Development of Hexapod Robot with Manoeuvrable Wheel

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Abstract

The necessity to utilize the usage of the robot cannot be denied since there are a lot of natural disasters occur everywhere around the world. The robot that can be used in this situation may be a remotely controlled by human or moves autonomously. Hexapod robot is one of the robots used in this situation because of its stability and flexibility during the motion on any type of surface. Hexapod robot is a robot that has six legs to walk or move. Since the robot has many legs, the robot is easily programmed to move around because it can be configured to many types of gait such as alternating tripod, quadruped and crawl. There are various designs of hexapod with certain function and advantages. In this research, a hexapod robot with manoeuvrable wheel is designed and developed. The purpose of the hexapod robot with manoeuvrable wheel is to ease the movement either on the flat surface or on the inclined surface. On the flat surface, the robot will move using the manoeuvrable wheel while on incline surface, the robot will climb using its legs. The decisions for the robot to use either wheel or legs are based on the sensory devices and algorithm develops at the controller attached to the robot.

Keywords: Autonomous, Manoeuvrable Wheel, Programmable, Hexapod

1. Introduction

The study of this project is to develop a new hexapod robot which is quite different from the existing product in the market today. This project is mainly about a hexapod robot with manoeuvrable wheel which is a combination of six legs robot and mobile robot. Hexapod robot is one of most statically stable and posses a great flexibility while standing or moving due to its movement using six legs that can easily manipulated. Mostly, for every robot created will be biologically inspired from behaviour of animal or insect especially on their walking behaviour. For the hexapod robot, cockroach and the stick insect are the most commonly used and have been ethologically (scientific study of animal behaviour) and neurophysiologically (study of nervous system function) are extensively studied by other people previously. In contrary the wheeled mobile robot is a mechanical wheels vehicle which has capability to move around the ground using motorized wheels. These two types of robot are classified as mobile robot. Therefore, it will be great to produce new mobile robot that has variety of movement either walking using its legs or manoeuvre using wheels.

2. Literature review

This section will discuss about the journals and articles which are related to this project. The journals studied will cover the hexapod robots that have been previously developed by

the institutions, individuals or companies. Furthermore, the section also explains about the hexapod robot that already published and available in the market nowadays.

2.1 Background of Hexapod Robot

A new technology emerges faster by adapting a new idea to develop a new design, prototype and new system control. One of the technologies that has high pace advancement such as the technology of hexapod robot which has increased from a simple function, size and weight to a various functions, bigger size and weight. LAURON is the example, a six-legged robot which has been developed at the Forschungszentrum Informatik Karlsruhe (FZI) in Germany. The first LAURON project was started in early 90s and continuously improved until the latest project called as LAURON IV [1].

The hexapod robots have various types and functions. Some of them are quite simple in the design and controller, while some of them possess a complex design and controller. For instance, in the tele-operation system, the robot [2] is capable to perform various tasks using a remote control at hazardous and narrow area which is cannot be covered by human beings. The operations are search and rescue, monitoring radiation hazard and planetary exploration. However, the most important factor to accomplish the task in a shortest time is the speed of the robot. The movement of robot by the wheels is faster than movement of the robot by legs. Thus, one method to increase the speed of hexapod robot is by equipped it with maneuverable wheels.

2.2 Literature Review of System Design

The system designs of hexapod robots from each journal have their own differences. RHex developed by [3] is a different robot compared to other hexapod robot because it is actuated by brushed DC motor. The motors that are used at this robot are Maxon type motor with a 33:1 planetary gearhead powered by a 24V NiMH battery. The design of the leg is one degree of freedom and half-circle. According to the author, the method is easy to build and maintain the robot and no sliding friction during spring displacement. This design is most suitable for stair climbing.

Another hexapod robot, Bill-Ant-P robot done by [4] is made of 6061 aluminum and carbon fiber sheets. It uses MPI MX-450HP hobby motors for its reliability, high torque, and affordability movement. The motor have 8.37kg-cm of torque, can rotate about a 60 degree in 0.18sec, and has a small internal dc motor consumes 1125mW of power at stall torque.

In the journal done by [5], a robot called as Gregor has been developed. The Gregor robot development model has Autodesk Inverter 9.0 to define properties of parts such as mass. Rhinocerus 2.0 software is used to coordinate of the constraints and model the robot that can be easily exported into the dynamic simulation environment which is also used the same software.

MSR-H01 hexapod developed by Micromagic System is built from 26 precision laser-cut 5053 aluminum body and leg components. It is controlled by using a p.Brain-HexEngine and used eighteen servomotors from three different types of servomotors. The link for the robot is Bluetooth with quality 99.2% from 17215 packets sent, 17083 packets are acknowledged [6].

Hexapod robot developed by [7] used Devantech SD-21 board to control 18 servos by interfaced with the preferred microcontroller, which is Arduino Decimilla board. The software that is used to control the servo controller is Matlab. In other to control the robot leg, Jacobian inverse matrix method is used to define the angles and leg position.

The hexapod robot's journal done by [8] states that the hexapod used smart actuator module Dynamixel RX-28 by ROBOTIS as joint actuators. The control board based on the

16-bit AVR ATmega128 and able communicates with external computers by RS232. The main controller communicated with the robot by sending and receiving data packets to the motors and sensors

The walking robot Ragno developed by [9] is 33 cm long and 30 cm wide and 2.15 kg weights. It has four layers control architecture where the first is at off-board to compute the appropriate control signal for all leg's joint and send control commands to robots. The second layer is on-board control layer that interprets commands from first layer and sends to leg controllers. There are six leg controllers that work simultaneously and control the inputs send to them. The robot has a double axis accelerometer and a gyroscope to measure the trunk orientation in a 3D space. The on-board and off-board parts of the control system communicate by means of a Bluetooth connection.

2.3 Literature Review of Hexapod Robot Movement

The robot's legs movement or method of forward motion using hexapod legs is called gait. There are varieties of gaits available and the famous gait used by hexapod robot is the tripod gait. In the tripod gait, three feet of hexapod is always in contact with the ground for the whole time. For example, the hexapod robot that used the gait method is [10].

Method of movement for Gregor 1 hexapod robot designed by [7] is the locomotion control inspired from the biological paradigm of the Central Pattern Generators (CPG). CPGs are neural networks that produce rhythmic patterned outputs without sensory feedback and biological paradigm means medical model.

In the journal by [2], there are three types of robots motion. Those are walking mode, lifting mode and shifting mode which can be selected by the user. However, only the walking mode is selected in this subchapter to be explained further. The author used tripod gait is used because it is stable compared to other gaits for hexapod robot. The first step in gait control, the initial posture of all legs is decided, and the position of the leg tip is defined as the "reference position". Then, six cylinders of the legs movement are generated so as to be included in the work space with the center of the robotics base is set as the reference position. Thus, the center of rotation of the motion is obtained. Then, the diameter of each cylinder is reduced so that it may be proportional to the distance between the centre of robot (COR) and each reference position. The desired path of each leg is generated along the circumference of the cross section of the cylinder which is perpendicular to the line from the COR to the reference position and passes through the reference position. Finally, the angles of all joints are generated at every control period so that each leg tip might track the desired path and the center of body might have the provided velocity, and transmitted to the robot.

The hexapod robot in the research done by [8], the hexapod robot also use tripod gaits, the body of the robot and ground in parallel mechanism and supported by three legs. This journal is focused on the kinetics movement of robot and the locomotion system. It is about the calculation on how the hexapod robot moves. The important aspects taken into consideration are the inertial frame, locomotive referenced coordinate system of chassis and coordinate system on the coxa.

In the disaster recovery [11] , the robot used two types of gait which help it move at all kind of terrain. On even terrain, tripod gait is used while on uneven terrain, wave gait is used. The most rear leg is start moved forward in succession to all the legs. This gait is highly stable since a leg is lifted at a time. The reason for choosing the gait is the greatest stability edge for uneven terrain navigation. Wave gait locomotion adopting the control algorithm with an angular position input and torque command output. Each foot is moved at same length as analysis from the main body at each integration time interval.

Dash robot by [12] can move at 11 body-lengths per second or 1.5 meters per second. The weights of entire system is 16.2 grams (10x5 cm body dimension) with include weight of battery, electronics, microcontroller, motor driver, and Bluetooth communication module. The alternating tripod gait is used with 10 cm wide and 5 cm tall of legs. When it moves, the center of mass follows a roughly sinusoidal trajectory, which is stable sinusoidal motion.

Two statically stable gaits is programmed for Ragno robot [9] that are exploits a simple crawl and a tripod-like gait. The crawl is used for lower speed by transfer one leg per time while tripod gait is the fastest stable gait with three legs placed on the ground at a time. The configuration of the robot's gait is shown in Figure 1.
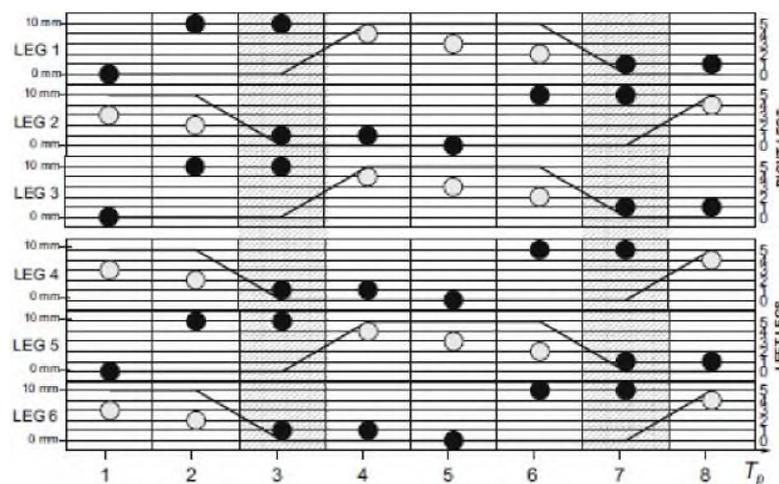
Figure 1. Tripod-like Gait Designed by [9]

With a single step length which is the distance between two consecutive footholds of one leg set to 50 mm, the average walking speed of the Ragno robot by using the tripod movement is 0.09 m/s.

3. New Physical Model of Hexapod Robot

This section discusses about the details on how the hexapod robot is being developed. The development starts by design and sketch a several design of hexapod robot with different aspect and criteria until to the design of the controller before the hexapod robot is being test.

The designs of hexapod robot have been sketched in eight different designs and every design has it different criteria, specifications, shapes, advantages and disadvantages. The eight designs of the hexapod robots are shown in Table 1.

From the designs mentioned in Table 1, the specifications for each robot are depicted in the Table 2. The specification of the robots cover a few main aspects such as the amount of motors used, legs available and the wheels attached to the robot's body.

Table 1. Eight Sketches of Hexapod Robots

Design 1	Design 2
Design 3	Design 4
Design 5	Design 6
Design 7	Design 8

Table 2. Design Specification Table

Design	Specification
1	• Has 12 servomotors • Has 3 wheels at bottom of body • Use a DC motor
2	• Has 16 servomotors • Has 4 wheels at bottom of body • Use 2 DC motor
3	• Has 12 servomotors • Has 4 wheels at bottom of body • Use a DC motor
4	• Has 12 servomotors • Has 5 wheel, 4 at the legs and 1 at bottom • Use a DC motor to drive the wheel
5	• Has 14 servomotors • Has 3 wheels, 2 at legs and 1 at bottom • Use a DC motor to drive wheel
6	• Has 18 servomotors, 6 for drive wheel at each leg • Has 6 wheels, one at each leg
7	• Has 14 servomotors, 2 use for drive the wheels • Has 6 wheels at 6 legs
8	• Has 14 servomotors, 2 use for drive the wheels at front leg • Has 6 wheels at 6 legs

3.1 Design Selection

From the eight designs mentioned in Table 1 and 2, one of the best designs should be selected before it is drafted into a detail dimension and size. The method that is used to select the design is based on House of Quality because the comparison between each design can be clearly determined. In addition, every design has different specifications, aspects and shapes, and the best design defined based on the researcher's own observation and opinion.

From all designs that have been sketched, the design 8 is selected as the best design because of the design possesses less overall weight. It only exploits fourteen servomotors to move either by using legs or wheel. The design of the maneuverable wheels and legs make the robot easy to move and climb. Besides that, the combination of the wheels and the legs will make the hexapod robot move more stable. This design has higher rating from the comparison that has been made.

3.2 House of Quality

In order to select the best design of hexapod robot in this project, House of Quality is employed. House of Quality is one of the comparison method used to select the different the

design in this project. The house of quality is a diagram that is used to define the relationship between the customer needs and the product capabilities or requirements. This project's house of quality is shown in Figure 2.

Based on the House of Quality, there are two different requirement which are; design requirement and customer requirement. The measurement used in design requirement are by using wheel on the flat surface, total number of parts and servomotors, overall mass and dimension, configuration of gait, types of material use and selection of controller. The measurements used in customer design are speed, quality, stess or pressure, shape, number of part and cost. The rating of the hexapod robot's design from positive strong, positive, negative, to strong negative is determined by the studied on the literature review of the hexapod robot's journals. The design requirement and customer requirement is also compared to give a rating for the most important aspect to the less important.

House of Quality

Legend: ● Strong + ○ Positive X Negative # Strong -

Customer Requirements (What)		Importance (1-5)	Use wheel on flat surface	Number of parts and servomotors	Overall mass and dimension	Configuration of gait	Type of material use	Selection of controller	Design	Design 1	Design 2	Design 3	Design 4	Design 5	Design 6	Design 7	Design 8
Improve	Speed	●	●	○	○					○	●	△	○	○	△	●	●
	Quality	○		△		●				△	△	●	△	○	△	●	●
	Stress/pressure	●			●		●			○	●	●	○	△	△	○	●
Reduce	Shape				●		△			○	●	△	●	●	●	△	△
	No. of part	△	○	●	△	△	○			△	○	△	○	●	△	○	○
	Cost		○			○	●			●	△	○	△	○	●	△	●

Figure 2. House of Quality

3.3 Hexapod Draft using Solidworks Software

After the best design is chosen, the size and dimension of the each part of the hexapod robot need to be determined so that it can be drawn using Solidworks software. The purpose of utilizing this Solidworks software is because Solidworks can provide a detail, real images and walkthrough overviews for demonstrating design. Solidworks is a fast drawing detailing software which can reduce time-consuming in the overall development process especially in true product detailing portion. It is not only just for drawing but also can be used to analyze the simulation, motion, animation, and other things. Faster analysis can be achieved by analyzing the entire structure to obtain the strength, stress, load, force and pressure of the selected material. Indeed, Solidworks support many types of files to import or export to other software format, for instance to .stl file which can be used at rapid prototyping machine (RPM).

The hexapod robot consists of body, two parts of legs (Femur and Coxa), body holders, servomotors and wheels. Each part is designed in single part file then it will be assembled as

one design to build a hexapod robot. The views of each part of the robot are shown in Figure 3 to Figure 6.

The design of each part is analyzed by using Solidwork's simulationXpress to calculate the displacements, strains, and stresses of the system based on the material, fixtures, and loads. A material fails when the stress reaches a certain level on the material strength because each material has different stress levels. SimulationXpress uses linear static analysis, based on the Finite Element Method, to calculate stresses. Linear static analysis makes several assumptions to calculate stresses in the part. Using the displacements, SimulationXpress calculates the strains in various directions while using stress analysis, the forces and pressure is calculate base on material and fixture.

Stress is used to measure the strength of a material in how the material can stand without undergoes on physical change when pressure or force is applied. The formula use to calculate the stress is   , which is F is force and A is cross sectional area. In addition, stress is dividing into two types that are tensile strength or known as fracture stress and yield strength or known as yield stress. Stress will cause strain which is the stretched of the object. The formula for strain is   , which is is the original length and is the different of length stretched. The relation between stress and strain will obtain Young's modulus in order to measure the stiffness of a material. The formula is given by $E = \frac{\sigma}{\epsilon}$ with units as N/m^2 or Pa.
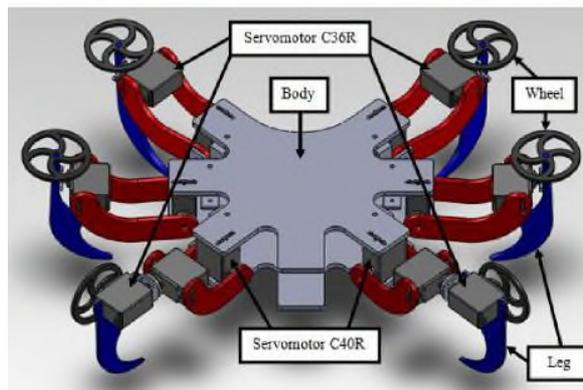
Figure 3. Hexapod Robot Isometric View Draft
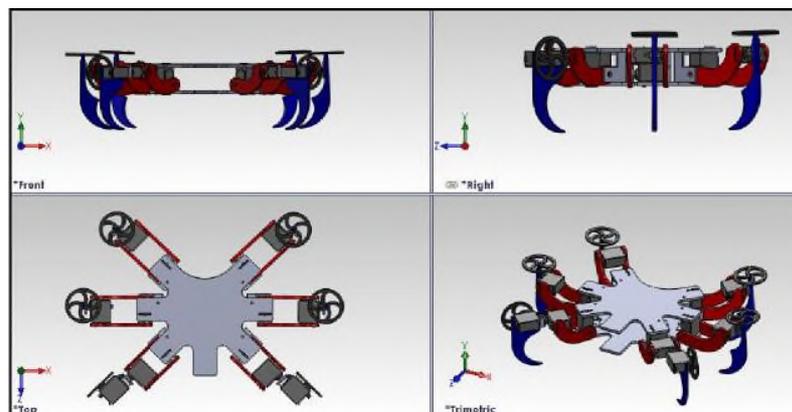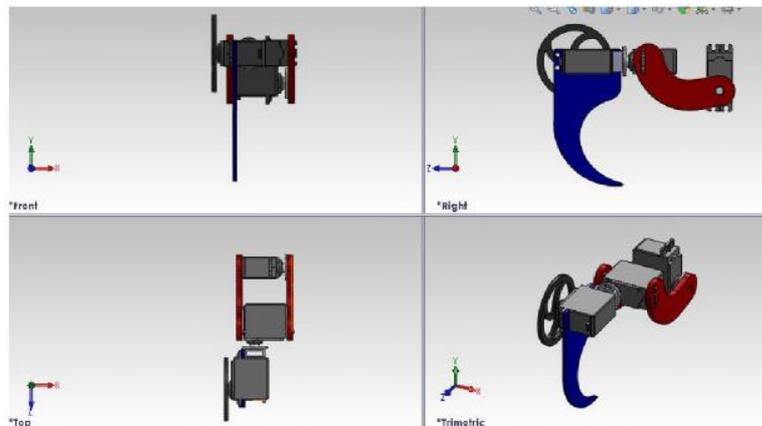

Figure 4. Hexapod Robot Multiple View

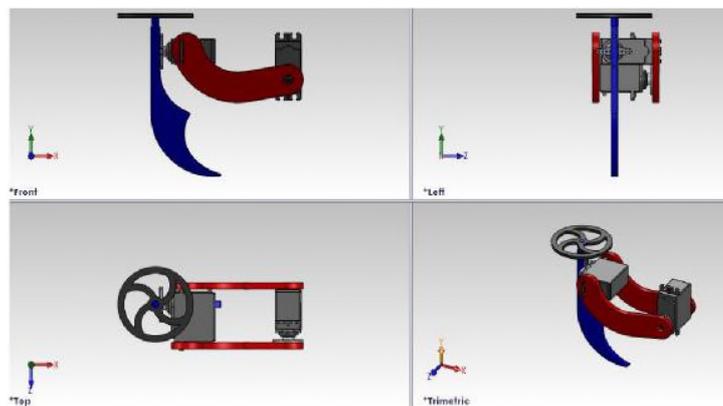**Figure 5. Hexapod Front Leg's View**

Figure 6. Hexapod Middle Leg's View

3.4 Component Selection

3.4.1 Selection of Motor

In order to actuate or move a robot, some components like motors are needed. There are many types of motors such as AC motor, DC motor, stepper motor and servomotor. For this project, servomotors are used and there are three types of servomotors used. The motors are C36R, C36R (360 degree) and C40R as depicted in Figure 7. The Cytron servomotors are selected due to the lower cost compared to other servomotor supplier but the performance are quite same with other servomotor. The total servomotors used to accomplish this project are fourteen pieces. The target for the servomotor selection is to make the hexapod robot can move. The servomotor is the low cost actuator used in educational robotic project. The specification of the servomotor is shown in Table 3.

Figure 7. Servomotor C36R and C40R

Table 3. Servomotor Specification

Type	C36R	C40R
Gear material	Plastic	Plastic
Speed (sec/60deg)	0.16/4.8V ,	0.16/4.8V, 0.14/6.0V
Torque (Kg.cm)	3.5/4.8V, 4.5/6.0V	6.0/4.8V, 7.0/6.0V
Size (mm)	40.8x20.18x36.5	40.2x19.8x36
Weight (g)	36	38
Pulse width range	0.546ms to 2.4ms	0.54ms to 2.4ms
Rotation angle	180 degree	180 degree
Designed	Closed feedback	Closed feedback

3.4.2 Selection of Controller

The controller used to control the servomotor is 16 channel servo controller (SC16A) as shown in Figure 8. By using this SC16A, the 14 servomotor can be controlled simultaneously in a single board. The controller also provides sample GUI software to control from computer. The size of dimension is 8.2cm x 4.7cm.

Figure 8. 16 Channel Servo Controller

For the movement of the hexapod robot, Programmable Integrated Circuit (PIC) is used and run through the programming MikroC code. There are two conditions to control the servomotors which are by connect to the PIC16F877A or by using servo controller but it will need other compiler like MPLAB but . Thus, the PIC16F877A is chosen to be used.

3.4.3 Selection of Sensor

Sensor is a device use to sense something to control the movement of robot. In this project, the infrared sensor is chosen because it is high sensitivity, detection accuracy and process for experimental robots. There are two types of infrared sensor that is passive (PIR) and active (emit an IR beam and detect reflection). The active infrared sensor type is used for the hexapod robot because it can detect the presence of object in certain distance in front of the sensor. The sensor used as shown in Figure 9.

Figure 9. Distance Infrared Sensor

3.5 Hexapod Robot Hardware Model

The hardware of the hexapod robot is fabricated after the design and analysis on Solidwoks has been done. The hexapod robot is fabricated part by part using a few simple and low cost mechanical tools such as saw, grinder, hand drill, knife and ruler. When all parts have been fabricated, all the parts and components are assembled together to complete the hexapod robot. The hexapod robot hardware are shown in Figure 10.

Figure 10. Hexapod Robot using Legs and

Wheels 3.6 Movement Selection

Hexapod robot can move in variety gaits because of it has six legs. The surface and the design of the leg will influence the robot movement. Thus, the movement of hexapod robot with maneuverable wheel is proposed by using combination of mobile robot and tripod gait. There are two conditions for the robot to move which is by using the legs or by using maneuverable wheel. Firstly, the robot will stand up when the switch is on. Then, the sensor will operate to detect the condition in front of the robot. If there is flat surface, the maneuverable wheels is selected. The hexapod robot will move the legs to set in wheel moving condition and start moving. Next, if the sensor detects an inclined surface, the robot will stop and the legs are selected to be used. The robot will stand up and start to walk through the inclined surface by using tripod gait. It is starting with right front leg and follows by left front leg. The sequence of the legs is repeatable until the sensor change the conditions which is not detect inclined surface so it return to use maneuverable wheels.

4. Result and Discussion

This section will discuss the result of hexapod robot have been done. The results cover the ideas that have been translated into sketches, design, programming, simulation controller and prototype. Several experiment and analysis in this project is to show how the problems are solved and the toughness of the robot developed.

4.1 Design Analysis

Every parts of hexapod robot is required to be analyzed to find out either it is strong enough to hold some force or pressure before the overall parts are assembled. Simulation using software is a way to reduce time and cost before the prototype is being fabricated. Thus, by using SimulationXpress that is provided inside SolidWorks software, the strength of the part that has been designed can be analyzed.

In this simulation, there are three types of analysis is created which are deformation, displacement and stress analysis. In the deformation analysis, the movement of the part when applied by some force or pressure can be animated. The effect can be seen and can be play in slow or fast motion. For the displacement, it is show to which area of the part is move from the initial condition. The high impact will give it higher displacement and more critical point. The color of the parts show the effect which is from less to high that is from blue to red. Different situation occur for stress analysis, the effect of color from blue to red show which area has less stress to higher stress.

4.1.1 Stress Analysis of Hexapod Robot Parts
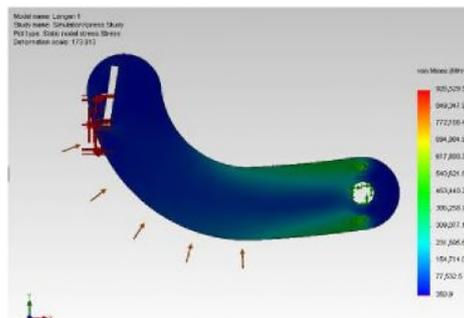
Figure 11. Leg (Femur) Stress Analysis
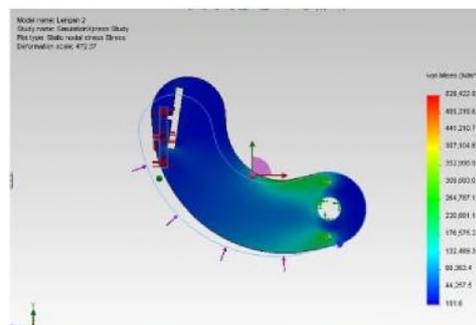
Figure 12. Front Leg (Femur) Stress Analysis
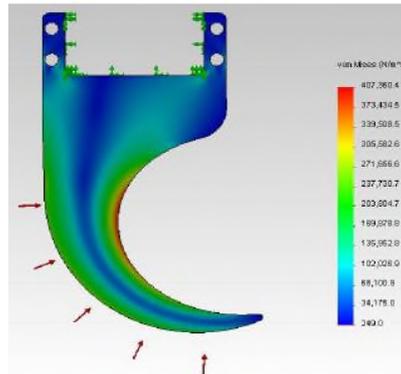
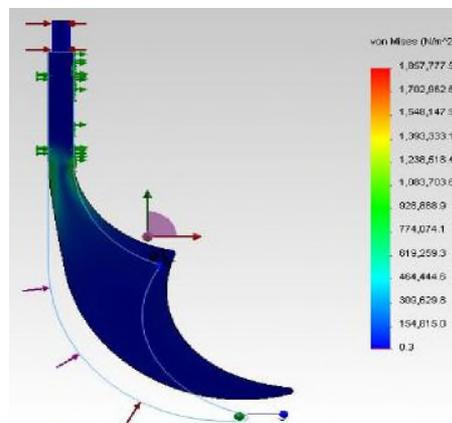**Figure 13. Front Leg (Tibia) Stress Analysis**

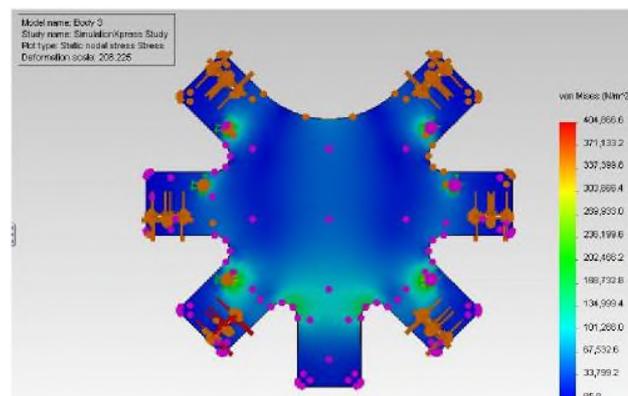**Figure 14. Leg (Tibia) Stress Analysis**

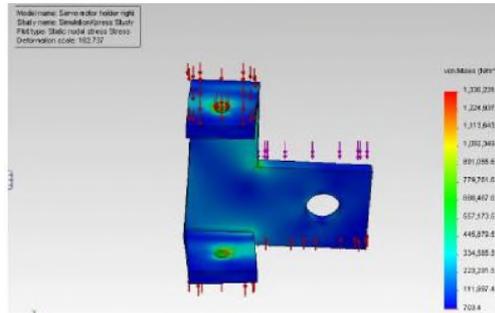**Figure 15. Body Stress Analysis**
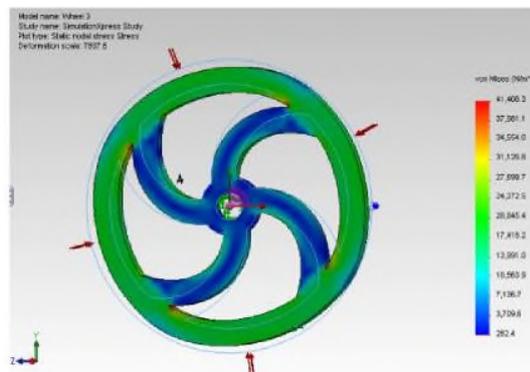
Figure 16. Holder Stress Analysis

Figure 17. Wheel Stress Analysis

4.1.2 Displacement Analysis of Hexapod Robot Individual Parts
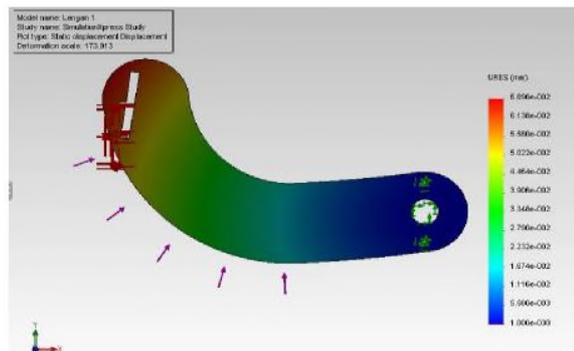
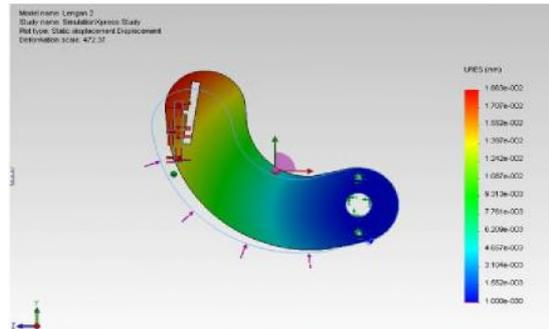**Figure 18. Leg (Femur) Displacement Analysis**

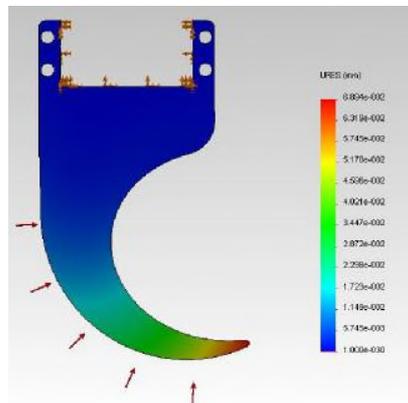**Figure 19. Front Leg (Femur) Displacement Analysis**
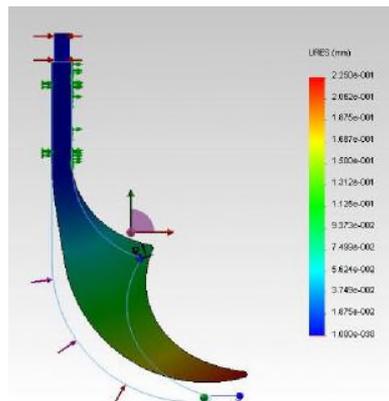

Figure 20. Front Leg (Tibia) Displacement Analysis

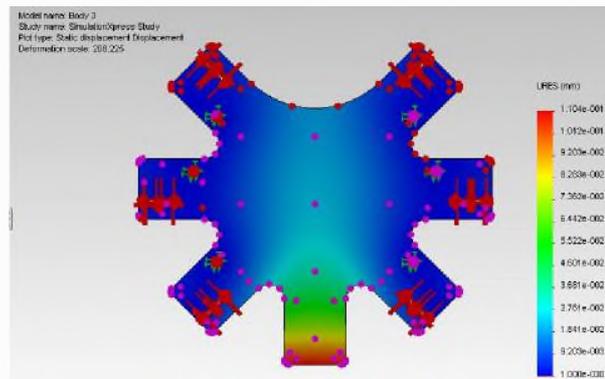**Figure 21. Leg (Tibia) Displacement Analysis**

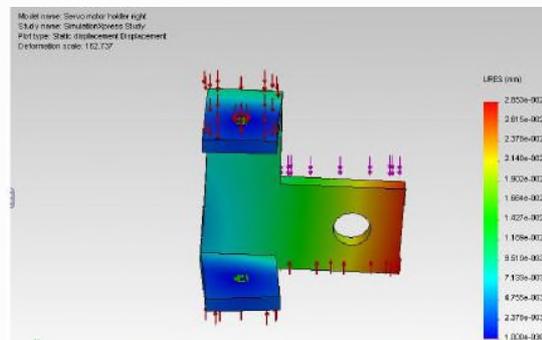**Figure 22. Body Displacement Analysis**

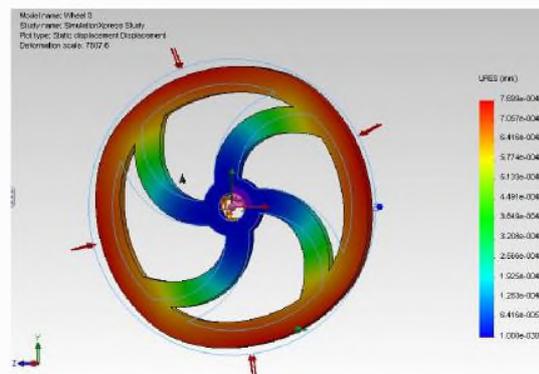**Figure 23. Holder Displacement Analysis**

Figure 24. Wheel Displacement Analysis

5. Conclusion

This section will conclude the overall project's achievement. It can be concluded that the new design of hexapod robot with maneuverable wheel has been successfully designed and drafted by using Solidworks software. Moreover, by using Solidworks, the study of stress analysis of the design created could be done in SimulationXpress. Besides, the component

selection of the robot has been successfully carried out. The robot is actuated using 14 servomotors including six wheels. This project also implemented by using PIC16F877A and programmed with MikroC software.

Acknowledgements

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