Hexapod Robot

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***Abstract*—This report presents the design, modelling, control, simulation and analysis of an electromechanical system known as a the hexapod using matlab simulink and solid works software. A modeling procedure is described together with analytical formulas to justify our design specifications for the design specifications of the hexapod robot. Tables containing these specifications can also be found within this report. The results are based on the analysis of the simulation values obtained in matlab. Experimental results are provided for the a servo motor powered hexapod while analytical results are presented from the various force and torque calculations performed.**

***Index Terms*—Hexapod, Servo, Torque**

I. INTRODUCTION

Group 17 was given the task of designing, modeling, simulating and analysing an electromechanical system that includes different aspects of actuators and power electronics. Our group chose the hexapod robot as our choice for the electromechanical system. A hexapod is a robot with parallel kinematic positioning systems consisting of six independent actuator controlled struts or simply put a mechanical vehicle which walks on six legs. Hexapods offer several advantages over other types of multi-legged walking robots such as being able to maintain statically stable while in motion. A robot is considered to be statically stable when on three or more legs and due to the hexapods legs operating independently of each other it can still operate even when some of its legs become disabled. This combined with the fact that the hexapod acts on a single motion platform helps to eliminate the accumulation of guiding errors and increases precision. Furthermore it means that the hexapod can use its additional legs to gain new foot placements or control a payload. Hexapods are the fastest moving robot with the optimum number of legs for movements as adding more legs does not increase speed. The Hexapod will use a servo motor as its actuating device in order to move the legs. A servo motor is a rotary actuator that allows for precise control of angular position, consisting of a motor coupled to a sensor for feedback, the feedback system increases accuracy and allows the motor to precisely control the rotary motion. The servo motor was selected instead of a stepper because of it's high rate of efficiency, power and torque compared to the stepper, additionally the stepper motor produces high amount of heat when in operation which can lead to issues with the circuitry in the long run. Hexapods are useful for a variety of tasks particularly ones that can be dangerous for humans such as space exploration, undersea cable construction and rescue missions to name just few.

II. DESIGN SPECIFICATION

A. Problem Description

1) Design of a hexapod robot
2) Design must be statically stable
3) Must maintain dynamic stability when carrying a specified load
4) Modelling and simulation of hexapod robot in matlab.
5) Analysis of finished design.

B. Design Requirements

In this subsection, break the problem description down into the fundamental requirements. Your proposed design should meet each of the criteria you create.

- Robot is a hexapod therefore it should move on six legs
- In order to maintain static stability the robot should be capable of maintaining motion even when up to 3 of its legs have been disabled.
- Robot will use a servo motor as its actuating device.
- Servo motor will meet the following specifications:

TABLE I
SERVO MOTOR SPECIFICATIONS

Frame Size	22.2 x 11.8 x 31 mm
Modulation	Analog
Torque	1.5 kg/cm
Stall Torque	1.2 kg/cm
Mass	9g
Speed	0.12 s/60 deg
Operational voltage	4-7.2 V
Rotational Range	180 deg
Motor Type	3-pole
Driver Input Voltage	DC
Pulse Cycle	20 ms
Pulse Width	500-2400 micro sec
Temperature Range	0-55 deg Celsius
Internal Resistance	0.31 Ohm
Motor Inductance	0.516 mH

III. MODELING AND SIMULATION

A. Diagrams

Before calculations for the final design could take place several assumptions regarding the forces and torques of the hexapod had to be taken into consideration. These can be seen in figures 1 and 2 along with the hexapod diagrams and variables needed for the final design.

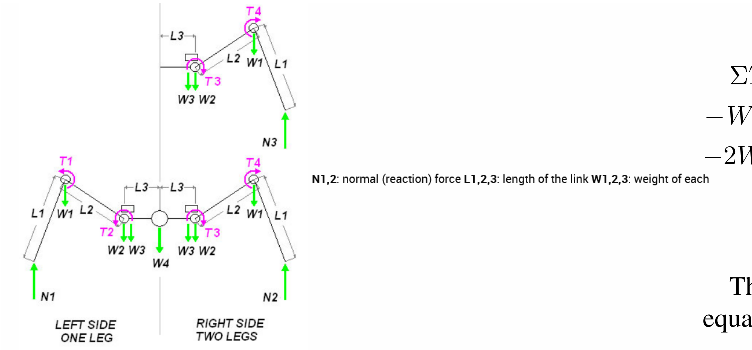

Fig. 1. Hexapod diagram with assumptions made

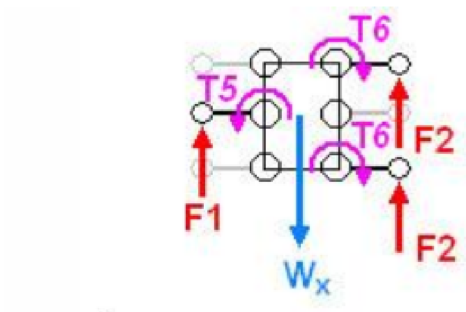

Fig. 2. Diagram for horizontal motor torque of a hexapod.

B. Equations

The was following assumption was made regarding the horizontal force on the hexapod using equation [1]

$$F_1 = 2F_2 \tag{1}$$

The motor inertia was found using the formula [2]

$$J_{motor} = \frac{J_{load}}{n^2} \tag{2}$$

The first set of e quations focused on the motor inertia as well as the torque value of the model at critical positions along the frame. The horizontal motor was found using the formula below [3]

$$\begin{aligned}\Sigma T_5 = T_1 - F_1(L_1 \cos\theta_1 + L_2 \cos\theta_2) - L_3 W_x \\ + 2F_2(2L_3 + L_1 \cos\theta_1 + L_2 \cos\theta_2)\end{aligned} \tag{3}$$

Another critical factor the torque on the upper leg was also calculated using the below listed formula [4]

$$\begin{aligned}\Sigma T_{hip} = T_2 - N_1(L_1 \cos\theta_1 + L_2 \cos\theta_2) \\ + W_1(L_2 \cos\theta 2) - W_4 L_3 - 2W_2 L_3 - 2W_3 L_3 \\ -2W1(2L_3 + L_2 \cos\theta_2) + 2N_2(2L_3 + L_2 \cos\theta_2 + L_1 \cos\theta_1)\end{aligned} \tag{4}$$

The reaction force on one side of the hexapod for a single leg was represented as the torque for the foot of the leg and was calculated using the equation [5]

$$\begin{aligned}\Sigma T_{LeftFoot} = -W_1 L_1 \cos\theta_1 - W_2(L_1 \cos\theta_1 + L_2 \cos\theta_2) \\ -W_3(L_1 \cos\theta_1 + L_2 \cos\theta_2) - W_4((L_1 \cos\theta_1 + L_2 \cos\theta_2 + L_3) \\ -2W_3(2L_3 + L_1 \cos\theta_1 + L_2 \cos\theta_2) - 2W_2(L_1 \cos\theta_1 + L_2 \cos\theta_2 + 2L_3) \\ - 2W_1(L_1 \cos\theta_1 + 2L_2 \cos\theta_2 + 2L_3) \\ + 2N_2(2L_1 \cos\theta_1 + 2L_2 \cos\theta_2 + 2L_3)\end{aligned} \tag{5}$$

The remaining reaction forces were calculated using the equation [6]

$$N_1 + 2N_2 = W_4 + 6(W_1 + W_2 + W_3) \tag{6}$$

The hexpods weight could be calculated as the summation of its component weights as can be seen in equation[7]

$$W_4 = W_{Frame} + W_{Battery} + W_{Elect} \tag{7}$$

The hexapods incline control was determined using the following equation [8]

$$W_x = W \sin\beta \tag{8}$$

C. Solid works Model

The results of these calculations along with the information from the design specifications were used to create the solid works model.

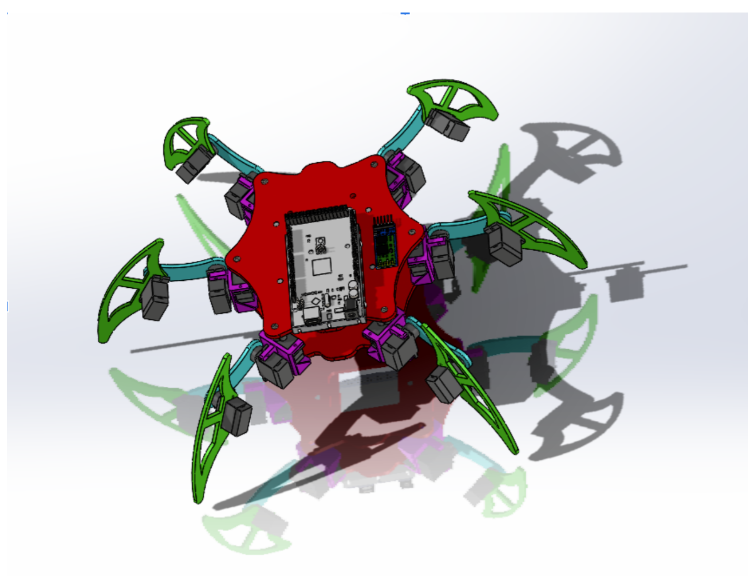

Fig. 3. Hexapod Solidworks Model

The figure above depicts a hexapod developed with the core concepts above in mind. This hexapod robot is developed using PVC plastic. Using this mechanical model three core concepts were pulled for future use within the simulink model. The first is the structural safety factor determined from placing the mass of a third of the robot's weight (due to 3 legs up, 3 legs down) as a pressure upon a given test leg.The following table II lists the design specifications of the solid works model

TABLE II
HEXAPOD DIMENSIONS

Foot Mass	20.18 g
Foot Length (L1)	65.5 mm
Knee Mass (W1)	57.54 g
Knee Length (L2)	2 mm
Thigh Mass (W3)	57.54 g
Arduino Mass (Warduino)	47 g
Half Body Length (L3)	79.72 mm
Full Body Mass (W4)	598.06 g

Creating a model in solid works allowed us to perform simulations to determine values that would normally be difficult to calculate by hand for such an oddly shaped device. Using the solid works simulation we were able to observe the stress-strain relationship of our mechanical design.

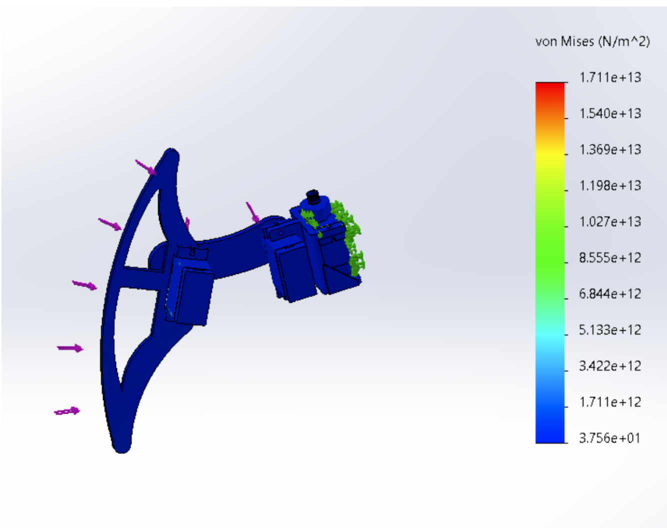

Fig. 4. Stress-Strain of Mechanical Design

From the figure above it is determined that the model is structurally sound and thus is within the clear to perform test upon. Next we move onto understanding the specifications of each link and how they interact with each other. The solids works tool was used to determine the weights and lengths of each link; these values were later recorded for future use. As well the solids work model was then used to determine the range of motion the motors would be able to achieve. While the inertias could be hand solved using the formula in the matrix.

$$I_c = \begin{bmatrix} \frac{1}{12}M_c(3R^2+H^2) & 0 & 0 \\ 0 & \frac{1}{12}M_cR^2 & 0 \\ 0 & 0 & \frac{1}{12}M_c(3R^2+H^2) \end{bmatrix}$$

It was determined that a solid works model could be used to simplify inertias within the 3 sets of components.

In order to understand the kinematic characteristics of a hexapod robot with arbitrary values imputed into link weights and link lengths we normally would use the Denavit-Hartenberg algorithm, applying it to a leg of the hexapod robot. Through the assumption that the model involved is a symmetrical structure composed of six identical legs, having three degrees of freedom in each leg we can thus assume due to symmetry that we only need to work on a single leg with a degree of freedom of 3 rather then the complete model with a degree of freedom of 18.

D. Electromechanical Model in Simulink

Once the necessaey calculations an physical modelling had been complete the project continued with the design of the Electromechanical model using simulink simulation software.

Before the models construction,research had first been conducted on various servo motors and their performance as well as subsequent electro mechanical models. Figures 5 and 6 represent the load effects on the system .

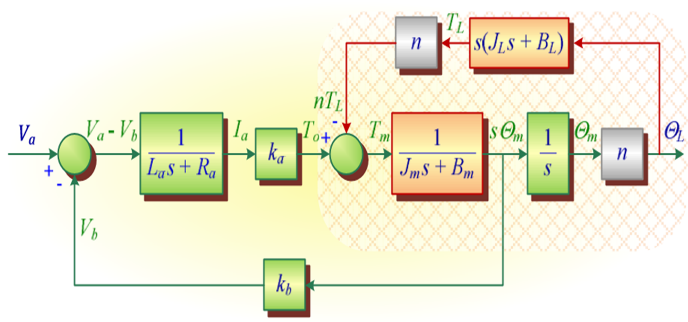

Fig. 5. Model of DC motor with external load coupled by gears

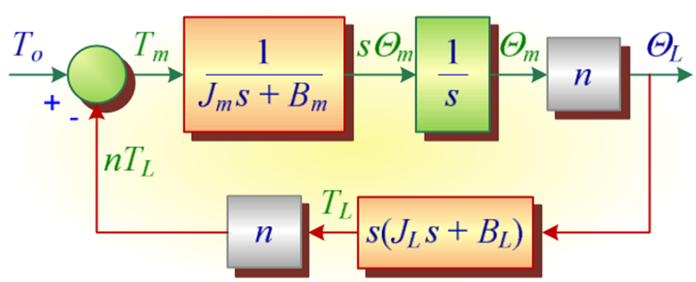

Fig. 6. Model showing load effect on motor

Once the necessary research had been conducted the electromechanical model was designed as can be seen in figure 7

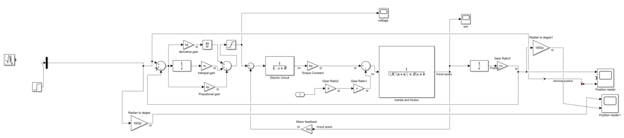

Fig. 7. Electromechanical Model of servo motor

The model of the servo motor in figure 7 uses a PID controller to measure the difference in desired and current position adjusting the voltage output accordingly. It should be noted that the servo motor would also include a potentiometer represented by a block relating voltage to angular position and a pulse with signal, however is was assumed that the pulse with would be generated by the micro controller and their by making creation of the pulse with and by extension the potentiometer relating to it not necessary. During testing the PID controller and gearbox were the only variable tuned as all other variables had been calculated from data sheet and experimental with reference 9g servo model. Both the Kp and gear box were increment together as the kp decreased response time contracting the gearboxes effect on load torque, a Kd value was included to minimize overshoot. Due to the high kp value it was decided to add a saturation block to represent the motoring reaching its max input voltage saturation to allow the model to remain plausible. Though simulation results shown in figure 8 and figure 9 Model Simulation varying input positions it was concluded that the created motor was able to proved a response time of 0.177 seconds for a 60 degree change and over multiple changes in position was able to average a overshoot of 3 percent each time.

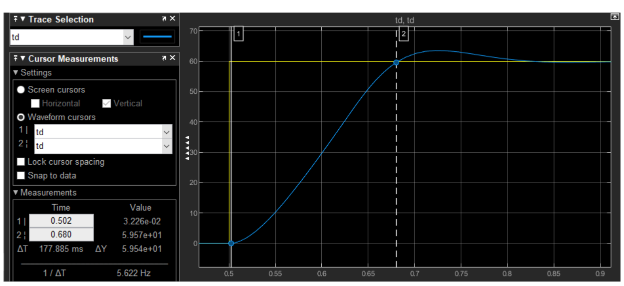

Fig. 8. Electromechanical Model Simulation Results

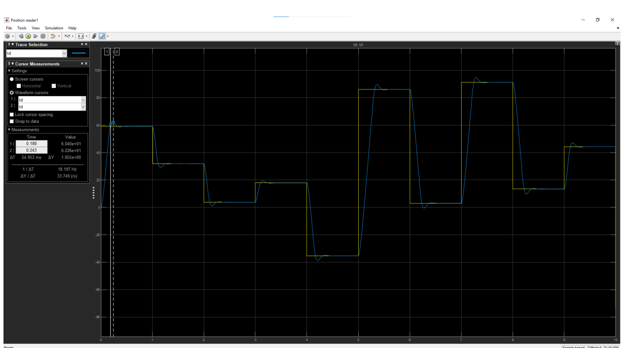

Fig. 9. Electromechanical Model Simulation Results

E. References

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IV. Conclusion and Discussion

Upon the completion of this project an understanding of electromcechanical system control specifically with hexapods was developed. This