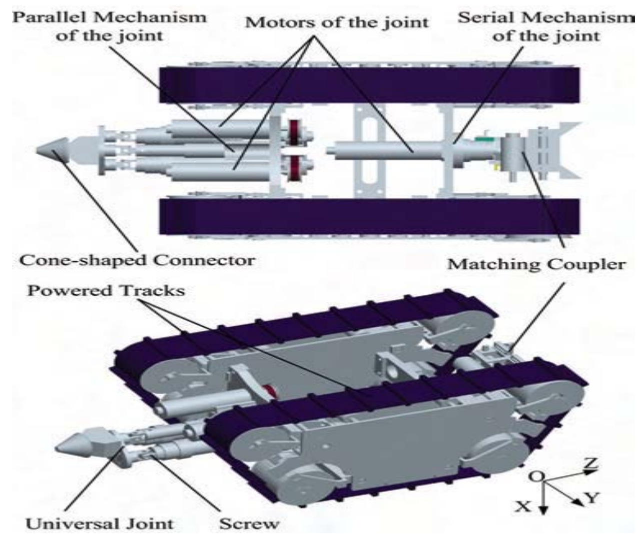


Figure 2.3 : Picture of wheel and chain-track vehicle

Nowadays, we can see a lot of robots designed by engineers to make it walk with four legs and even six legs.

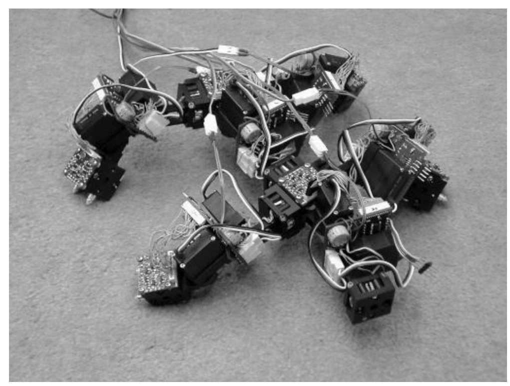


Figure 2.4 : Multi legs Robot

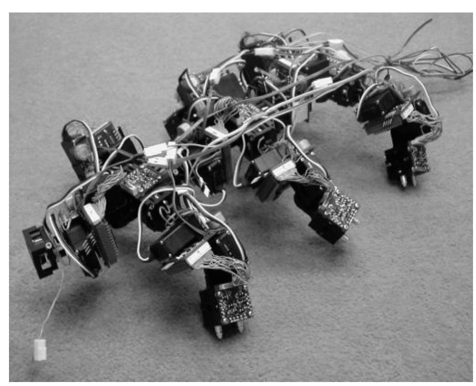


Figure 2.5 : Multi legs Robot

However, there are not much on focusing the reconfigurable legs. The objectives of this project is to improve the capability of the robots by making the legs of the robot to be adjustable according to the environment. The motor plays important role to realize this objective.

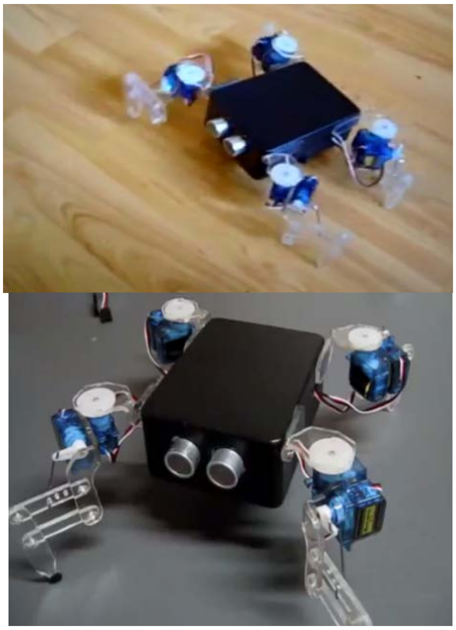


Figure 2.6 : four legs robot

This paper emphasizes the reconfigurable robot with four legs. It would not be complex enough since it will have several degree of freedom only. Each of the leg contain two link which will be connected through a servo motor. The principal of the movement of this robot is simple enough to understand. The servo motor will act as a joint and the movement of the legs will be based on the servo motor rotation or translation move.

Figure 2.7 : Servo motor

a) A chronological development of self reconfigurable robot

i. *Cebot (1988)*

CEBOT is the first modular self- reconfigurable robot that have been ever created in history. The modules were considered cellular in structure[7].

ii. *Fracta (1994)*

This robot (Murata etal,1994) is capable of reconfiguration, transportation in 2 dimensions, and self-repair[8,9].

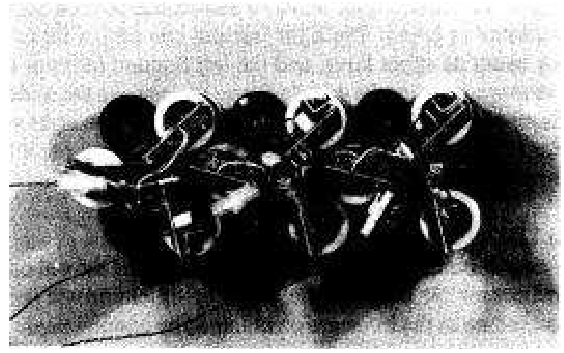


Figure 2.8 : Fracta modules

iii. *Metamorphic (1996)*

Metamorphic robots (Pamecha etal, 1996)are homogenous, 2 dimensional, and lattice-based reconfigurable robots. It has square or hexagon-shaped modules. Figure below illustrated the metamorphic robot.

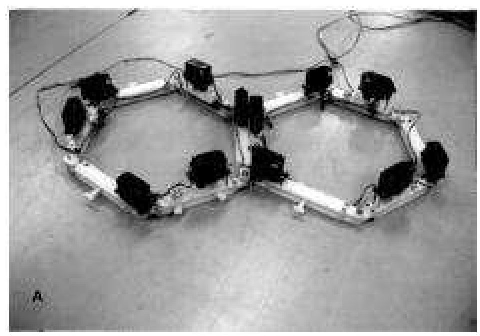


Figure 2.9 : metamorphic robot with hexagon-shaped

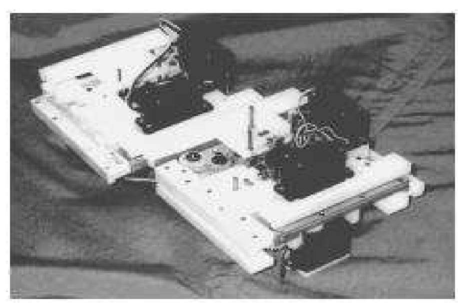


Figure 2.10 : metamorphic robot with square-shaped

iv. *3D-Unit (1998)*

3D-Unit (Murata etal,1998) is the first robot 3 dimensional robot that have been prototyped. The shape is taken from common hexagon-based. The modules are homogeneous type. They can change their local connection, communicate with neighbours, and process information. The figure below shows the illustration of the robot[9].

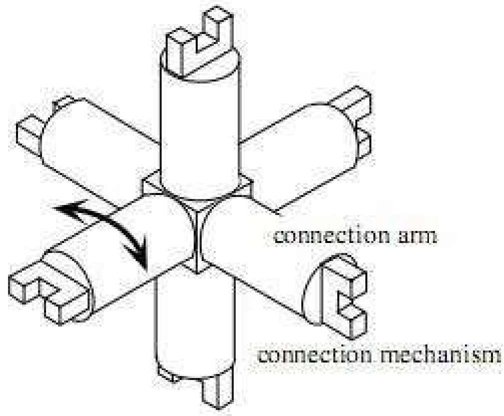


Figure 2.11 : 3D-Unit module

v. *Molecule (1998)*

The Molecule (McGray etal, 1998) is a robot based on 3D lattice. The modules comprised of two atoms connected by a bond while the modules are connected by electromagnets. Figure below shows the picture of molecule robot that was created[10,11].

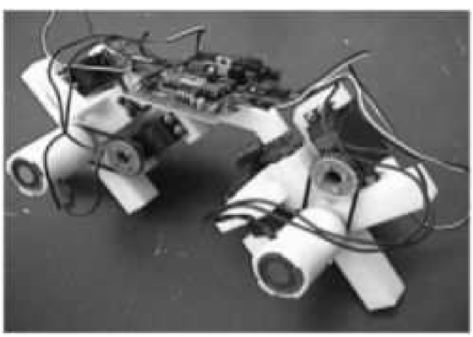


Figure 2.12 : molecule robot

vi. *Vertical (1998)*

This robot (Hosokawa etal,1998)has climbing stairs-like structures and have a capability to reconfigure against gravity. This robot also has potential to be used as to build a bridge structure for transporting cargo across a gap. There were four prototype modules that have been built[11-13].

vii. *I-Cubes (1999)*

As we can see in the figure below, these type of robots (Unsal etal,1999)consist of active link and passive cube. The cubes can be rotated, translated simultaneously in two direction, and also act as pivot joint for a moving link. These type of robots are very ptential to move over obstacles, climb stairs, traverse through tunnels and pipes, manipulate objects, formbridges and towers, and be utilized for space applications [12-14].

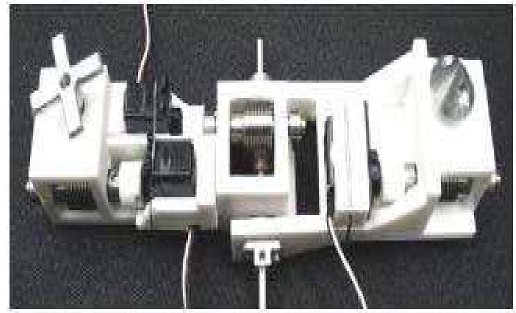


Figure 2.13 : i-cube link structure(Murata etal, 1998)

viii. *Crystalline (2000)*

Crystalline robots (Rus etal, 2000)are homogeneous square modules. Similar to muscles, this type of robot perform locomotion using expansion and contraction movements. Using a key and lock (channel) mechanism, the connection between the modules can be performed[14].

ix. *Polybot (2000)*

This robot, polybot (Yim etal, 2000) was built from a chain structure consisting of segment and node modules. The structure make the robot capable of several types of locomotions, including rolling, earthworm motion, and spider-like motion.

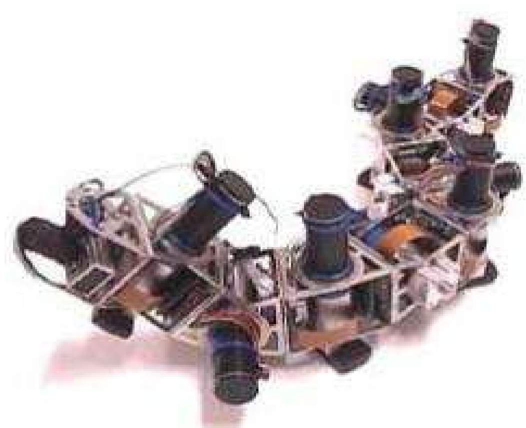


Figure 2.14 : polybot modules in a snake-like structure

x. *Conro (2000)*

The name CONRO was taken from the (CONfigurable RObot)(Castano etal, 2000). The modules are self-sufficient, homogenous, autonomus, three-dimensional, and form into chain-like structures.

The modules are connected by using a pin/hole mechanism[13-15].

xi. *Pneumatic (2002)*

The pneumatic (Inou etal, 2002) was inspired by animals such as worms and caterpillars with hydrostatic skeleton. The pneumatic modules are homgeneous, cubic-shaped structures with pneumatic actuators consisting of flexible bellows[15-20].

xii. *Telecubes (2002)*

This type of robot (Vassilvitskii, 2002) perform motion by expanding and contracting the sides of the cube. Permanent switching magnet is used for the connection mechanism[14-17].

xiii. *Chobie (2003)*

This robot, Chobie (Koseki etal, 2004) can reconfigure by means of slide motion and successive cooperative movements. This robot is potential in cooperative transportation, collection, and construction [15-18].

xiv. *Deformatron (2006)*

It is a homogeneous 3D modular robot (Stoy, 2006)with modules. The modules can form in two structures which are rigid lattice and flexible chain. This robot has limitations which are no communication between modules and the modules do not contain power source. Therefore, it need to be controlled externally[15,16].

xv. *Odin (2007)*

It is a hierarchical lattice-based robot (Stoy etal, 2007). It is built with two different types of modules which are cylinder-shaped and sphere-shaped. The link modules are able to communicate with neighbours, performing computation, and power sharing among modules[16,17].

xvi. *Morpho (2008)*

Morpho robot is based on deformation and transegrity model of cellular structure. The cells exert expansion and contraction forces on the entire structure. There are four types of modules where this robot can be assembled. They are active link, passive link, surface membrane, and interfacing cubes[18].

xvii. *Anatomy-based catomns (2008)*

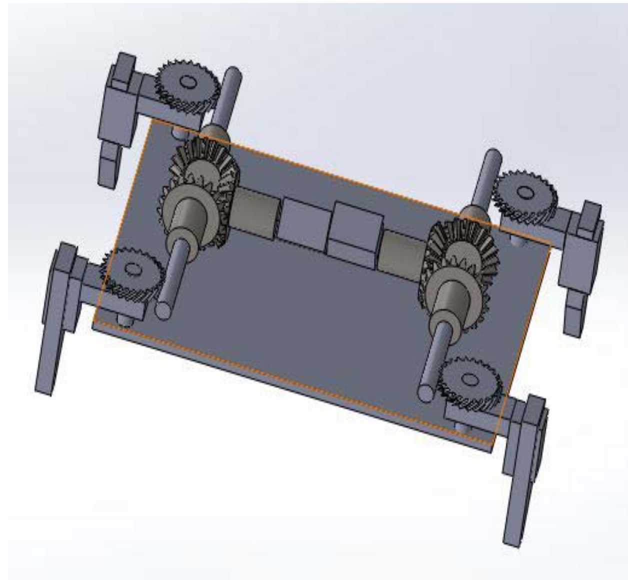
The claytronics project (Goldstein etal, 2004) is an inspiration for this anatomy-based catomns (Christensen D.J., 2008) robot being built. Truthfully, this type of robot has not been physically created yet. However, several promising simulations have been done using Open Dynamics Engine. This type of robot is expected to be able to performing computation, sensing points of contact with neighbours, sensing the gravity direction and local actuation. This robot can assemble a muscle-actuated arm, and grasping objects by using whisker feedback [17-20].

xviii. *Swarmorph (2009)*

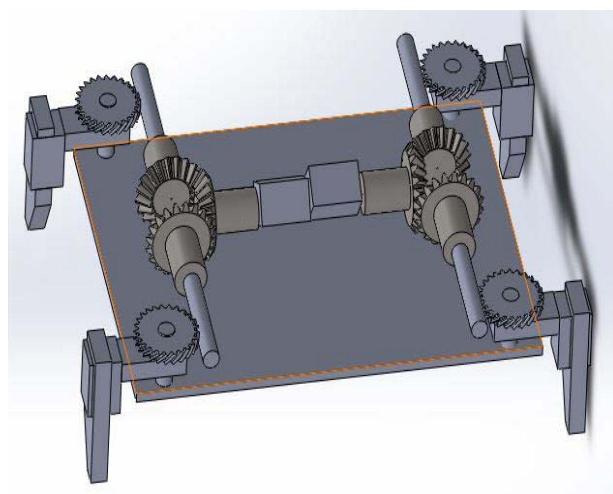
The SWARMORPH (O'Grady etal, 2009) project involves the development of a distributed scheme forgenerating morphologies using autonomous self-assembling mobile robots[18,19].

This technique is applied to the swarmrobot (s-bot) platform. However, there is a limitation of this self-assembling mobile robots. There is little control over the structure of the formed robot assembly. This work proposes a mechanism for control of the growth of morphological structures based on self-assembly. One by one, individual robots connect to the forming assembly.

III. Drawing of the Robot

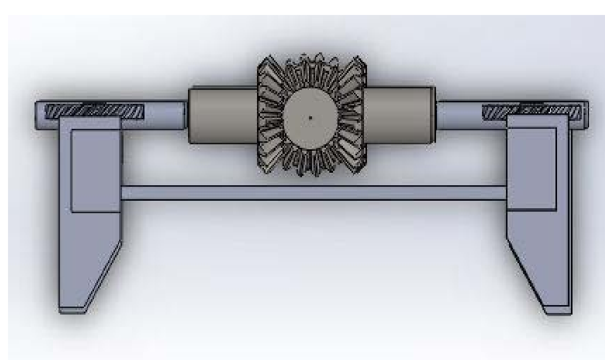


(a)



(b)

Figure 3.1 : (a) and (b) show thethe 3D robot design in solidworks



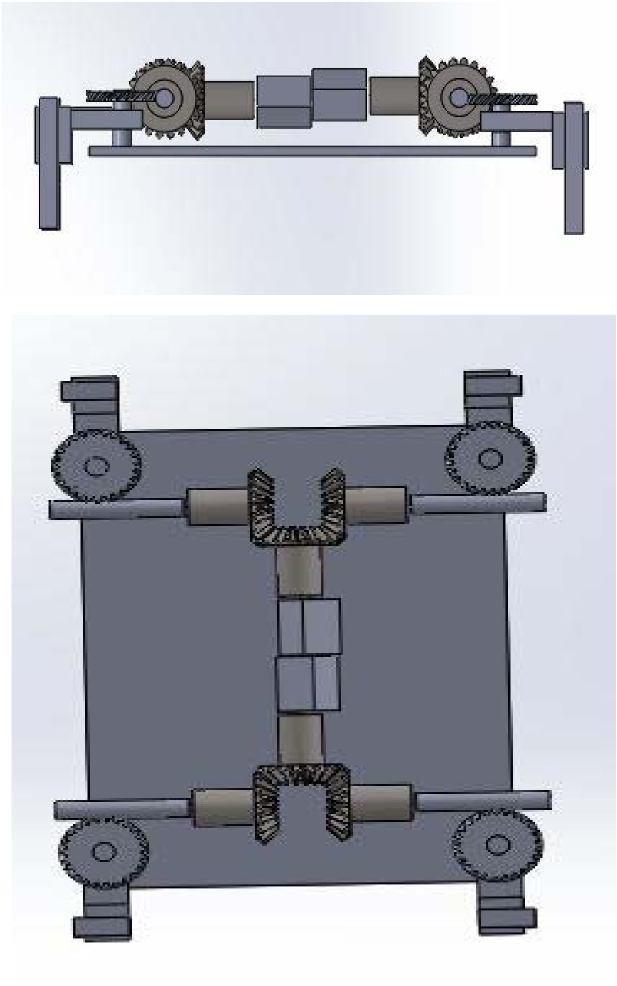


Figure 3.2 : show the robot in front,side, and top view

a) Design analysis

The main thing that should be consider when doing this project is about how the motion of the robot would be. In this project, after consulting with the supervisor, we agreed on building a robot with walking leg for this type of reconfigurable robot. A servomotor is a crucial part to determine the direction of the robot to move, wether forward or backward. The servo motor can be placed into the robot once the code have been made and have been transferred through arduino board. For the robot to turn the leg, we also need a motor to turn the bevel gear. The rotation motion from the bevel gear will be tranferred to a worm gear. Since the leg is attached to the worm gear, it will automatically turn the direction of the leg once the worm gear start rotating.

The robot also consists of inertial sensor that will detect when the robot fall or flip, so that the robot will be able to reconfigure and walk again.

b) Force division between the legs

The whole body of the robot will stand on two legs while it is taking forward motion. Thus, the whole weight will be divided between these two legs equally so that the robot will stand balanced.

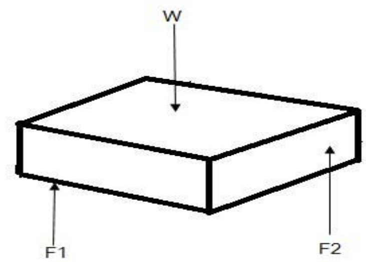


Figure 3.3

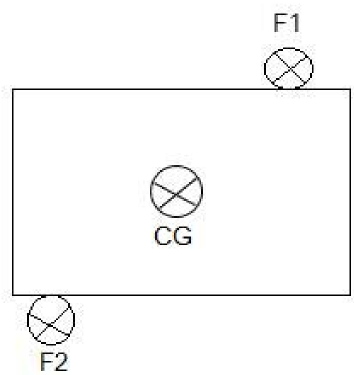


Figure 3.4

Figure 3.2 and 3.3 show the forces that are equally divided between the two sides of the frame.
By using the formula :

$F1 + F2 = W$

$F1 = F2 = W/2$

c) Bill of materials

Table 2 : Bill

Materials	Price (1 unit)	Quantity	Total
DC Servo motor	USD10	6	USD60
Worm gear	USD2	4	USD8
Bevel gear	USD3	6	USD18
Plastic	USD10	1	USD10
Inertia sensor	USD67	1	USD67
			USD163

d) Selection of components

i. Servo motor

Figure 3.5 : dc servo motor, model/SKU E0695

General specifications

Storage temperature range : -20°C ~ 60°C

Operating temperature range: -10°C ~ 50°C

Operating voltage : 4.8V ~ 6V

Mechanical Specification:

Description	Specification
Overall dimension	40 x 20 x 37.5mm
Limit Angle	360°±10°
Weight	38±1g
Connector wire gauge	#28 PVC
Connector wire length	320±5mm
Horn gear spline	25T/ψ5.80
Reduction ratio/td>	240:1

Electrical Specification:

Description	5V	7.2V
Operating speed (at no load)	0.14sec/ 60°	0.12sec/ 60°
Running current (at no load)	20mA	25mA
Stall torque (at lock)	3kg.cm	3.5kg.cm
Stall current (at lock)	300mA	350mA
Idle current (at stopped)	4mA	5mA

Control Specification:

Description	Specification
Operating frequency	50Hz
Operating angle	90° (from 1000 to 2000 usec)
Neutral position	1500 usec
Dead band with	4 usec
Rotating direction	Counter clockwise (from 1500 to 2000 usec)
Pulse width range	From 800 to 2200 usec

Figure 3.6 : Specification

ii. Set of worm gear

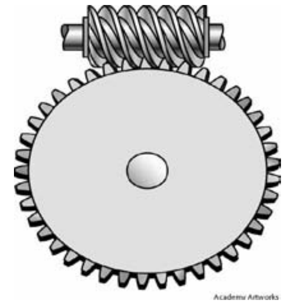


Figure 3.7 : worm gear

iii. Bevel gear

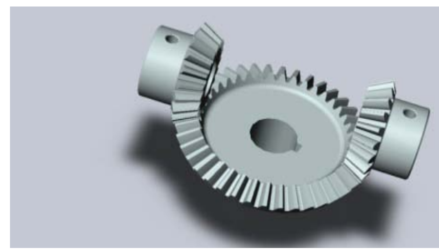


Figure 3.8 : bevel gear to transmit the rotation motion

IV. Conclusion

The design of the robot for this project is not achieved just by thinking once. The redesign and the development of this reconfigurable robot is always challenging. In the process of making this project, some fundamental design principles which are applicable to all components of the system became more clear. The very first important step that we should be aware of before beginning the implementation of a robot systemis to go through a thorough design, analysis and also the specification. It is crucial in order to verify wether the implementation will work or not.

Upon completing this project also, I also learned that the simplicity of the design should not be overlooked. As an engineer, it is our job to make something which is easy for humankind to handle but at the same time give a maximum output. In designing, creativity and experimentation are two of the most valuable design tools available until today. From the research that have been made, it can be concluded that the reconfigurable robot is one of the most desirable technology that people need today.

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