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Design of Automatic Wall Climbing Equipment For Cleaning Glass Surfaces With Multi-Faceted Aspects

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Abstract - *This project is implemented to design the possible window cleaning robot for high-rise building. The study focuses on designing a conceptual design where three main tasks being carried out. The first is to generate several design concepts based from engineering specification generated using designing and analyzing software's. The second step involves an engineering analysis on the selected design concept such as the static frictional force, suction cup force, and motor torque required. The final step is to come out with final design using CATIA, ANSYS. Based from this, the final design of the project is designed weighted approximately of 5kg. The window cleaning robot uses 20 motors and 6 suction cups where 18 of the motor acts to drive the robot vertically (upward/downward) and the other one horizontally while the suction cups are used to grip onto the windowpane. This thesis includes background and objectives of this research, design concepts, engineering analysis, the final design, discussion and a conclusion.*

Keywords – Window cleaning mechanism, Multi-utility equipment, Coefficient of Friction, Vacuum Ejectors, Gripping Systems, Torque Calculations.

1. INTRODUCTION

Glass window cleaning in high rise building is currently having high demands in modern cities. As a result, window cleaners need to risk their life by climbing the wall using rope and gondola to do the cleaning. Currently maximum are still cleaned manually. Statistics shows that glass window cleaning is probably the most hazardous maintenance activity carried out on most work premises. At US only, average of 70 window washers die each year in the US, while another 130 are injured. By designing a mobile machine that can do the cleaning, this will help reducing the statistics. While there are already numbers of the same project outside, it is still not yet fully finished and commercialized; this project is done to bring in new ideas and innovation on the window cleaning robot to a new perspective. Currently, the market demands many automatic windows cleaning system. From the survey, the requirements of window cleaning robot are listed below:

i. The size of the robot should be small and lightweight for mobility and portability

ii. The robot must be able to clean window's corner because fouling is left there often

iii. The robot must be able to sweep the windowpane continuously to prevent stripe pattern on the window

iv. The robot can operate automatically during moving on the window This project will basically cover up these requirements which are elaborated in details in this thesis to come out with a working conceptual design

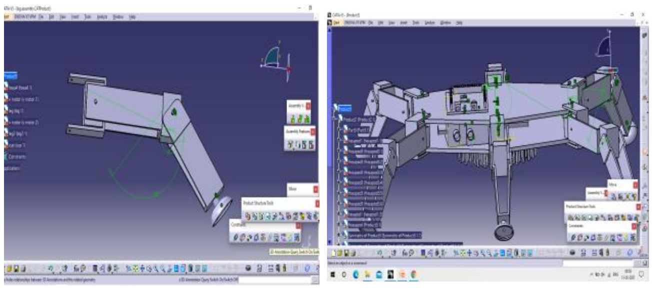
1.1 Scope of Study

This project will be focusing on designing a window cleaning robots. The robots must include 4 mechanisms which are gripping mechanism, locomotion mechanism, cleaning mechanism and turning mechanism. To come out to the final design, three main steps need to be carried out. The first part is the concepts generation where several concept designs are created based from the engineering specifications that are derived from customer's requirements. The second part is the engineering analysis. Based on the best concept chose in the previous section, an analysis done to calculate the static frictional force involve in the robot system, the suction cup calculation and selection and the motor torque calculation and selection. And base from the first and second part, final conceptual design is drawn in CATIA, ANSYS, etc before the fabrication can be started.

2. MECHANICAL SYSTEM DESIGN

(KLANN MECHANISM)

The CAD design of the platform was done on CATIA Software and the Structural Analysis was performed on Ansys Software. The geometry generated on CATIA was imported in Ansys and a mesh was generated. The mesh generated was automatic type with a very high resolution. The Material selected for the body is ABS (Acrylonitrile Butadiene Styrene).



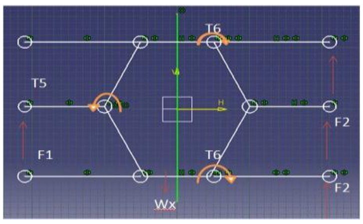
2.1 Torque Calculations

- Objective is to find out the torques acting at each degree of freedom of a 6-legged robot.

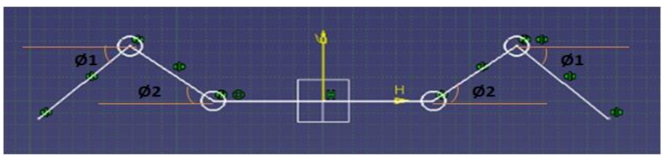
- In order to obtain a proper balance during the motion the robot must be statically sable.

- In the case of a hexapod, so long as 3 legs are always in contact with the ground and the center of mass is located within the triangle formed by these feet, it will be statically table.

- The condition is shown in the figure:- N is the normal force



- The links that make up an “insect” leg do not necessarily need to be perpendicular to one another, as shown in the image below:-



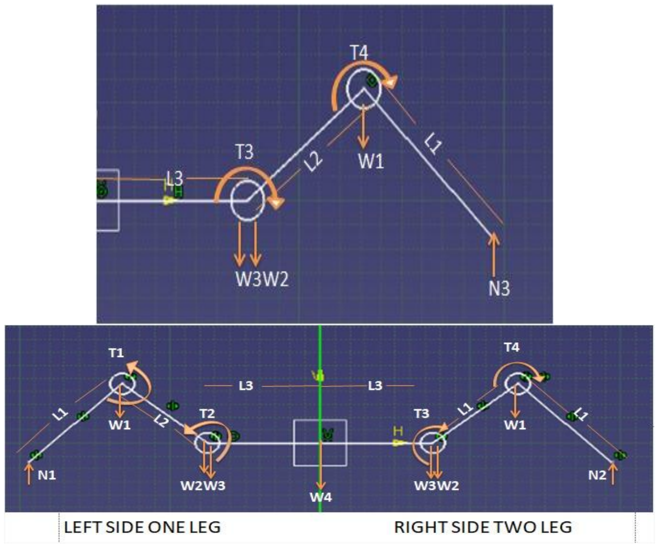
- The angles are taken between the horizontal and the link and it is assumed the legs are configured the same on both sides.

- The following assumptions must also be made in order to simplify the calculations and inputs required:

➢ 6 legs, configured as two rows of 3.
➢ All the legs are identical.

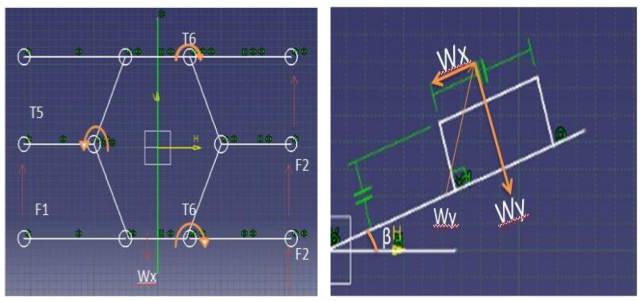
- In order to find the torque acting at each joint, a free body diagram must be drawn.

- All supporting legs must be considered:-



- N1, 2: normal (reaction) force.
- L1, 2, 3: length of the link.
- W1, 2, 3: weight of each actuator (W2, 3 are assumed to be very close).
- W4: Weight acting at the center of mass.
- T1,2,3,4: Torque acting at each joint (each side is different)
- In order to determine the torque T1 acting at the "knee", we must assume that the rest of the structure is rigid (not moving).
- Similarly, when finding T2, acting at the "hip" the rest of the structure (including the torque T1) is considered rigid.
- The links are considered to be massless.
- The torques T3 and T4 will be different than T1 and T2 because the central weight is not being supported equally among the three legs.
- In this case, T1>T4 and T2>T3, so we will only calculate T1 and T2
- The weight W4 acting at the center of the robot when 3 legs are raised is a combination of various parts below:-

$$\mathbf{W_4 = W_{Frame} + W_{Elect} + W_{Battery} + W_3 + Legs}$$



- The reaction forces counteract the weight of the robot which would otherwise cause it to slide down the incline.

- The magnitude of the weight of gravity along the slope can be calculated as:-

$$W_x = W * \sin\beta$$

- A torque balance about the left shoulder actuator gives:-

$$\sum Ts = T_1 - F_1 * (L_1 * \cos\theta_1 + L_2 * \cos\theta_2) - L_3 * W_x + 2 * F_2 * (2 * L_3 + L_1 * \cos\theta_1 + L_2 * \cos\theta_2)$$

- In order to move straight, the force on the left side must equal the force on the right side, otherwise the robot would begin to turn.
  So, **F1=2*F2.**

- The torques above represent the required to keep the robot stationary and does not include the extra torque required for motion.

- For selection of motor we must add 25% to each torque as a factor of safety.

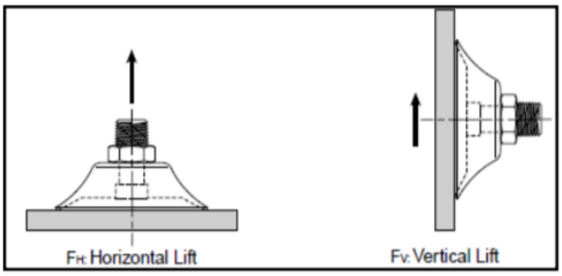
- Calculation of the required suction rate V [M^3/H, L/Min].

- V = n x VS

1. n = number of suction pads.
2. VS = required suction rate for single suction pad [m^3/h, I/min].

2.2 Suction Cup Gripping Force

To achieve a good adhesion, the suction cup need to have high gripping force and at the same time not too high so that we can reduce the torque and force of the motors that move the wheels. For forward movement, the robot will use linear actuator and the actuator needs to have a capacity to push or pull the robot weight. Thus, the calculation is done to ensure the right choice of suction cup and motors for the robot gripping and locomotion mechanism.



Horizontal lifting Force

Apply Newton Law to calculate the force on a 5 kg robot mass with a change in acceleration of 2m/s2 and a safety factor, SH of 2.

$$FH\ (N) = mass\ (kg) \times (ag + a) \times SH$$

$$FH\ (N) = 5kg \times (9.81 m/sec^2 + 2 m/sec^2) \times 2$$

$$FH = 118.1\ N$$

Vertical Lifting Force

Apply Newton Law to calculate the force on a 5 kg robot mass with a change in acceleration of $2m/s^2$ and a safety factor, Sv of 4.

$$Fv\ (N) = mass\ (kg) \times (ag + a) \times Sv$$

$$Fv\ (N) = 5kg \times (9.81 m/sec^2 + 2 m/sec^2) \times 4$$

$$Fv = 236.2\ N$$

Calculate the force on a 5kg mass with a dry surface, a change in acceleration of $2m/sec^2$, and a change in travel acceleration of $2m/sec^2$.

$$F_m\ (N) = \sqrt{F_v^2 + F_T^2}$$

$$F_m\ (N) = \sqrt{([5leg * 2m/s^2 * 4]^2 + [5kg * 9.81m/s + 2m/s^2 * 2]^2)}$$

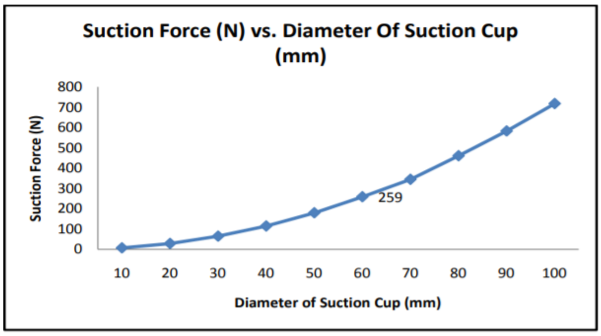
$$= \sqrt{1600\ kgm/s^2 + 13947.6\ kgm/s^2}$$

$$F_m = 124.69N$$

At 90% of full vacuum and 6 cups working together,

$$F_m/n = 124.69N/6 = 20.78N$$

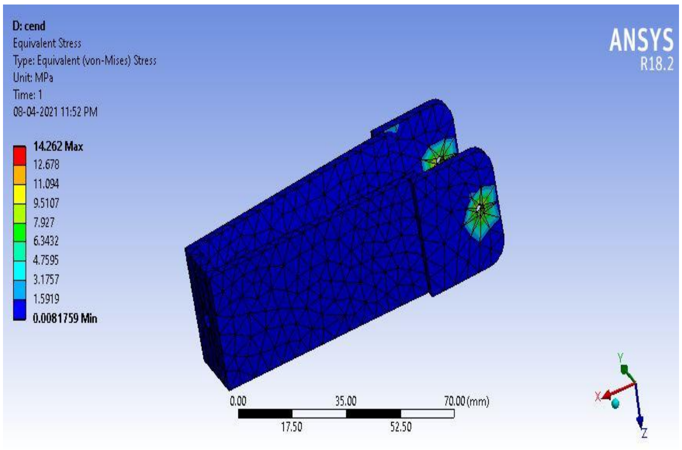
The force value is compared in the Table. By applying a safety factor of 2, it is recommended to select a suction cup with diameter of 50mm with theoretical lifting force of 259N. From chart, we can then plot a graph of the suction force (N) vs. diameter of suction cup at 90% of operating vacuum pressure in Figure.



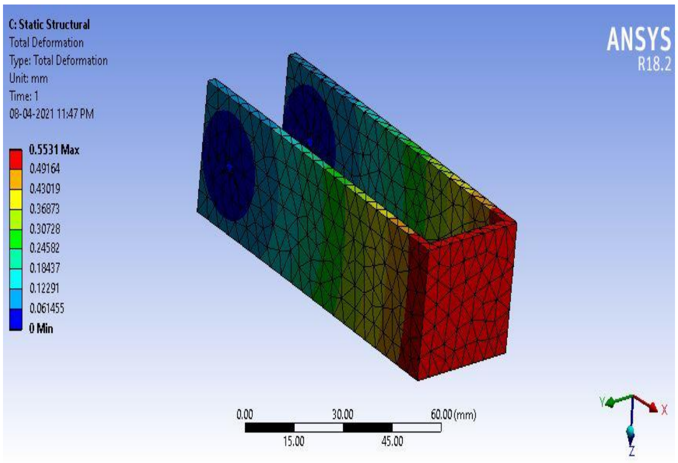
3. ANALYSIS

3.1 Ansys Results

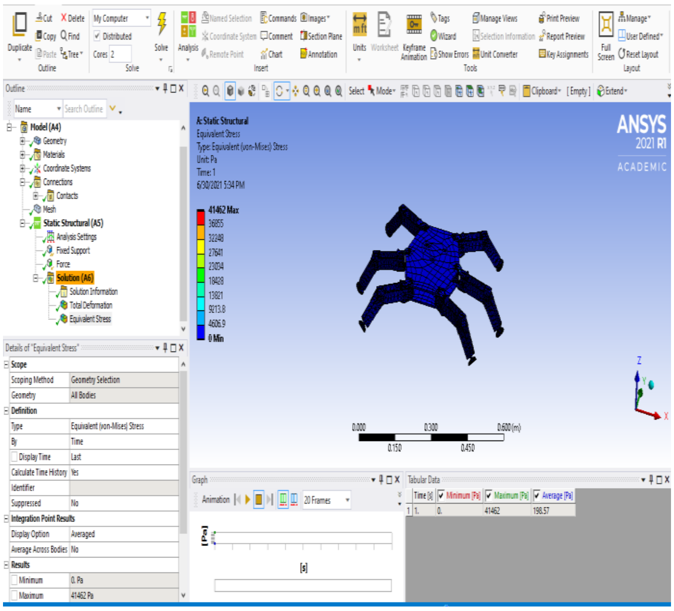
To check whether the selected material and design are safe, structural analysis was performed using Ansys software.The figures below show the Ansys results for Structural Analysis.



Ansys result for Equivalent Stress



Ansys result for Total Deformation



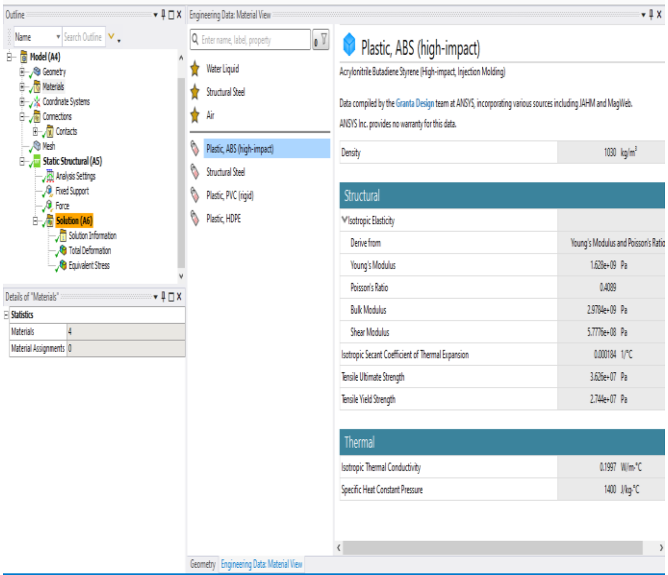
Assembly Equivalent Stress Analysis

The results found out after the analysis are tabulated below.

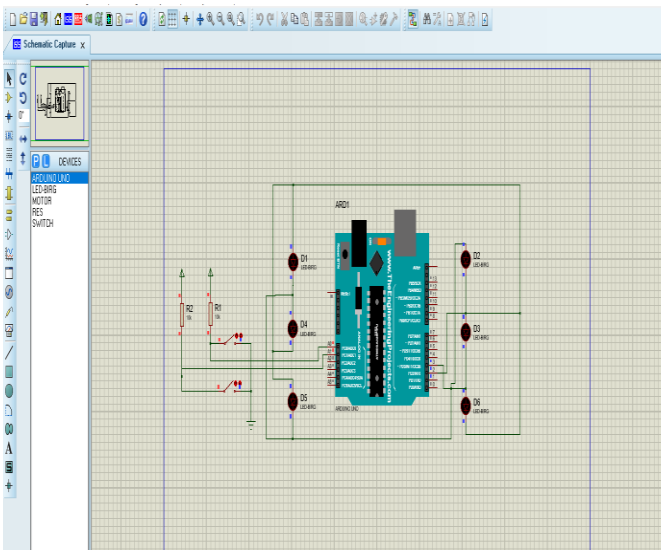
The Ansys results of the Platform.

Equivalent Stress	Leg - 14.262 MPa Plate – 7.1725 MPa Clamp – 13.981 MPa C Clamp – 6.4287 MPa Assembly – 0.04146 MPa
Total Deformation	Clamp - 0.5531 mm C Clamp – 0.371 mm Leg – 0.60009 mm Plate – 3.3141 mm Assembly – 0.4562 mm
Factor of Safety (FoS)	Plate – 15 C Clamp – 15 Clamp – 15 Leg - 15

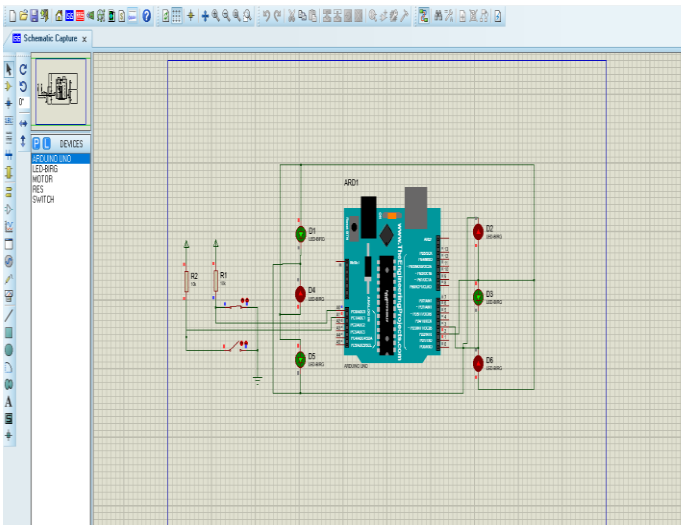
2.2 Material Properties



3.2 Circuit Connections



The circuit design which is required for the working of the robot is designed and checked on the software called Proteus. In the above figure the connections between motors and Arduino to operate alternately is defined.



Simulation of the circuit.

3. CONCLUSION

- Desired calculation for robot have obtained.
- The robot is small and compact.
- The designed mechanism is favorable of robot.
- The Material selected for the design is light in weight and can withstand in required conditions.
- The components selected for the robot are cheap and easy to available.
- Successful simulation of circuit is obtained on Proteus. The circuit represents the working of motors and other components accurately as per the designed codes.

4. FUTURE APPLICATIONS

With little or no modification, the climbing robot can be used for the following applications and also its advantages are mentioned-

- It has the potential to serve as a base on which to mount data acquisition devices, surveillance equipment, or object-manipulation tools.
- Wireless/wired video surveillance can be possible. Public safety & military applications (surveillance, search & rescue).
- Consumer applications (window cleaning and painting). Inspections (building, aircraft & bridges, Pipes) etc.
- Wall/glass cleaning and water sprinklers can be mounted.
- On board vacuum cylinders are not used, which increases payload capacity.

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