FABRICATION OF AUTOMATIC BLACKBOARD CLEANING SYSTEM BY USING VACUUM

A PROJECT REPORT

Submitted by

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in partial fulfillment for the award of the degree

of

BACHELOR OF ENGINEERING

in

MECHANICAL ENGINEERING

M.KUMARASAMY COLLEGE OF ENGINEERING, KARUR

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M.KUMARASAMY COLLEGE OF ENGINEERING, KARUR

BONAFIDE CERTIFICATE

Certified that this project report **"FABRICATION OF AUTOMATIC WALL CLIMBING GLASS CLEANEAR ROBOT "** is the bonafide work of **GOKUL.T (927622BME021) , GOWSIK.M (927622BME022) , GOWTHAM.B(927622BME023)** who carried out the project work during the academic year 2023 – 2024 under my supervision. Certified further, that to the best of my knowledge the work reported herein does not form part of any other project report or dissertation on the basis of which a degree or award was conferred on an earlier occasion on this or any other candidate.

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This project report has been submitted for the end semester project viva voce Examination held on ________________

INTERNAL EXAMINER EXTERNAL EXAMINER

DECLARATION

We affirm that the Project titled **“**FABRICATION OF AUTOMATIC WALL CLIMBING GLASS CLEANER ROBOT**”** being submitted in partial fulfillment of for the award of Bachelor of Engineering in Mechanical Engineering, is the original work carried out by us. It has not formed the part of any other project or dissertation on the basis of which a degree or award was conferred on an earlier occasion on this or any other candidate.

Student name	Signature
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Name and signature of the supervisor with date

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Words are boundless to thank Our Parents and Friends for their constant encouragement to complete this project successfully.

INSTITUTION VISION & MISSION

Vision

- ❖ To emerge as a leader among the top institutions in the field of technical education.

Mission

- ❖ Produce smart technocrats with empirical knowledge who can surmount the global challenges.
- ❖ Create a Diverse, fully engaged, learner- centric campus environment to provide quality education to the students.
- ❖ Maintain mutually beneficial partnerships with our alumni, industry and professional associations

DEPARTMENT VISION, MISSION, PEO, PO & PSO

Vision

- ❖ To create globally recognized competent Mechanical engineers to work in multicultural environment.

Mission

- ❖ To impart quality education in the field of mechanical engineering and to enhance their skills, to pursue careers or enter into higher education in their area of interest.
- ❖ To establish a learner-centric atmosphere along with state-of-the-art research facility.
- ❖ To make collaboration with industries, distinguished research institution and to become a center of excellence

PROGRAM EDUCATIONAL OBJECTIVES (PEOS)

The graduates of Mechanical Engineering will be able to

- ❖ PEO1: Graduates of the program will accommodate insightful information of engineering principles necessary for the applications of engineering.
- ❖ PEO2: Graduates of the program will acquire knowledge of recent trends in technology and solve problem in industry.
- ❖ PEO3: Graduates of the program will have practical experience and interpersonal skills to work both in local and international environments.
- ❖ PEO4: Graduates of the program will possess creative professionalism, understand their ethical responsibility and committed towards society.

PROGRAM OUTCOMES

The following are the Program Outcomes of Engineering Graduates: Engineering Graduates will be able to:

1. **Engineering knowledge:** Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.
2. **Problem analysis:** Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.
3. **Design/development of solutions:** Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.
4. **Conduct investigations of complex problems:** Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.
5. **Modern tool usage:** Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.
6. **The engineer and society:** Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.
7. **Environment and sustainability:** Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.
8. **Ethics:** Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.
9. **Individual and team work:** Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.
10. **Communication:** Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.
11. **Project management and finance:** Demonstrate knowledge and understanding of the engineering and management principles and apply these to one’s own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.
12. **Life-long learning:** Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

PROGRAM SPECIFIC OUTCOMES (PSOs)

The following are the Program Specific Outcomes of Engineering Graduates:

The students will demonstrate the abilities

1. **Real world application:** To comprehend, analyze, design and develop innovative products and provide solutions for the real-life problems.
2. **Multi-disciplinary areas:** To work collaboratively on multi-disciplinary areas and make quality projects.
3. **Research oriented innovative ideas and methods:** To adopt modern tools, mathematical, scientific and engineering fundamentals required to solve industrial and societal problems.

Course Outcomes	At the end of this course, learners will be able to:	**Knowledge Level**
CO-1	Identify the issues and challenges related to industry, society and environment.	Apply
CO-2	Describe the identified problem and formulate the possible solutions	Apply
CO-3	Design / Fabricate new experimental set up/devices to provide solutions for the identified problems	Analyse
CO-4	Prepare a detailed report describing the project outcome	Apply
CO-5	Communicate outcome of the project and defend by making an effective oral presentation.	Apply

MAPPING OF PO & PSO WITH THE PROJECT OUTCOME

Cos	COURSESTATEMEN T	BLOOMS LEV EL	PO 1	P0 2	PO 3	PO 4	PO 5	PO 6	PO 7	PO 8	P0 9	PO 10	PO 11	PO 12	PS O1	PS O2	PS O3
1	Formulate a real world problem, identify the requirement and develop the design solutions.	K3	3	3	3			3	3	3	3	3			3	3	3
2	Identify technical ideas, strategies and methodologies	K3	3	3	3			3	3	3	3	3			3	3	3
3	Utilize the new tools, algorithms, techniques that contribute to obtain the solution of the project	K4	3	3	3	3	3	3	3	3	3	3		3	3	3	3
4	Test and validate through conformance of the developed prototype and analysis the cost-effectiveness.	K4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
5	Prepare report and present oral demonstration	K4	3							3	3	3		3	3		3
	Average		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

ABSTRACT

This project report is on a wall climbing cleaning robot that is designed to cater the demand of high rise building maintenance where human involvement is dangerous. A wall a robot must need a mean to cling on a vertical surface. Propeller thrust force is considered for designing the robot as a mean to cling on a vertical surface for this project. The thrust force must be sufficient enough to hold the whole body of the robot on a vertical surface. A brushless DC motor is selected to produce the required RPM to rotate the propeller for the thrust force. For the movement on the surface of the wall, the robot uses four rubber wheels which are connected to four gear motors that can move at any direction while subjected to the propeller thrust force. These gear motors are able to generate enough torque to move the robot on the wall. A suitable Li-Po battery is used as a power supply for the whole robot. Since it is a remote control robot a very precise coding is done to control all the motors through a motor driver and an Arduino Nano. The chassis of the robot plays a very important role. It will be subjected to deformation and the chassis will also have to be light weight. Aluminum polymer Composite Material is used to meet all the requirements. A custom cleaning mechanism is designed to serve the cleaning purpose. A set of springs are integrated into this mechanism in such way that it will engage on operator’s command. This mechanism is designed such in a way that it does a negligible interference to the thrust force and its components. The cleaning mechanism is driven by a servo motor. The wheels are set in such a way that the outer periphery of the front wheels will be slightly outside of the chassis so that it can climb on a vertical surface without any external assistance.

TABLE OF CONTENT

INTRODUCTION

he purpose of this paper a capable of a simple and light weight robotic structure. It combines a set of motions composed of parallel linear motion, rotational motion and interference avoidance motion. In modern society, there is an increasing need for climbing robots to clean, weld or inspect different kinds of surfaces of high buildings, large oil tanks and rough concrete facilities, replacing workers in these hazardous environments. Consequently, robotic technologies have been developed and applied according to the need sin different fields. However, some problems, such as difficulty in overcoming barriers and complex structures, also emerge. So, the robotic structure develop din this paper will be designed to clean wall glass

II- PROBLEM STATEMENT

Currently, market demands many automatic glass leaning systems. The requirements of glass cleaning robot are listed below:

- The size of the robot should be small and light weight form ability and portability
- The robot must be able to clean corner because fouling is left there often
- The robot must be able to sweep the wall pane continuously to prevent stripe pattern on the glass.
- The robot can operate automatically during moving on the glass wall.

III – OBJECTIVE

The objective of this project is to design a robotic device for used in cleaning glass in high-rise building.

- To Fabricate the Low weight plastic chassis.
- Working of Proximity sensor with microcontroller.
- Analyzing the behavior and characteristic of the proximity sensor
- The prototype of glass cleaning robot that we are developing. The dimensions of prototyped robot are approximately 300mm x300mmx100mm and its weight is approximately1-1.5 kg.
- The prototyped robot consists of two in dependently driven wheels and an active suction cup.

IV- LITERATURE REVIEW

In this chapter following research paper has been studied for the conduction of this project.

Many researchers have worked on wall climbing robot mechanisms and specialized applications.

- To moakiyano, etal has developed as emiself- contained wall climbing robot with scanning type suction cups which has two vacuum pumps that gave positive results.

- James Jkerley has conferred in his paper about invention of robotic devices, especially to mobile robot that is able to move in caterpillar fashion along a variety of different surfaces.

Ritesh G. Mahajan and Prof. S. M. Patil explained, the Wall Climbing Robot (WCR) having capability that it can stick on a vertical as well as inclined surface and can easily move over the surface. The targeted capability to stick with surface can be achieved by suction cups. Suction cups create a vacuum pressure used to stick with vertical or inclined surface. For movement(climbing)of robot it is necessary that's one of suction cup should release & that arrangement is obtained by developing the structure such that in which one frame is used to hold the robot to wall & other for climbing (vertical movement of robot). The motion of the other frame is carried out by providing rack & pinion type mechanism. The whole action is controlled by an Arduino and the commands sending on the

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Chapter 02: Design and Construction

2.1 - Methodology and Planning

A Flow Chart and a Gantt Chart of the Methodology and Planning adopted in approaching the design and to fabricate the final product are as below:

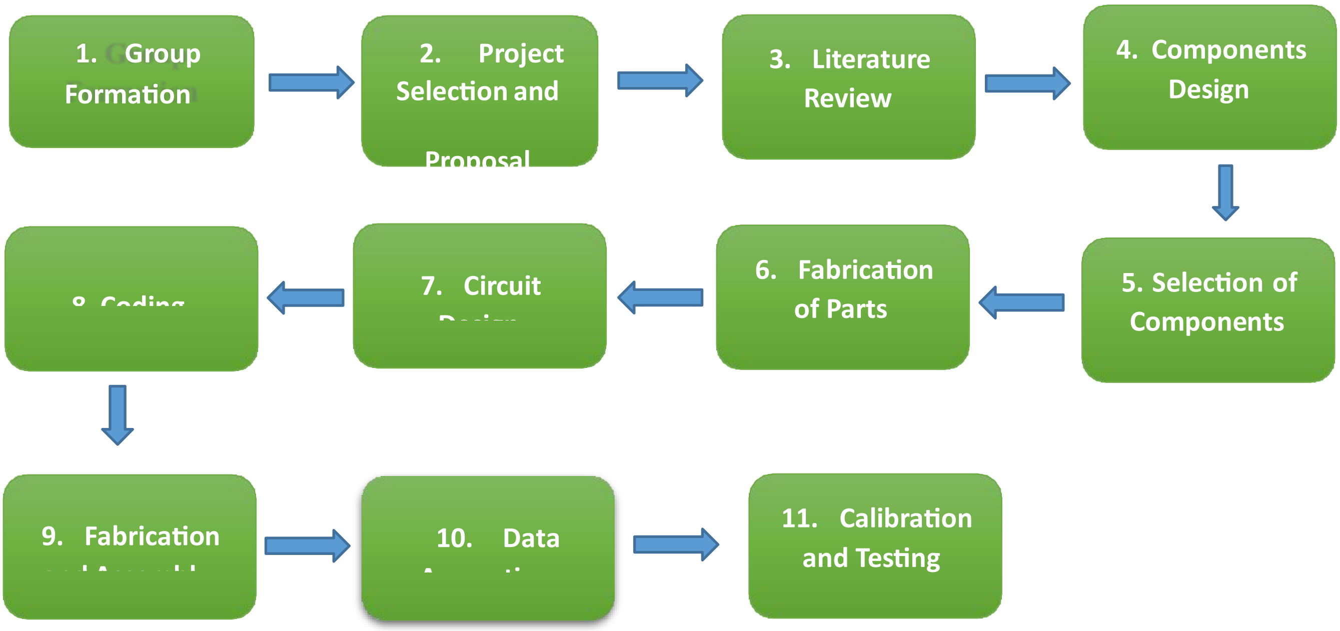


Figure 2.1.1: Flow Chart of Methodology and Planning

Task	Weeks Work	01	02	03	04	05	06	07	08	09	10	11	12
1	Project Selection and Proposal												
2	Literature Review												
3	Selection of Components												
4	Components Design												
5	Fabrication of Parts												
6	Circuit Design												
7	Coding												
8	Fabrication and Assembly												
9	Data Accusation												
10	Calibration and Testing												

Figure 2.1.2: Gantt Chart of Methodology and Planning

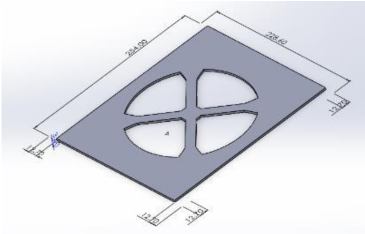


Fig 2.2.3: Chassis

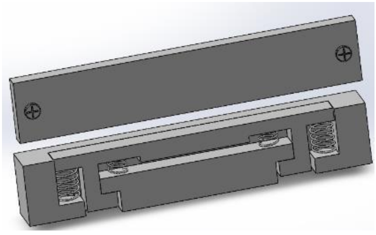


Fig 2.2.4: Cleaning Mechanism

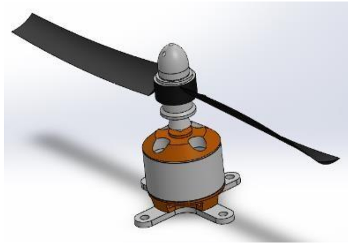


Fig 2.2.5: BLDC Motor

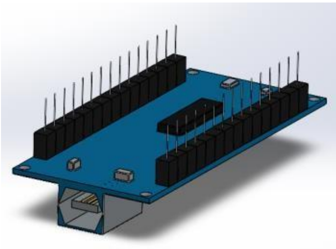


Fig 2.2.6: Arduino Nano

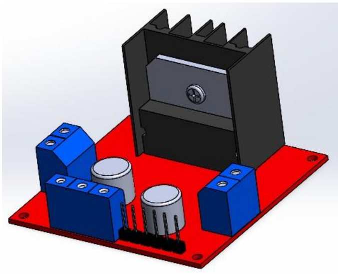


Fig 2.2.7: Motor Driver

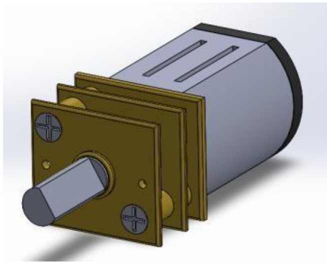


Fig 2.2.8: Gear Motor

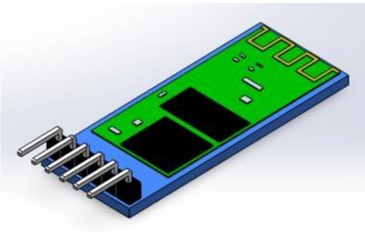


Fig 2.2.9: Bluetooth Module

Fig 2.2.10: Wheel

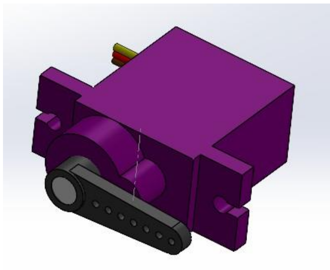


Fig 2.2.11: Servo Motor

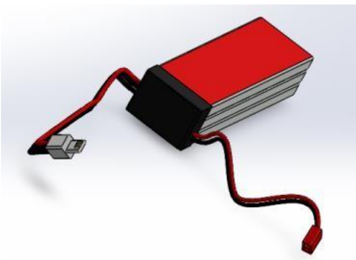


Fig 2.2.12: LiPo Battery

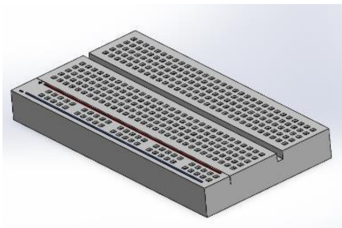


Fig 2.2.13: Breadboard

Fig 2.2.14: Button

2.2 - Details of Core Components

- **List of All components and respective mass:**

No	Component	Quantity	Total Mass (gm)
1	Chassis	1	139.0
2	Wheel	4	77.6
3	N20 Gear Motor	4	38.8
4	Breadboard	2	66.6
5	BLDC Motor	1	50.0
6	Propeller	1	6.0
7	Motor Driver	1	26.0
8	Arduino Nano	1	7.0
9	Bluetooth Module	1	3.5
10	Battery	1	177.5
11	ESC	1	28.0
12	Servo	1	9.0
13	Motor Mount	5	15.0
14	Button	1	7.0
15	Cleaning Mechanism + Wire + Fasteners + battery shield+ Others	-	57
Overall Approximate Mass			708 gm

1Chassis:

Aluminum Composite Panel (ACP) has been used as chassis Material because of its light-weight and high bending resistance. 4mm thick panel is chosen. It is made up of aluminum composite material (ACM), which contains two thinly coated aluminum sheets. Being comprised of two distinct materials that is metals and non-metal, as aluminum is a metal and polyethylene plastic is a nonmetal, it overcomes the limitations and the drawbacks of the original material. The chassis weight is approximately 139 gram. It has a length of 254mm, width is 198mm, height is 4mm. There is a central circle with a diameter of 6 inch. Two 12.7mm or half inch bar thick coming from the periphery intersect with each other in the middleof the circle and divide it into 4 equal quadrants. This design has done to minimize the deformation.

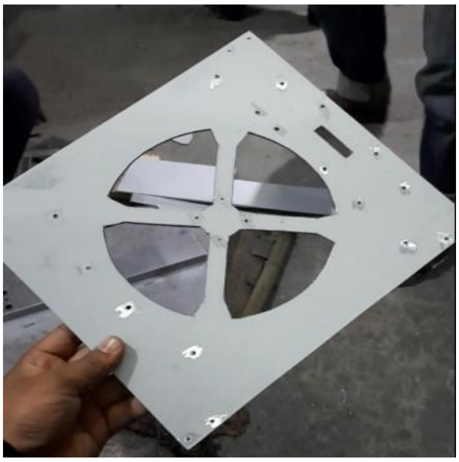


Figure 2.3.2: Chassis

1. BLDC Motor:

A Brushless DC Electric Motor (BLDC) is an electric motor powered by a direct current voltage supply and commutated by an electronic commutator continuously switches the DC current through the windings, and thus switches the magnetic field too. This way, the rotor cankeep rotating as long as the motor is powered. An A2212/6T 2200KV brushless motor has beenused in this project. Here A2212 is an indication of motor’s structural properties. It means 22mm motor diameter, 12mm motor shaft height. 6T represents 6 turns per pole. 2200KV means if 1V supply is given to the motor, it will rotates 2200 times in one minute.

Figure 2.3.3: Brushless DC Motor

2. Propeller:

A device for propelling an aircraft or boat, consisting of a shaft with radiating blades that are placed so as to thrust air or water in a desired direction when spinning. The reason behind using this in this project to generate thrust force which allows the robot stick on the wall. A 6 inches propeller has been attached with the BLDC.

Figure 2.3.4: Propeller

3. Electronic Speed Controller (ESC):

ESC or an Electronic Speed Controller controls the brushless motor movement or speed by activating the appropriate MOSFETs to create the rotating magnetic field so that the motor rotates. The higher the frequency or the quicker the ESC goes through the 6 intervals, the higher the speed of the motor will be. Though a 30A ESC is used but a 50A or 80A ESC would be more appropriate considering the specification of the BLDC that has been used in the project.

Arduino Nano:

Arduino Nano is a small, compatible open-source electronic development board based on an 8-bit AVR microcontroller. Two versions of this board are available, one is based on ATmega328p, and the other on Atmega168. ATmega328p has been applied in this project. There are 14 digital pins on board which is used to connect external component. 6 analog pins on board that is used to measure voltage in a range from 0 to 5V. V_{in} pin inputs voltage to the Arduino board when using an external power source (6-12V). 5V and 3.3V pin produce 5V and 3.3V respectively by voltage regulator. Two ground pins are available on the board. There are as many other pins with different functionality.

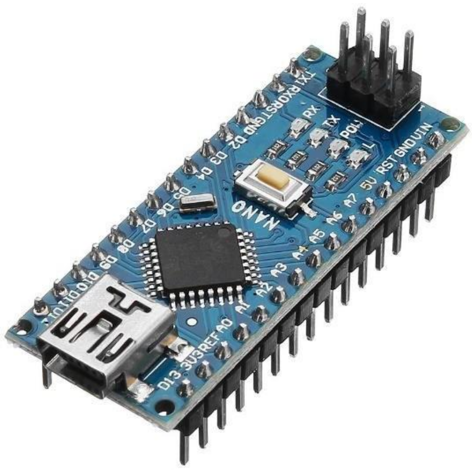


Figure 2.3.6: Arduino Nano

4. Bluetooth Module:

This module gives the Arduino board the possibility to communicate with the computer, laptop or even telephone via Bluetooth. HC-05 Bluetooth module is connected with the Arduino Nano for this project. The working voltage is 5V and the signal covering range is 10 meters of this module.

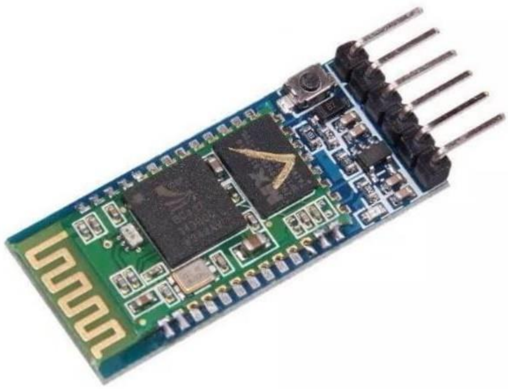


Figure 2.3.7: Bluetooth Module

4 Motor Driver:

A Motor Drive is a electronic system that includes an electric motor and drives the machine. Generally, it controls the speed, torque, directions .When we need to control the motor using a controller, we need a motor driver. For this project, a L298N H-Bridge motor driver has been connected. This L298N Motor Driver Module is a high power motor driver module for driving DC and Stepper Motors. This module consists of an L298 motor driver IC and a 78M05 5V regulator. L298N Module can control up to 4 DC motors, or 2 DC motors with directional and speed control.

Figure 2.3.8: Motor Driver

5. Gear Motor:

Four N20 12V 110RPM gear motor are attached on the robot. This is a DC Mini Metal Gear Motor, ideal for making robots .Light weight, high torque and low RPM. Fine craftsmanship, durable, not easy to wear. With excellent stall characteristics, can climb hills easily. For this project, these motor are the main components in climbing the vertical surface by generating high torque.

Figure 2.3.9: Gear Motor

6. Servo Motor:

Servo motors are high torque motors which are commonly used in robotics and several other applications due to the fact that it's easy to control their rotation. Servo motors have a geared output shaft which can be electrically controlled to turn one (1) degree at a time. A MG90S 9g servo motor is mounted on the cleaning mechanism of the robot. Overall weight of the servo is around 9 grams and its stall torque 2.0kg/cm (4.8V). It has 180 degree rotational range.

Figure 2.3.10: Servo Motor

7. Battery:

A lithium polymer battery, or more correctly lithium-ion polymer battery is a rechargeable battery of lithium-ion technology using a polymer electrolyte instead of a liquid electrolyte. High conductivity semisolid (gel) polymers form this electrolyte. A 2200mAh 11V 3S 20C Li-Po battery is used as power source in this project. It has 3 cell. The full charge voltage is 12.7, rated voltage is 11.1 and continuous discharge rate is 20C.

Figure 2.3.11: Li-Po Battery

2.3 - Circuit Diagram

The schematic circuit diagram of this Wall Climbing Cleaner Robot is as follow:

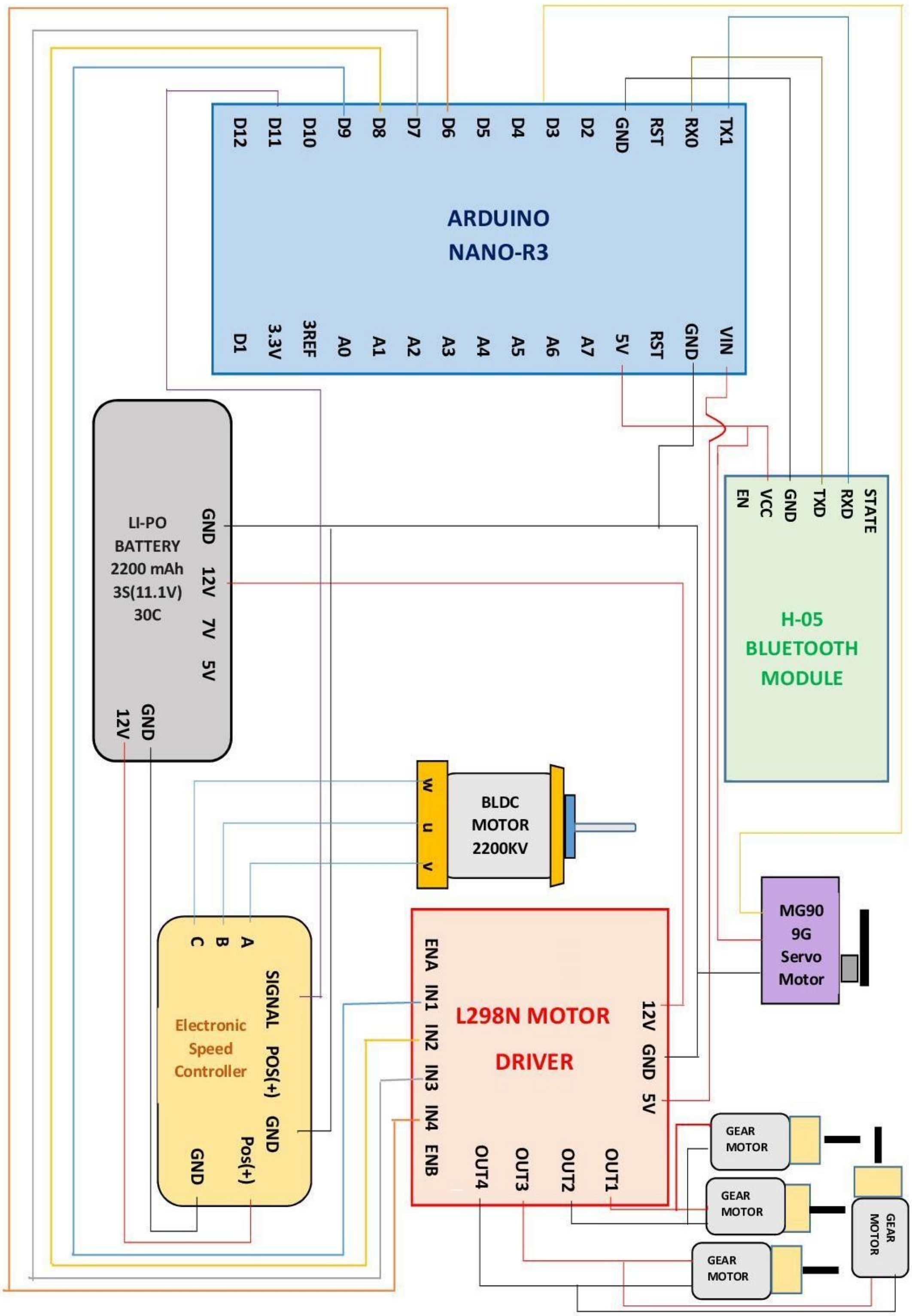
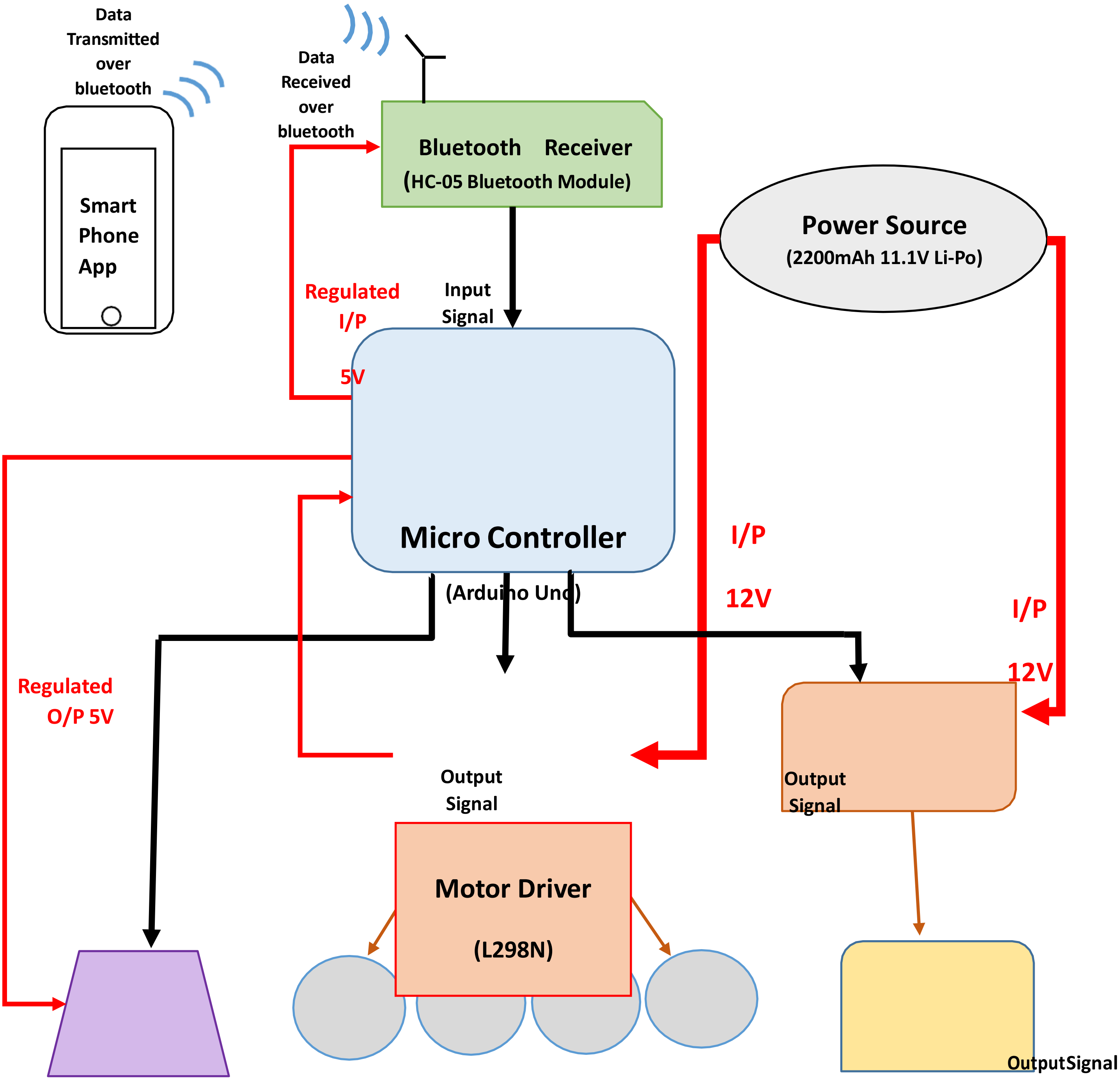


Figure 2.4.1: Schematic Circuit Diagram of Wall Climbing Cleaner Robot

Chapter 03: Working Methodology

3.1 - Illustration of working Methodology

The Block Diagram of working methodology of Wall Climbing Cleaner Robot fabricated for this project are given below:



3.2 - Layout of Robot Controlling Remote

The following Layout of our Robot Controlling Remote has been designed in RemoteXY website. It is an online open platform where developer can design and customize his own unique graphical user interface (GUI) to control Arduino via smartphone or tablet. The GUI runs on the phone or tablet by RemoteXY application. Our graphical interface has been designed to:

i. Control the direction of the Robot
ii. Control the RPM of the BLDC motor
iii. Engaging and Disengaging Cleaning Mechanism
iv. Turn off and Turn on the whole controlling system

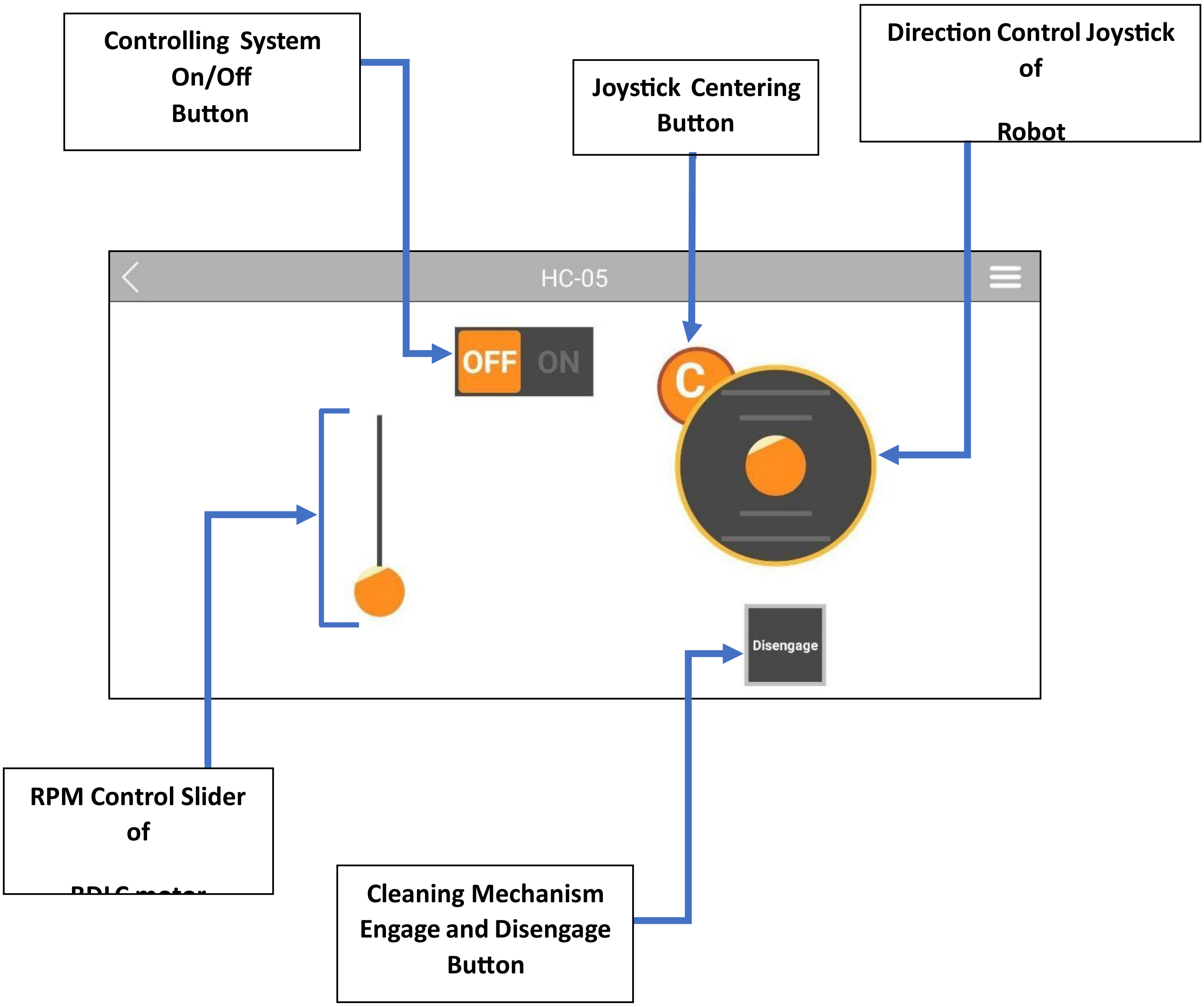


Figure 3.2.1: Layout of Robot Controlling Remote

3.3 – Working Procedure [Back to : Subchapter 5.1]

The working procedure of this Wall Climbing Cleaner Robot is explained step by step and the visuals of relative working action are as follow:

1. There is a push type on-off button which use to connect or disconnect the motor driver with the 12V of the Li-Po battery. As the Arduino's 5V connection comes from the motor driver and Bluetooth module gets power by the Arduino. Soby turning on this button, approximately full system gets power except ESC. Because the ESCis directly connected with the main 12 V of Li-Po
2. After turning on the switch, the red indication light of the robot turns into the green after a while.The green light indicates that the robot is ready tooperate.
3. While the green light is on, the android RemoteXY application need to open and connectit to our robot's Bluetooth. Then the turn onbutton of our GUI need to turn on to use other controlling functionality of the remote designed to control the robot. By using joystick of the controlling layout, the robot is controlled andmoved it to the climbing point.
4. The wheels of the robot have been set in such a way, so that it can climb up itself to the initial climbing position. For this, the joystick only needto slide in forward driving position to set it on theinitial climbing position
5. After setting on the initial climbing position, the operator slide up the RPM control slider of controlling remote. By sliding up, operatorincreases the RPM of the BLDC motor. It increases the thrust force. The operator increasesit until the robot stuck the wall properly.
6. After the operator think that that the robot has clung with the vertical surface properly, he movesit on the vertical surface with the direction controljoystick. Then he moves it to the cleaning point of the vertical surface
7. After reaching to the point which need to becleaned, the cleaning mechanism is engaged by the operator by pressing the Engage-Disengage button of the controlling GUI. After engaging thebutton, operator need to wait until the indication light turns into blue from green. The blue light indicates that the cleaning mechanism has been engaged on the surface and ready to clean.
8. Then the operator simply move the robot over thepoint which need to be cleaned. The cleaning device simply wipes such type of dirt which can be cleaned by the cleaning device. Thus, the cleaning is happened
9. After completing the cleaning, the robot isclimbed down carefully by the operator.

Chapter 04: Experimentation and Calculation

4.1 - Electronic Speed Controller (ESC) Selection [Back to : Subchap 5.3 / Subchap 5.4]

Calculation Load current of the BLDC A2212/6T 2200KV 3 phase induction motor:

From the specification of this BLDC,

Power, P = 239W

Assuming Power Factor, Cosφ = 0.8

Measured line to line voltage of 3 phase connection, $V_{line} = 7.95$ V

Load current draw by BLDC motor, $I_{rms.load} = P / \sqrt{(3 * V_{line} * \cos\varphi)}$

$= 239 / \sqrt{(3 * 7.95 * 0.8)}$

$= 54.72$ A

Hence, we need at least 50A ESC to run our robot properly. But due to the unavailability, we used a 30A ESC instead. For this, while running the BLDC, the ESC generating excessive heat that why we get a short running time.

4.2 - Condition for Clinging on Vertical Surface

- Measuring the thrust force generating by the propeller:

  Firstly, the BLDC motor attached with a six inches propeller was placed on the weight machine and rotated it near to full angular speed. The BLDC is connected through a 30A ESC with 12V 2200mAh Li-Po battery. The reading measured from the weight machine was 917 gm.

  Therefore the thrust force generated by the propeller, $F_{Thrust} = (917/1000)\ \text{Kg} * 9.81 \text{m/s}^2$

  $= 8.99577$ N

By applying static equilibrium equation horizontally,

$(\overleftarrow{+})\ \Sigma F_x = 0$

⇨ $F_{thrust} - F_{normal} = 0$

Therefore, $F_{thrust} = F_{normal}$ ....(i)

By applying static equilibrium equation vertically,

$(+\uparrow)\ \Sigma F_y = 0$

⇨ $F_{friction} - mg = 0$

⇨ $F_{friction} = mg$

⇨ $\mu s\ .\ F_{normal} = mg$

⇨ $\mu s\ .\ F_{thrust} = mg$ [from eq. i]

Therefore, $F_{thrust} = mg/\mu_s$

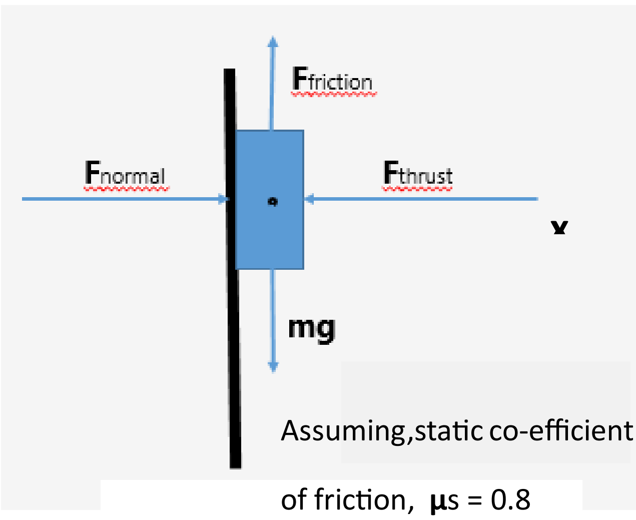


Figure 4.2.1: Free-body diagram of

In sense, if thrust force is greater than $mg/\mu s$ then the body should be more static. Hence,
$F_{thrust} \geq mg/\mu_s$

So, $m \leq (F_{thrust} \cdot \mu_s) / g$

$\Rightarrow m \leq (8.99577 * 0.8) / 9.81$
$\Rightarrow m \leq 0.733$ kg
$\therefore m \leq 733$ gm
According to this calculating we have to pack up our Wall climbing cleaner robot's overall mass within 733 gm.

4.3 - Maximum Mass of Robot can be Clung on Different Surface

- <u>On White Board</u>

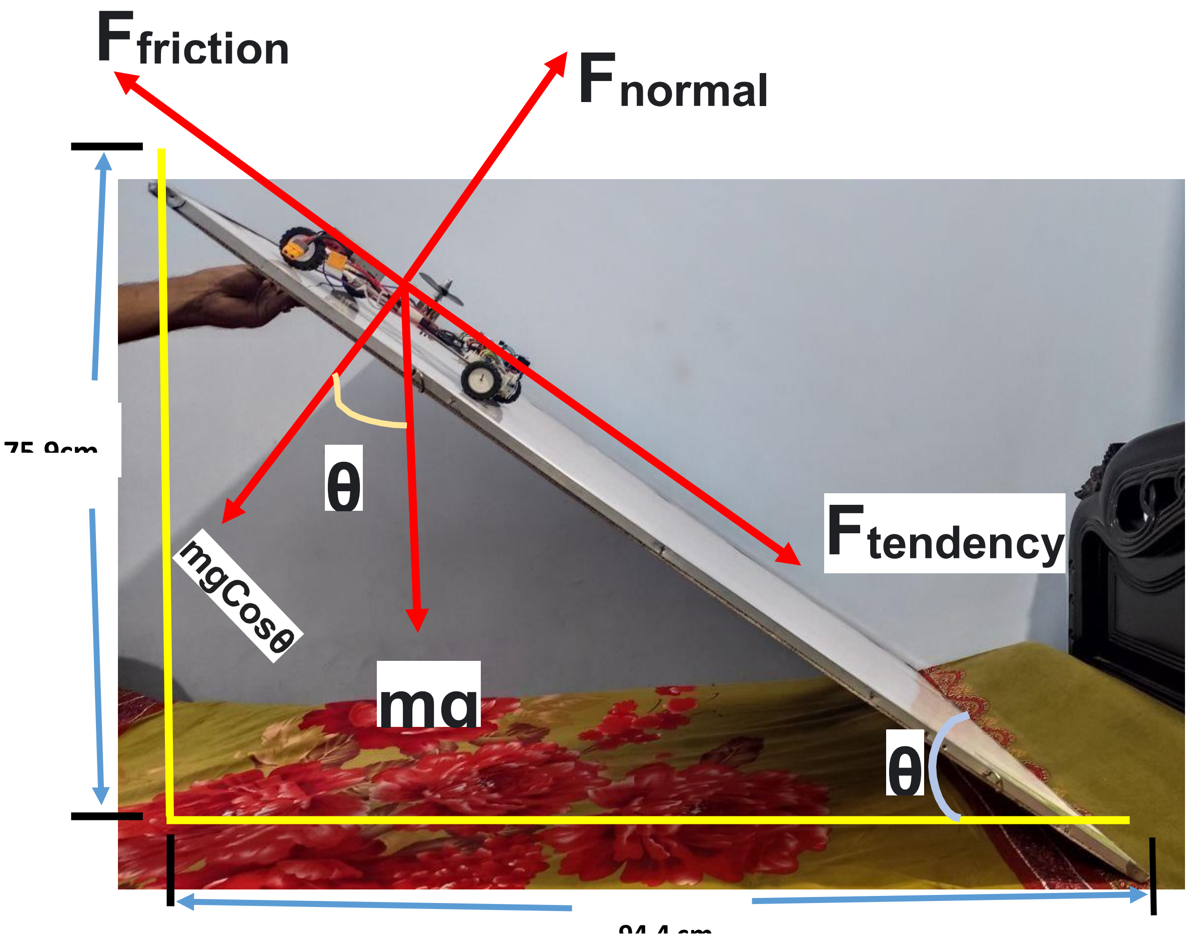


Figure 4.3.1: Experiment of determining the static frictional coefficient of rubber tyre on white board

Friction Force ∝ Normal Reacion Force

- ⇨ $F_{friction} = \mu_s * F_{normal}$
- ⇨ $\mu_s = F_{friction} / F_{normal}$
- ⇨ $\mu_s = mg \sin\theta / mg \cos\theta$
- ⇨ $\mu_s = \tan\theta$
- ⇨ $\mu_s = 79.9 / 94.4$

Therefore, $\mu_s \approx 0.80402$

Hence, static friction co-efficient of rubber tyre on white board is approximately 0.80402

Probable mass can be clung when the vertical surface is a white board,

From 4.2,
$m \leq (F_{thrust} * \mu_s) / g$

- ⇨ $m \leq (8.99577 \text{ N} * 0.80402) / 9.81 \text{ m/s}^2$
- ⇨ $m \leq 0.73729$ Kg

Therefore, $m \leq 737.29$ gm

According to this calculation, we have to pack up our Wall climbing cleaner robot's overall mass within 737.29 gm while clinging on white board surface.

Surfaces in contact	μ. Static friction coeficiente
Wood on wood	0,5
Steal on ice	0,03
Teflon on teflon	0,04
Rubber on dry cement	1
Glass on glass	0,9
Ski (waxed) on snow (0°C)	0,1
Wood on leather	0,5
Aluminum on steel	0,61
Human joints	0,02

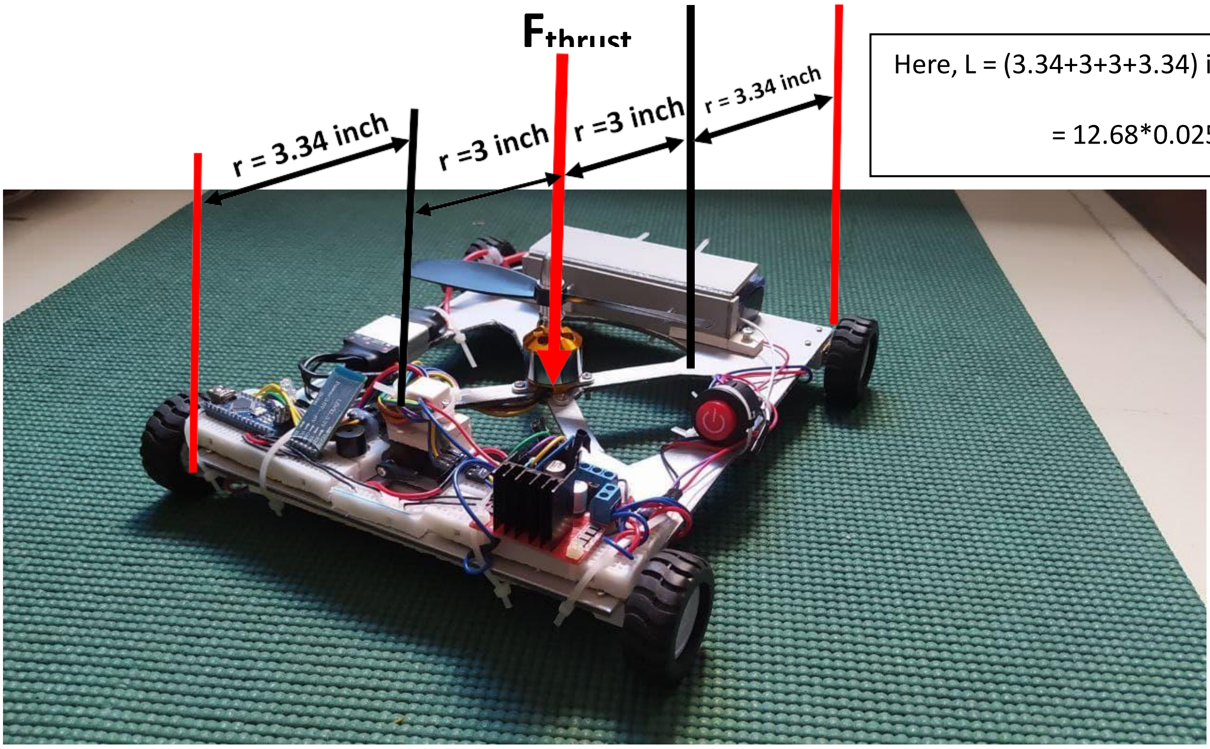
From 4.2, **Fig 4.3.2:** Climbing on Dry Concretem :

- ⇨ $m \leq (8.99577\ N * 1) / 9.81\ m/s^2$
- ⇨ $m \leq 0.917$ Kg
- ⇨ $m \leq 917$ gm

According to this calculation, we have to pack up our Wall ClimbingCleaner robot's overall mass within 917gm while clinging on dry concrete surface.

4.4 - Chassis Material Selection

We have to select such type of chassis material which has certain amount of bending moment to resist bending of chassis.



Here, L = (3.34+3+3+3.34) inch

= 12.68*0.0254 m

Assuming this case is with in simply supported beam with constant cross-sectional area :

Moment produced due to thrust force F_{thrust} ,

$M_C = F_{thrust} * L / 4$

$= 8.99577 * 0.3134 / 4$

$= 0.7049$ Nm

So, the moment produce due to thrust force is 0.7049 Nm

Now determining resistive internal bending moment of ACP material,

$M./ I = \sigma_b / y$

⇨ $M = \sigma_b * I / y$

Here,
Width, b = 1.4 cm = 0.014 m
Thickness, h = 4 mm = 0.004 m
Moment of inertia, $I = bh^3 /12 = 7.467\times10^{-11}\ m^4$
Distance from neutral axis, y = 0.014/2 = 0.007 m

- $\Rightarrow$ $M = (\sigma_b * bh^3 /12) / (b/2)$
- $\Rightarrow$ $M = (\sigma_b * bh^3 /12) / (b/2)$
- $\Rightarrow$ $M = (145x10^6) * (7.467x10^{-11} / 0.007)$
- $\Rightarrow$ $M = 1.55$ Nm
- In sense, if,

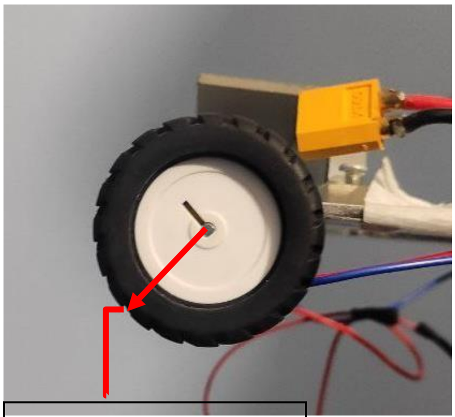
$M_C > M$: then it should bend

$M_C < M$: then it should not bend

As, we get M = 1.55 Nm and M_C = 0.7049 Nm. So, it satisfies our desired condition, $M_C < M$.

Hence, ACP is suitable chassis material for this project.

4.5 - Torque and Force Calculation of Gear Motor



r =2.15cm

Radius of wheel, r =2.15cm = 0.0215m

For gear motor,

Voltage, V = 12 V

Current, I = 70 mA = $70x10^{-3}$ A

From specification of our gear motor,

Angular velocity, $\omega = (2*\pi*110) / 60$

$= 11.52$ rad/sec

So, power,

$P = \tau*\omega$

- $\Rightarrow$ $\tau = P / \omega$
- $\Rightarrow$ $\tau = VI / \omega$
- $\Rightarrow$ $\tau = 12*70x10^{-3} / 11.52$

Therefore, $\tau = 0.0729$ Nm

We know torque, $\tau = r* F_{gear}$

So, force generated by gear motor,

$F_{gear} = \tau / r = 0.0729 / 0.0215$

$= 3.391$ N

For climbing on the vertical surface the gear motor should provide such amount of force $F_{desired}$.

$F_{desired} = F_{thrust} / 4 = 8.99577/ 4 = 2.249$ N

The reason behind dividing the thrust force by 4 because there are Force gear motor installed

So, force can delivered by each gear motor F_{gear} = 3.391 N, Force have to face while climbing on the vertical surface is $F_{desired}$ = 2.249 N

In sense, if,

$F_{gear} = F_{desire}$: The robot will operate under thrust force

$F_{gear} > F_{desire}$: It can successfully operate with more stability under thrust force

$F_{gear} < F_{desire}$: It can't be operate under thrust force

For our robot, $F_{gear} = 3.391$ N and $F_{desired} = 2.249$ N

So, $F_{gear} > F_{desire}$ is satisfied

Hence, the robot can successfully climb with more stability under thrust force.

Chapter 05: Result and Discussion

5.1 - Objectives Completed

- ✓ Design and fabricate a robot that can climb and clean the vertical surface.[See, Subchapter 3.3]
- ✓ Construct a custom cleaning mechanism that puts less amount of force against thrust force as the robot will mainly hold itself on the wall by thrust force. [See, Subchapter 1.5]
- ✓ Build a robot that can climb faster than the suction based climbing robot.

5.2 - Objectives Not Achieved

All of the three objective have been achieved successfully. No objective changed during the project timeline.

5.3 - Limitations

- If the full robotic system runs continuously with a full charge of 2200mAh 12V Li-Po battery, it will run only three and a half or four minutes. So, the duration of work with a full charge is very low.
- The cleaning mechanism that has been installed on this robot is very inefficient in terms of cleaning. The width of cleaning area by a single wipe is very small. [See, Subchapter 1.5]
- Heating issue is one of the major limitations of this robot. The heat mainly generates in the ESC and BLDC motor. [See, Subchapter 4.1]
- The signal range is very short. A HC-05 Bluetooth module is used as signal receiver in this project. The range is only 10 meters or approximately 30 feet.

5.4 - Future Improvements

- A vacuum and thrust based hybrid wall climbing robot can be developed in the future. A vacuum based system shows more stability while clinging on the wall than the thrust based. On contrary, thrust based system is faster in climbing on the wall.[See, Subchapter 1.6] . This combination can make this robot more efficient.
- More versatile and efficient cleaning mechanism can be developed. There are various type of vertical surface which need different types of cleaning. For this project, we have only focused on the smooth surface, like glass.
- It can be integrated with sensors. By this, the robot will become a self-operating, self-detecting cleaner robot.

Chapter 06: Conclusion

In this project, our objective was to design a cost efficient simple wall climbing cleaning robot. Among the other mean of wall climbing methods the propeller thrust method is quite cost effective and easy to design. During the climbing operation, a very precise calculation is done so that it can generate enough thrust to cling the whole body of the robot to the vertical surface. A very important term in this calculation was the determining the friction coefficient (μ_s) in static condition of the rubber wheels of the robot on white board. It was calculated through an experimental procedure. The programming code of the robot is also a vital part. This needs to be done in the most accurate way possible otherwise the robot will not work properly. The cleaning mechanism is a custom made mechanism which is designed especially for this robot. A separate calculation is also done for the stress and deformation of the chassis. It is a very important step as this calculation is directly related to material selection for the chassis. Overall weight distribution and the component set ups and their positions also plays a very important role for this robot to maintain its stability and fluent operation. However, this project is at its initial stage. Further development and research can be done to maximize the robot's efficiency and to enhance its abilities.

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Chapter 08: Appendix

8.1 - Programming Code

- ❖ Following coding is developed to create a program to control the overall operating system of the robot through GUI designed in RemoteXY website:

```
#define REMOTEXY_MODE__HARDSERIAL
#include <RemoteXY.h>

// RemoteXY connection settings
#define REMOTEXY_SERIAL Serial
#define REMOTEXY_SERIAL_SPEED 9600

// RemoteXY configurate
#pragma pack(push, 1)
uint8_t RemoteXY_CONF[] =
  { 255,5,0,0,0,64,0,15,31,0,
  5,36,66,10,32,32,2,26,31,4,
  0,15,14,8,36,2,26,10,59,77,
  48,13,13,12,26,31,69,110,103,97,
  103,101,0,31,68,105,115,101,110,103,
  97,103,101,0,2,0,31,4,22,11,
  2,26,31,31,79,78,0,79,70,70,
  0 };

// this structure defines all the variables and events of your control interface
struct {
// input variables
  int8_t joystick_1_x; // =-100..100 x-coordinate joystick position
  int8_t joystick_1_y; // =-100..100 y-coordinate joystick position
  int8_t slider_1; // =0..100 slider position
  uint8_t  switch_1;  //  =1  if  state  is  ON,  else  =0
  uint8_t switch_2; // =1 if switch ON and =0 if OFF

    // other variable
  uint8_t connect_flag;  // =1 if wire connected, else =0
} RemoteXY;
#pragma pack(pop)
```

```
#include <Servo.h>
Servo  Motor;
Servo myservo;
int x=60;

#define PIN_SWITCH_1 13

//define right motor control pins
#define right_motor_A 6
#define right_motor_B 7
#define right_motor_speed 5 //enable pin

//define left motor control pins
#define left_motor_A 8
#define left_motor_B 9
#define left_motor_speed 10 //enable pin

//define two arrays with a list of pins for each motor
uint8_t RightMotor[3] = {right_motor_A, right_motor_B, right_motor_speed};
uint8_t LeftMotor[3] = {left_motor_A, left_motor_B, left_motor_speed};

//speed control of motors
void Wheel (uint8_t * motor, int v) // v = motor speed, motor = pointer to an array of pins
{
  if (v > 100) v=100;
  if (v < -100) v=-100;
  if (v > 0){
    digitalWrite (motor [0], HIGH);
    digitalWrite (motor [1], LOW);
    analogWrite (motor [2], v * 2.55);
  }
  else if ( v<0 ){
    digitalWrite (motor [0], LOW);
    digitalWrite (motor [1], HIGH);
    analogWrite (motor [2], (-v) * 2.55);
  }
```

```
  else{
    digitalWrite (motor [0], LOW);
    digitalWrite (motor [1], LOW);
    analogWrite (motor [2], 0);
  }
}

void setup()
{
  RemoteXY_Init ();
pinMode(2, OUTPUT);
pinMode(4, OUTPUT);
pinMode(12, OUTPUT);
tone(2, 2500);
delay(1000);
  noTone(2);
  delay(1000);
  tone(2, 2500);
  delay(500);
  noTone(2);
  delay(500);
  tone(2, 2500);
  delay(500);
  noTone(2);
  digitalWrite(4, HIGH);

   myservo.attach(3);
myservo.write(150);
delay(2000);
myservo.write(180);
delay(2000);
myservo.write(120);
delay(2000);
myservo.write(60);

  pinMode(3,OUTPUT);
digitalWrite(12, LOW);
```

```
  pinMode (PIN_SWITCH_1, OUTPUT);

  //initialization pins
  pinMode (right_motor_A, OUTPUT);
  pinMode (right_motor_B, OUTPUT);
  pinMode (left_motor_A, OUTPUT);
  pinMode (left_motor_B, OUTPUT);

}

void loop()
{
  RemoteXY_Handler ();
  if(RemoteXY.switch_2==1)
  {
    //manage the right motor
  Wheel (RightMotor, RemoteXY.joystick_1_y - RemoteXY.joystick_1_x);
  Wheel (LeftMotor, RemoteXY.joystick_1_y + RemoteXY.joystick_1_x);

 Motor.attach(11,1000,2000);
 Motor.write(RemoteXY.slider_1 * 1.8);

 if(RemoteXY.switch_1==1)
  {
  if(x>30)
  {
      digitalWrite(4, LOW);
for (x=60; x>0 ; x--)
{
        // bail out on sensor detect
    myservo.write(x);
 delay(50);
}
digitalWrite(12, HIGH);
}
```

```
else
{
  x=0;
  digitalWrite(4, LOW);
  digitalWrite(12, HIGH);
}
}
    else
  {
    myservo.write(60);
    x=60;

    digitalWrite(12, LOW);
    digitalWrite(4, HIGH);
  }
  }
else
{

}

}
```