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# DESIGN, DEVELOPMENT AND FABRICATION OF MULTI-UTILITY MILITARY ROBOT (UGV)



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# DESIGN, DEVELOPMENT AND FABRICATION OF MULTI-UTILITY MILITARY ROBOT (UGV) (Project Thesis)

Prof.A.B.Amale  
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## Preface

It is said that “nothing succeeds like success”. Success is achieved by hard work, determination and devotion. But apart from that, it is guidance which counts the most. So, we take it as a privilege and great pleasure to express our deep sense of gratitude and heartfelt thanks to all those who have helped and guided us through our project. Our foremost thanks to our **HoD, Prof. J.P. Giri** for his constant guidance and valuable time, which he has devoted for us. We extend our sincere thanks to our Principal, **Dr. U.P.Waghe** for providing us the variety of opportunities, facilities, infrastructure and inspiration to gather knowledge for our project.

At last but not the least, we remain grateful to all those who directly or indirectly were involved in the successful completion of our project.

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**Prof. R.V.Adakane**



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Nagpur)**

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## **DECLARATION**

We certify that

- a. The work contained in this project has been done by us under the guidance of our supervisor(s).
- b. The work has not been submitted to any other Institute for any degree or diploma.
- c. We have followed the guidelines provided by the Institute in preparing the project report.
- d. We have confirmed to the norms and guidelines given in the Ethical Code of Conduct of the Institute.
- e. Whenever we have used materials (data, theoretical analysis, figures, and text) from other sources, we have given due credit to them by citing them in the text of the report and giving their details in the references. Further, we have taken permission from the copyright owners of the sources, whenever necessary.

Signature

Prof. A. B. AMALE

Prof. R.V.Adakane

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## LIST OF ABBREVIATIONS

| Symbol | Description            |
|--------|------------------------|
| V      | Voltage                |
| W      | Watt                   |
| kg     | Kilogram               |
| cm     | Centimeter             |
| m      | Meter                  |
| mm     | Milli meter            |
| ft     | Feet                   |
| mA     | Milliampere            |
| *      | Multiplier             |
| g      | Gram                   |
| h      | Hour                   |
| min    | Minute                 |
| RS     | Rupees                 |
| rpm    | Revolutions per minute |

| Abbreviations | Description                                |
|---------------|--|
| UGV           | Un-Manned Ground Vehicle                   |
| UAV           | Un-Manned Aerial Vehicle                   |
| UUV           | Un-Manned Underwater Vehicle               |
| DOF           | Degree of Freedom                          |
| 3D            | Third Dimensional                          |
| MCU           | Microcontroller                            |
| WI-FI         | Wireless Fidelity                          |
| IOT           | Internet of Things                         |
| ASME          | American Society of Mechanical Engineering |

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|       |   |
|-------|---|
| SCARA | Selective Compliance Assembly Robot Arm |
| CAD   | Computer-Aided Design                   |
| DC    | Direct Current                          |
| IC    | Integrated Circuit                      |
| ESP   | Electronic Stability Program            |
| PWM   | Pulse Width Modulation                  |
| BOM   | Bill of Material                        |
| CAM   | Camera                                  |
| TF    | Trans Flash                             |
| SD    | Secure Digital                          |
| SOC   | System On Chip                          |
| GPIOs | General-Purpose Input/Output            |
| RF    | Radio-Frequency                         |

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## **ABSTRACT**

The purpose of our project work is to design and develop a UGV which consists of 4 wheeled platform mounted with a low-cost robotic arm which is mostly 3d printed and has 5 DOFs with a 2 fingered gripper. The robotic arm is controlled with a puppet controller which is a desktop model of the robotic arm with the same degrees of freedom whose joints are equipped with sensors. Manipulating the controller by hand causes the robotic arm to mimic the movement in master-slave fashion. The arm design could be used in various light-duty applications. The system uses Wi-Fi module pair as a data transmission medium. The master-slave operator interface provides an easy-to-learn method for robotic arm manipulation. Esp8266 aka Node MCU is used as a microcontroller.

**Keywords** - Master-slave, Manipulator, Puppet-control, 3D printed, Robot.

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**CHAPTER 1**  
**INTRODUCTION**

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## **CHAPTER 1 : INTRODUCTION**

### **1.1 OVERVIEW**

Robots are the electro-mechanical machines which follows a set of commands input by its human operator to carry out certain tasks. These machines ranges from a very common day to day application like automatic soap dispenser machine to quite advanced ones like NASA's curiosity mars rover. Robots are assisting humans from past 60 to 70 years in many fields some of which are manufacturing/casting/testing industries, space industries, medical, military, home-assisting, personal assistants etc.

UGVs are a short term for 'Un-manned ground vehicle' operates on ground without human operator being present on it via wireless data transmission mediums like Radio controllers, WIFI communication, IOT etc. UGVs are being used for both civilian and military purposes where it's dangerous and hazardous for a human to perform operation. Other types being UAVs (Un-manned aerial vehicle) & UUVs (Un-manned underwater vehicle) which operates in Air and water respectively.

Robotic arms are another generation of robots usually programmable and having similar shape and functions as that of human arm. This is a revolutionary machine invented by George Charles Devol Jr an American inventor in 1954. They are used in almost every big industry as of today. Apart from industries these robotic arms share common applications as of any robot as stated earlier.

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## **1.2 PROBLEM STATEMENT**

- Current robots (usually surveillance & rescue robots) are generally designed and manufactured for limited task and each of them requires at-least one operator online to carry out the operations
- Traditional control methods (i.e. dials/switches, joystick controllers, etc.) are inefficient and less effective for carrying out such operations.
- Each robot used for each task consumes resources that can be minimized by combining them into one.

## **1.3 THESIS AIMS & OBJECTIVES**

- **AIMS:**

There were 2 major Aims behind choosing this project. These Aims further became the motive to design, Develop and fabricate this entire Robot. They are stated as follows.

- 1. Development of a robotic system that can save lives by allowing humans to perform dangerous tasks at safe distances.**

Human life is most precious gift one can think of. If one can save even a single human life by allowing military/rescue/firefighter or any other personnel to carry out a task at enough distance to prevent potential harm by any means it must be of highest priority.

- 2. Development of low-cost robot that can be used for educational purpose.**

This Aim is in consideration with Robotic Arm. Unfortunately, accessibility of such robotic technology which is revolutionizing modern world is limited to certain institutions only. We aim at developing and making this project open source so that individuals can make, modify & explore it on their own. Being a low cost and fully open source, this may inspire fellow students to learn and explore this field.

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- **OBJECTIVES:**

1. Examine current developments in UGV robotics.
2. Determine the topology of Robot Arm according to its application and specifications.
3. Testing for cheapest replacement equipments in order to keep project as low in cost as possible
4. Examine and develop the control most suitable drive mechanism and feedback system for Arm.
5. Develop efficient control techniques for the assembly.

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## **CHAPTER 2**

### **LITERATURE REVIEW**

## **CHAPTER 2 : LITERATURE REVIEW**

### **2.1 LITERATURE REVIEW**

#### **[1]Design of a Robotic Arm By I.M.H. van Haaren**

Tulip is a bipedal robot which is a part of Dutch Robotics initiative which is a result of a cooperation Delft University of Technology, University of Twente and Eindhoven University of Technology. Based on the dynamic walker Flame and was especially designed for humanoid walking. It has six degrees of freedom which allows the robot to walk in any direction in a humanlike way. In order to pick up and move objects a new arm for TULip needs to be designed. Van Haaren describes the theory behind designing this arm and the designing process in this report. It should be able to make those movements while carrying a Weight of approximately 0.5 kg. In order to let the arm move in a human like way the Arm should have more degrees of freedom (DOF's) than tulip has at this moment. A human arm has 7 DOF's, three in the shoulder, two in the elbow and two in the wrist. The two DOF's in the wrist is negligible and can be adopted by the other two joints So the wrist joint will only have one DOF which gives the full control over the orientation of the gripper Therefore the robot arm that is designed has 6 DOF's 3 in the shoulder, two in the elbow and one in the wrist. Every DOF has a link so the robot arm consists of 6 links, these links connect the different DOF, therefore the upper arm and lower arm can be considered as a link. The lengths of the major body segments are expressed as a fraction of the total height Tulip is approximately 1.3 meter, so the measurements of the upper arm and lower arm will be respectively 0.24 and 0.19 meter.

#### **[2]John R. Rogers presented Low-Cost Tele-operable Robotic Arm in Elsevier.**

He made a controller which is a desktop model of robotic arm with the same degree of freedom whose joints are equipped with sensors. Manipulating the controller by hand causes the robotic arm to mimic the movement in master-slave fashion. This is accomplished simply and at low-cost by taking advantages of widely available hobby radio control components. The system uses the trainer function available on common radio control transmitters as a simple interface between microcontroller and transmitter. The arm design could be used for various light-duty

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applications. The master-slave operator interface provides an easy-to-learn method for robotic arm manipulation.

**[3] Prashant Kumar, Wael Saab & Pinhas Ben-Tzvi presented Design of A Multi-Directional Hybrid-Locomotion Modular Robot with Feedforward Stability Control in American Society of Mechanical Engineering (ASME).** The design of a modular robot capable of multi-directional mobility to aid reconfiguration on uneven terrain on uneven terrains, reconfigurable robots face challenges due to the requirement of precise alignment between modules during the docking procedure a survey of current modular reconfigurable robots is presented, analysing their strengths and shortcomings in reconfiguration and mobility. A novel design is formulated that features a hybrid combination of wheels and tracks, symmetrically assembled about the front and right planes, providing multi-directional mobility and modularity. The robot can move over uneven terrain via tracks, move at higher speeds via wheels placed orthogonally to the tracks. Tracks possess yaw mobility via differential drive.

**[4] Pinhas Ben-Tzvi, Andrew A. Goldenberg & Jean W. Zu presented Design and Analysis of a Hybrid Mobile Robot Mechanism with Compounded Locomotion and Manipulation Capability in American Society of Mechanical Engineering (ASME).** The mobile platform and the manipulator arm one entity rather than two separate and attached modules. Moreover, the mobile platform can be used as part of the manipulator arm and vice-versa. Some of the same joints that provide the manipulator's DOFs also provide the platform's DOFs, and vice-versa. The robot's adaptability is enhanced by "allowing" it to flip over and continue to operate instead of trying to prevent the robot from flipping over or attempting to return it (self-righteousness). When a flip over occurs, due to a fully symmetric design with the arm integrated, it is only required to command the robot to continue to its destination from the current position.

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## **CHAPTER 3**

### **WORK DONE**

## **CHAPTER 3 : WORKDONE**

### **3.1 OVERVIEW**

After aims and objectives of the project lets quickly jump to the procedure followed in building this robot vehicle. Following are the steps which were taken to build the Robot.

### **3.2 METHODOLOGY**

#### **3.2.1 TOPOLOGY OF ROBOTIC ARM**

Before making a Robot arm first thing to decide is that for what purpose one is going to use it. Based on our aims and objectives this robot is basically for lifting objects as well as to perform basic human task like opening door latch/car door, to pull or push a button or rotate a knob etc. Considering our scenario defining the topology includes defining the configuration of robot arm and its joint notation scheme.

Based on the types of joints (linear, rotational, orthogonal etc) different Robotic arm configurations are as follows

1. SCARA
2. Cylindrical Robot
3. Cartesian Robot
4. Polar/Spherical Robot
5. Jointed arm Robot

Selection criteria were based on the work envelop/volume obtained. As the aim was to achieve max operable work volume with ease of operation the most suitable type was jointed arm robot.

Different configurations along with their work volumes are shown in “**Fig 3.1**”

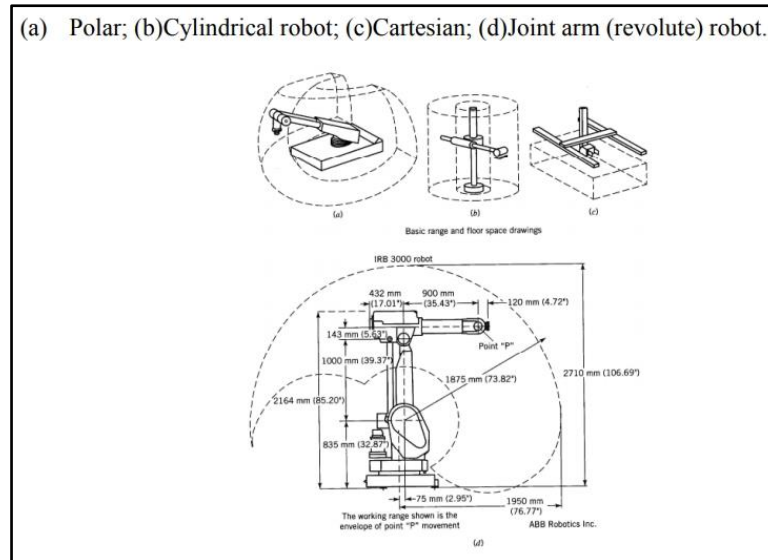


Fig 3.1 Robotic Arm Based on Types of Joints

Finalizing the configuration precedes by selection of joint types. When each joint type is defined they combine to define joint notation scheme of the robot which ultimately defines the work volume of robot.

Human arm consists of 7 DOFs 2 in shoulder similarly 2 in elbow and 3 in wrist.

Our robot has 5 DOFs with the joint types from base to TCP being

Joint 1 - twisting

Joint 2 - rotational

Joint 3 - rotational

Joint 4 - rotational

Joint 5 - twisting

with **joint notation scheme of TRR:RT**

(Note → ‘:’ separates body and arm assembly from wrist assembly).

### 3.2.2 SELECTION OF DRIVE MECHANISM

There are ample of drive systems available out there. All of these serve different purposes like varying torque, speeds, precision, flexibility etc.

When came into discussion we shortlisted 3 most convenient methods to drive the robot which are shown in “**Fig 3.2**”.Each of this has certain advantages and limitations which differentiates each one from other.

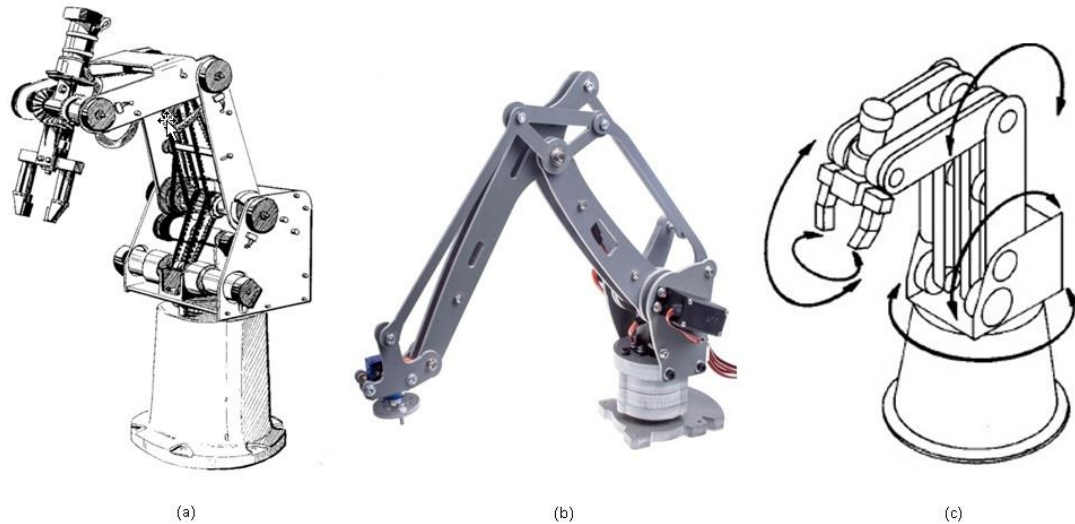


Fig 3.2

- **Belt And Pulley Driven:** It is possible that belt can slipover pulley when high dynamic loads are applied onto the joint which is will hamper precision of the robot. Also the belts are flexible (rubber belts) which may also cause accuracy issues.
- **Linkage Driven:** This system is best suitable when you don't want the weights of motors or actuators to be at the joints which causes a lot of power wastage in upcoming torque exerted by motor's weight. But one of the issues with this is that the links can't retreat fully so as to fold the arm for better maneuverability of the vehicle.
- **Gear Driven:** There are many choices when it come to using gear boxes. we used single spur gear and pinion pair arrangement. It quite economic and provide enough torque to fulfill the requirement which were lacking in above 2 cases.

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### 3.2.3 SELECTION OF LINK LENGTHS FOR OPTIMUM PERFORMANCE

Link lengths play a key role in performance of a robotic arm. While increasing lengths increases the reachability and work-volume but decreases dynamic stability and increases torque requirement to a great extent and vice versa. That's why choosing optimum link length is crucial.

I.M.H. van Haaren gave an excellent example of how he determined link lengths by using a biological reference in which lengths of the major body segments are expressed as a fraction of the total height. It's shown in "Fig 3.3"

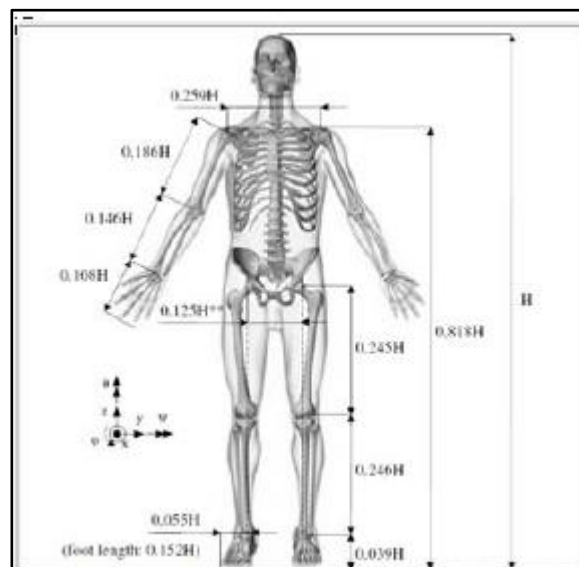


Fig 3.3

That's exactly what we used as a reference to formulate link lengths of our robot arm.

Further part of length calculation is described in next section of this chapter.

### 3.2.4 CALCULATIONS

#### 3.2.4.1 Link Length Calculations:

Taking further the discussion in (Section 3.2.3) we have to formulate link length based on human physiology. 'H' in "Fig 3.1" represent total height of body which in our case will be total arm length as we only have arm as body (excluding platform).

**Assumption:** with a bit of observation and discussion we came to conclusion that our robot should have total reach of about 800 mm (base to Tool center point i.e TCP)

For design constraints we assumed gripper to be 150 mm long which means excluding the end-effector (Two fingered gripper) arm would be 650 mm long.

From the figure 3.3 we can conclude that

$$0.186 (H) + 0.146 (H) + 0.108 (H) = \text{Arm Length} \quad \dots\dots\dots (1)$$

Where,

$$H = \text{constant}$$

& Arm length = 650 mm

Solving Eq (1) gives

H = 1477 (approx.) , substituting the value of H for each link gives desired length.

$$L_1 = 0.186 (H) = 0.186 * 1477 = 274 \text{ mm}$$

$$L_2 = 0.146 (H) = 0.146 * 1477 = 215 \text{ mm}$$

$$L_3 = 0.108 (H) = 0.108 * 1477 = 160 \text{ mm}$$

$$\text{Gripper} = 150 \text{ mm}$$

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### **3.2.4.2 Maximum Static Torque Calculations:**

**Introduction:** Once the link lengths were finalized and configuration was decided next step is to calculate the torque which will be acting on each joint because of self load and payload.

There are 2 types of torques which need to be find out,

- 1- Static Torque
- 2- Dynamic Torque

Static Torque corresponds to static conditions i.e. when velocity of system is zero or system is at static condition. This doesn't take in account forces due to inertia, drag forces etc.

While dynamic force is one which is considered while system is in motion or have some velocity. This is usually simulated on CAD model of system before fabricating it. Unfortunately we couldn't perform dynamic simulation of our Robot so, here is static calculations in which Torque at each joint is calculated when Arm is fully stretched in horizontal.

These calculations were done in 2 stages,

- 1- Assumed Calculations
- 2- Actual Calculations

These stages are explained in further part of thesis (PTO)

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### **3.4.2.2.1 Assumed Calculations:**

For calculating torque, we used basic concepts of torque and moments applied in engineering.

There are 2 major components in torque  $T = F$  (force)  $\times$   $R$  (perpendicular distance).

In our case  $F$ =load (mass of joint and link) and  $D$ =link length. As link lengths are already determined (Section 3.2.4) next thing is to find out weight of components. As we didn't buy any motors yet (Because required motor torque for each joint is unknown) so we did these calculations in following iterations.

1. We assumed aluminum channel (Link) as a uniform material throughout its length and divided weight of total 1 meter piece with length of pieces that are going to be used.

Weight of 1 meter aluminum piece = 1000g. (i.e. 1mm=1g, uniform material)

Hence Wt of links are as follows. (Except adding joint weight)

$L_1 = 274g$

$L_2 = 215g$

$L_3 = 160g$

2. As for the joints, We assumed certain values of weight for each joint (including motor weight + weight of 3D printed parts & others).

Following are assumed weights for joints:

Shoulder joint  $W_s$  = doesn't matter as its base and doesn't overhang.

Elbow joint  $W_e = 410g$

Wrist joint  $W_w = 380g$

Gripper + payload ( $W_g + p$ ) = 400 + 500 = 900g

**Table 3.1 Motor Torque**

| S. No | L(cm) | M(Kg) | A(Kg) | T(Kg-cm) | G.R | M.T(Kg-cm) |
|-------|-------|-------|-------|----------|-----|------------|
| 1     | 27.4  | 0.274 | 0.410 | 109.2    | 3.4 | 32.14      |
| 2     | 21.5  | 0.215 | 0.380 | 49       | 3.4 | 14.4       |
| 3     | 16.0  | 0.160 | 0.900 | 15.63    | 1.5 | 10.5       |

Where,

L = Link length

M = Weight of link

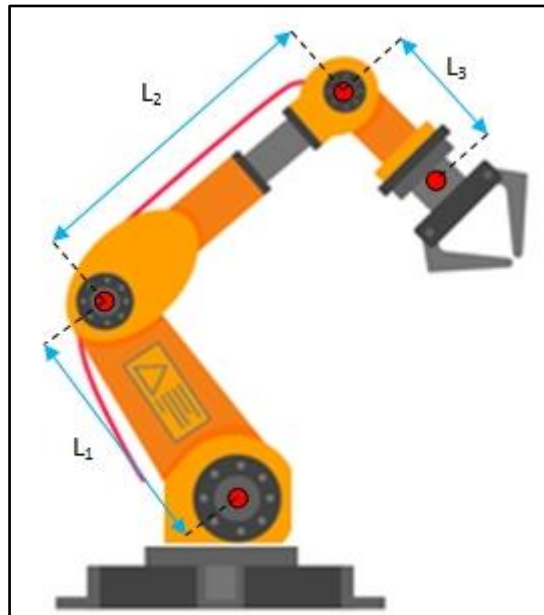
A = Weight of actuator (joint)

T = Torque at joint

G.R = gear ratio between motor and o/p shaft

M.T = Motor torque required

**(Note: Figure is unreal it's used for better understanding)**



**Fig 3.4 Link Length**

**Stepwise joint torque calculations are described below:**

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### STEP 1: - Joint 1

As joint 1 has no resistance to motion except for the inertia of robot assembly and friction in bearing (which is negligible) that also is insignificant. Hence, calculations were skipped.

Motor for joint 1 is selected by trial and error method.

- \* **Note:** - In “Fig 3.4” and “Table 3.1” only calculations for joint 2, 3 and 4 are demonstrated, joint 1 and 5 are skipped. Hence T1 corresponds to torque of joint 2 and so on.

### STEP 2: - Joint 2

$$T1 = A3(L1 + L2 + L3) + A2(L1 + L2) + A1(L1) + M3\left(\frac{L3}{2} + L2 + L1\right) + M2\left(\frac{L2}{2} + L1\right) + M1\left(\frac{L1}{2}\right)$$

$$T1 = 0.9(27.4 + 21.5 + 16) + 0.38(27.4 + 21.5) + 0.41(27.4) + 0.16\left(27.4 + 21.5 + \frac{16}{2}\right) + 0.215\left(27.4 + \frac{21.5}{2}\right) + 0.274\left(\frac{27.4}{2}\right)$$

$$T1 = 109.28 \text{ kgcm}$$

We know, Gear Ratio is  $\frac{T2}{T1} = \frac{N1}{N2} = \frac{D2}{D1}$  and we already know the pitch circle diameter (PCD) for gears we've used for each joint (Refer section 3.6, gears)

$$\therefore \text{Gear ratio for joint 2 is } \frac{D2}{D1} = \frac{85}{25} = 3.4$$

$$\therefore \text{Motor torque, } MT1 = \frac{T1}{GR1} = \frac{109.28}{3.4}$$

$$MT1 = 32.14 \text{ kgcm}$$

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**STEP 3: - Joint 3**

$$T2 = A3(L1 + L2) + M3 \left( L2 + \frac{L3}{2} \right) + A2(L2) + M2 \left( \frac{L2}{2} \right)$$

$$T2 = 0.9(21.5 + 16) + 0.16 \left( 21.5 + \frac{16}{2} \right) + 0.38(21.5) + 0.215 \left( \frac{21.5}{2} \right)$$

$$T2 = 48.9 \approx 49 \text{ Kgcm}$$

Gear ratio for joint 3 is 3.4 (Refer section 3.6, gears)

$$MT2 = \frac{T2}{GR2} = \frac{49}{3.4} = 14.4 \text{ Kgcm}$$

$$MT2 = 14.4 \text{ Kgcm}$$

**STEP 4: - Joint 4**

$$T3 = L3 \times A3 + \frac{L3}{2} \times M3$$

$$T3 = 16 \times 0.9 + \frac{16}{2} \times 0.16$$

$$T3 = 15.63 \text{ Kgcm}$$

Gear ratio for joint 4 is 1.5. (Refer section 3.6, gears)

$$\therefore M.T3 = \frac{T3}{G.R3} = \frac{15.63}{1.5} = 10.5$$

$$M.T3 = 10.5 \text{ Kgcm}$$

**STEP 5: - Joint 5**

As joint 5 has no resistance to motion expect inertia of gripper which is insignificant calculations were skipped.

Motor for joint 5 is selected by trial and error method.

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previous 2 steps provided us with 1st iteration motor torque (M.T) values as shown in the **table**. For these values we found out suitable motors online having considerable weight along with other specs (Torque and Rpm).

after finalizing the motors, weight of joints were measured including 3d printed part and other electronics mounted. These are shown below:

Shoulder joint  $W_s$  = doesn't matter as its base and doesn't overhang.

Elbow joint  $W_e$  = 380g

Wrist joint  $W_w$  = 340g

Gripper + payload ( $W_g + P$ ) = 400 + 500 = 900g

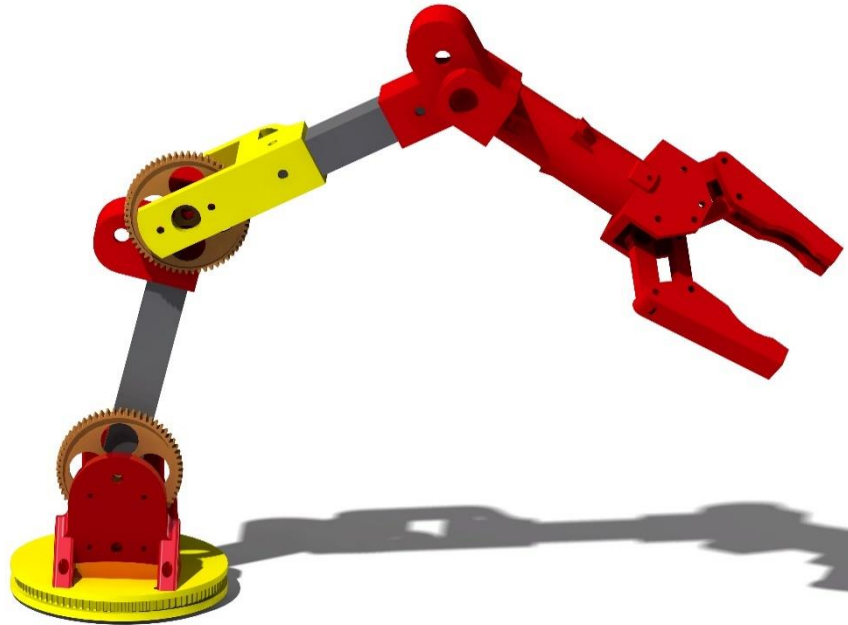
3. In 2nd iteration we used original weights of motors (which we found out in 3rd step) and again calculated the static torques for each joint.

**Table 3.2 Static Torque**

| <b>S. No.</b> | <b>L(mm)</b> | <b>M(g)</b> | <b>A(g)</b> | <b>T(kg-cm)</b> |
|---------------|--------------|-------------|-------------|-----------------|
| 1             | 274          | 274         | 380         | 106.5           |
| 2             | 215          | 215         | 340         | 48              |
| 3             | 160          | 160         | 900         | 15.7            |

### **3.3 PROJECT DESIGN**

#### **3.3.1 CAD Model**

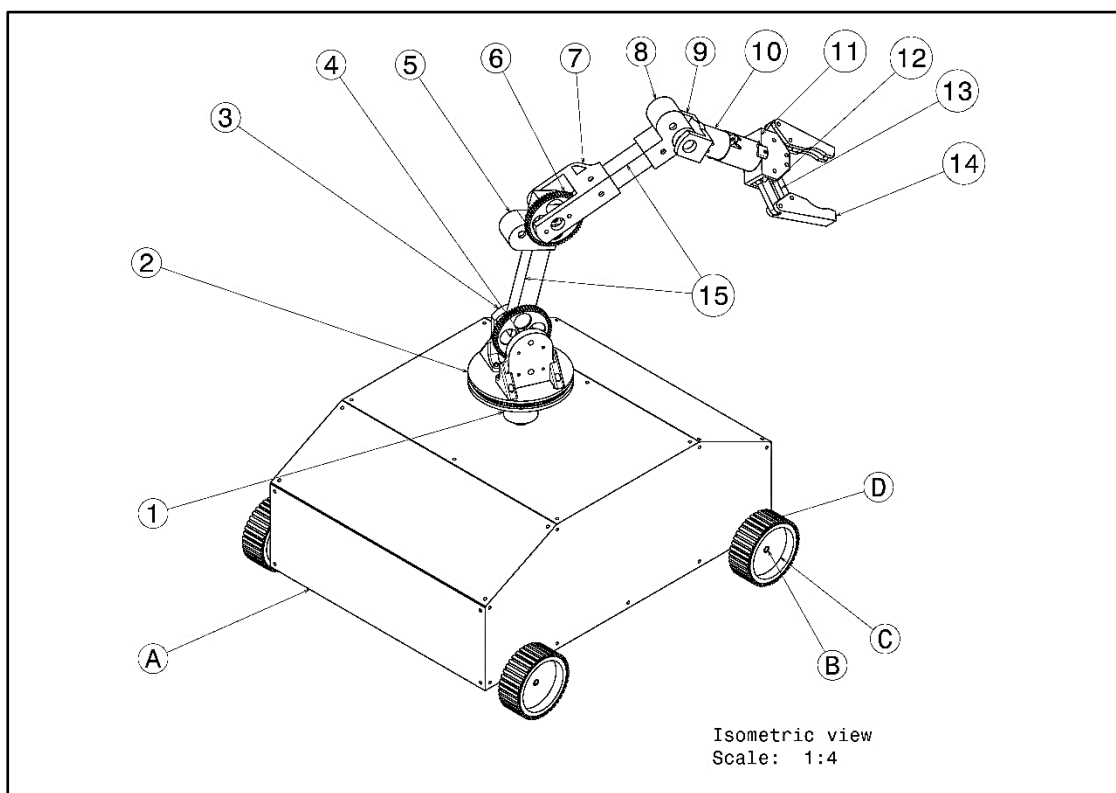


**Fig. 3.5 Robotic Arm**



**Fig 3.6 Arm Mounted On Platform**

### 3.3.2 Bubble Diagram



**Fig 3.7 Bubble Diagram of Assembly**

**Table 3.3 Components in Bubble Diagram**

| <b>SR.NO</b> | <b>COMPONENT</b>   | <b>QUANTITY</b> |
|--------------|--------------------|-----------------|
| 1            | Bearing mount      | 1               |
| 2            | Base joint pully   | 1               |
| 3            | Shoulder joint 1   | 1               |
| 4            | Shoulder joint 2   | 1               |
| 5            | Elbow joint 1      | 1               |
| 6            | Main gear          | 2               |
| 7            | Elbow joint 2      | 1               |
| 8            | Wrist 1            | 1               |
| 9            | Wrist 2            | 1               |
| 10           | Motor joint        | 2               |
| 11           | Side plate         | 1               |
| 12           | Long jaw           | 2               |
| 13           | Short jaw          | 2               |
| 14           | Gripper handle     | 2               |
| 15           | Aluminum extrusion | 2               |
| A            | Robotic Platform   | 1               |
| B            | Wheel Shaft        | 4               |
| C            | Wheel Rim          | 4               |
| D            | Wheel Tire         | 4               |

### 3.4 DRAFTING

#### 3.4.1 Robotic Platform Front View

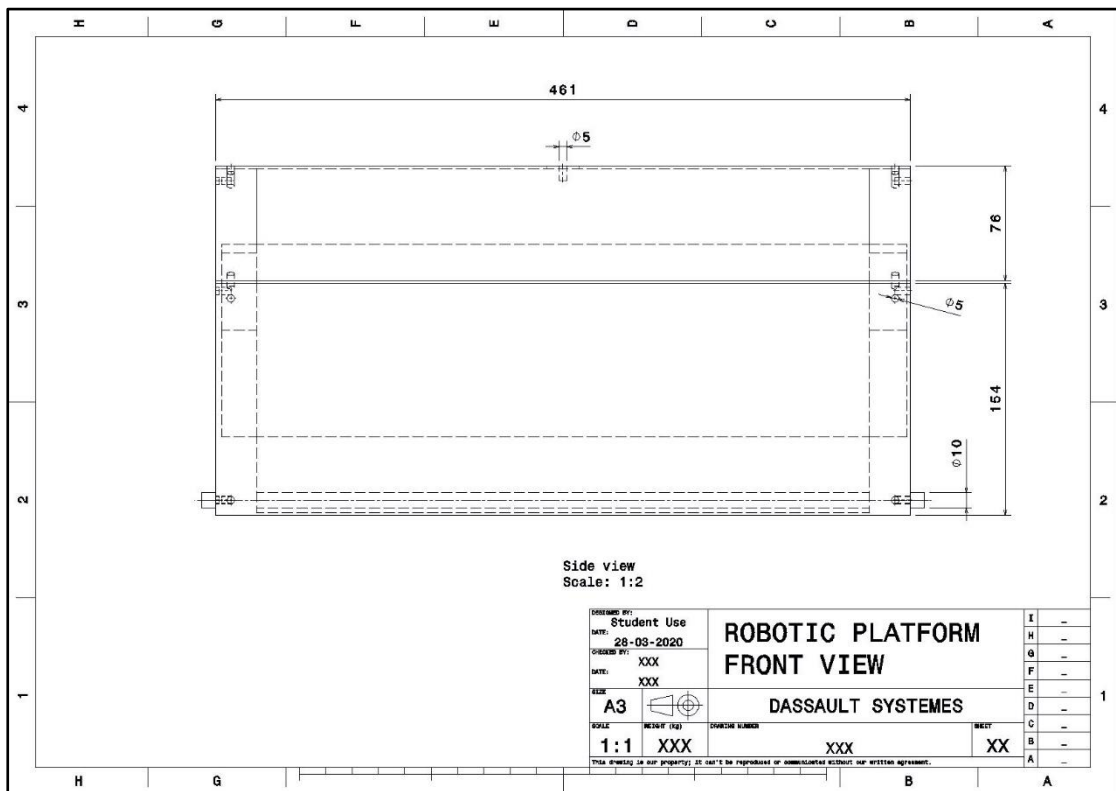


Fig 3.8 Drafting of Front View



### 3.4.3 Robotic Platform Different View

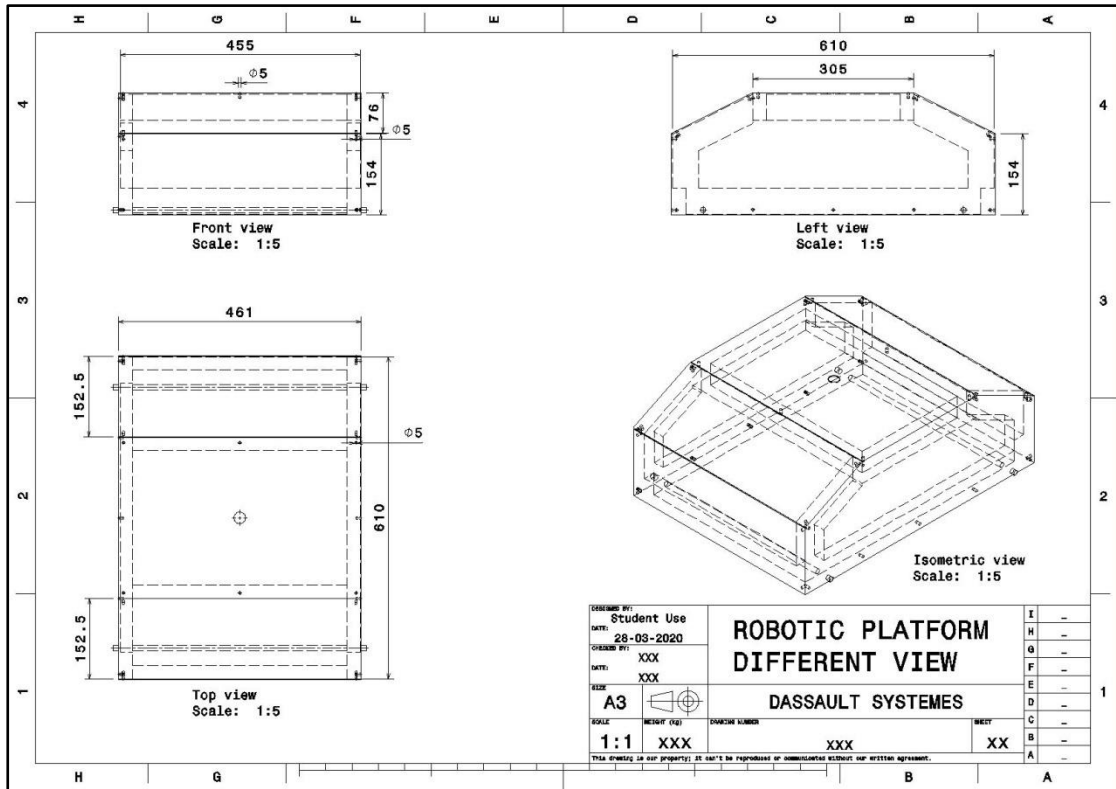


Fig 3.10 Drafting of Different View

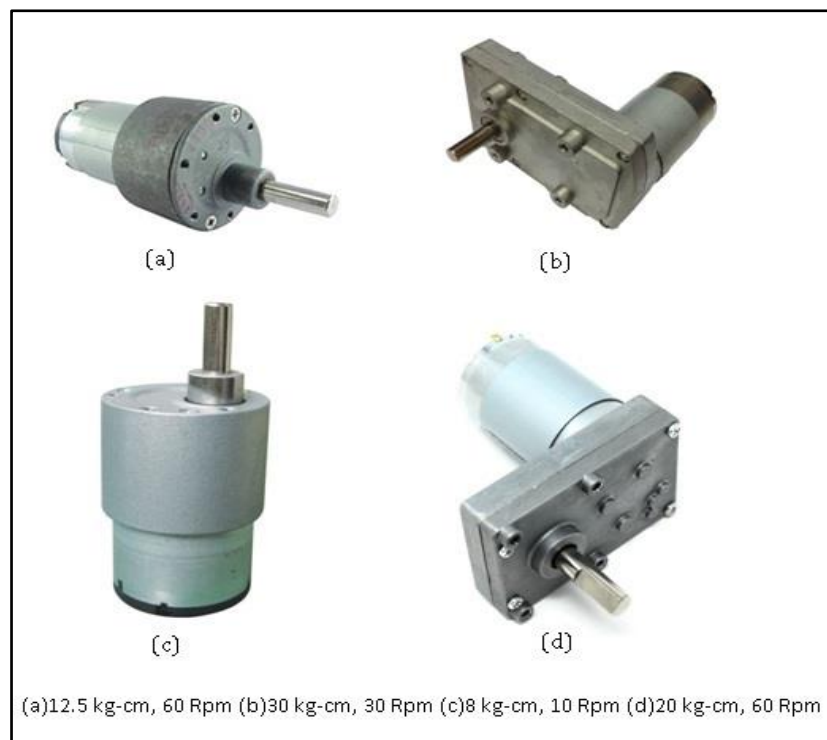
### **3.5 COMPONENTS**

#### **DC GEARED MOTOR (60 RPM)**

DC motor is used for the shoulder joint in robotic arm. The DC motor has armature control and set of gears on output shaft. These DC motor convert the DC electrical energy into mechanical energy. The DC motor works on the principle that “When a current carrying conductor is placed in a magnetic field, a torque is acted on it, due to these conductor moves”. This is called as motoring action.

These are the most common type of motor used in robotic. They come in variety of sizes and shapes like permanent magnet ironless rotor, permanent magnet brushless , permanent magnet iron core, wound field shunt connected, wound filed series connected, wound field compound connected, variable reluctance stepper, hybrid stepper motor, permanent magnet stepper.

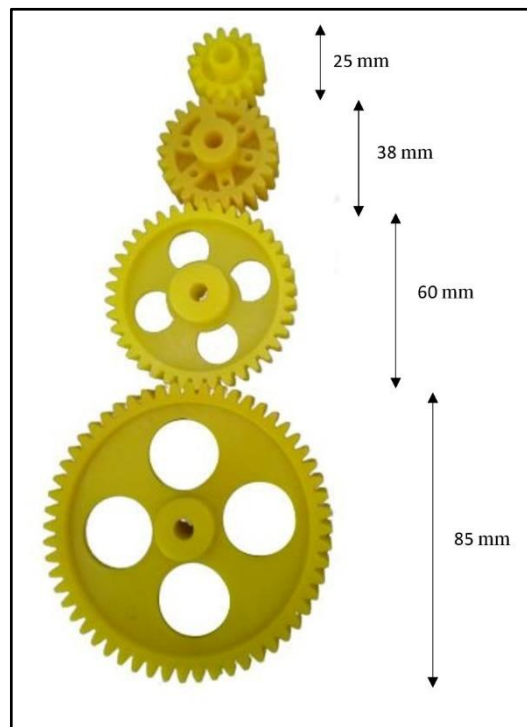
Following were the motors used in different joint with various torque and speed.



**Fig 3.11**

**GEARS**

Gear is a rotating machine part which having cut teeth or cogs, which mesh with another toothed part in order to transmit the torque. A gear can produce a mechanical advantage through a gear ratio and thus may be considered a simple machine. Geared devices can change the speed, torque and direction of a power source. A particular gear train is made up of two or more gears. Between an input and output shaft; there will be change in angular velocity and torque.



**Fig 3.12**

The previous gear system used in the design iteration involved four sets of spur gears, with one of those inside the gripper.

**Table 3.4 Gear Train**

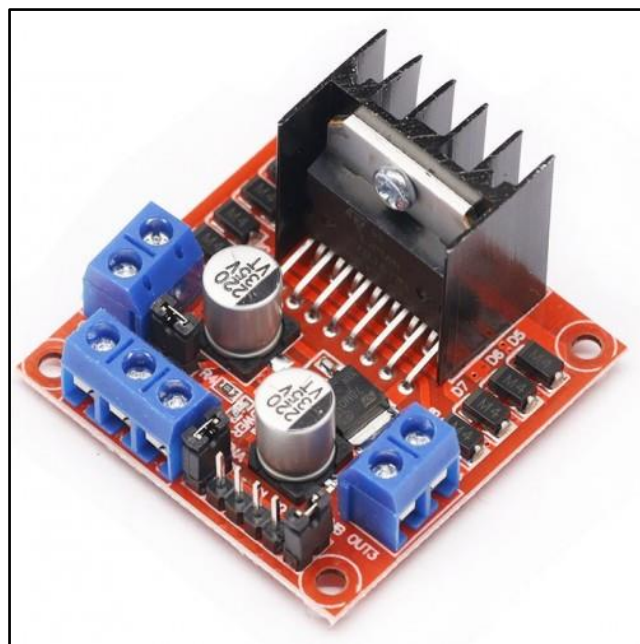
| Joint | Gear Ratio | Specifications( mm )                       |
|-------|------------|--|
| J1    | 4.25:1     | 85 mm / custom designed smaller gear 20 mm |
| J2    | 3.4:1      | 85mm/25mm                                  |
| J3    | 3.4:1      | 85mm/25mm                                  |
| J4    | 1.5:1      | 38mm/25mm                                  |

### **L298N DC MOTOR DRIVER**

This Driver is perfect for driving the DC motors and stepper motors. This motor driver module is a high-power motor driver. This driver uses IC L298 and has an onboard 5V regulator which can supply to an external circuit. It can control the direction and speed of 4 DC motors or 2 DC motors.

For robotics and mechatronics projects this motor drivers are used. They are also perfect for controlling motors from micro-controllers, switches and relays. The H-Bridge circuit is a circuit which can drive current in either polarity and can be controlled by Pulse Width Modulation (PWM).

We can control the duration of electronic pulse by the means of Pulse Width Modulation.



**Fig 3.13**

3 of such drivers were used in the Arm and 1 in robotic platform to control total of 8 motors as each driver is capable of only controlling 2 individual motors.

## POTENTIOMETER

It is a three terminal mechanically operated rotary analogue which is used in various electrical and electronics circuits. Potentiometer is a passive device. It does not require power supply or additional circuit in order to perform the linear and rotary positional functions. It is an electrical instrument which is used to determine the electro motive force of a given cell, internal resistance of a cell. It is an analog sensor which is used to measure absolute angular rotation of linear motion of a mechanism. It has three terminals which uses a moving contact to form a variable resistor divider. When the outer terminals are connected to 5V and ground and the analog output is connected to variable contact, the analog output will see an analog voltage which varies as the potentiometer is turned.



**Fig 3.14**

These potentiometers were used as output sensors for position feedback at each joint and input sensor in puppet controller for giving position command to robot arm.

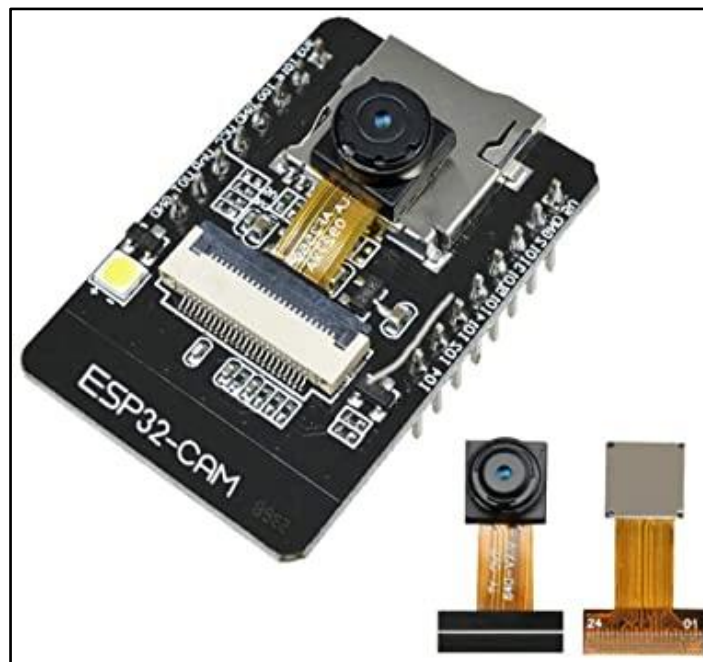
0.5W pot was used in the robot as it consumes less power and is loose (easy to rotate)

5W pot was used in puppet control. It consumes more power but is tight which causes puppet controller to hold its position while idle.

### **ESP 32 CAM (CAMERA MODULE)**

It is a very small size camera module that operates independently. It has deep sleep current of up to 6mA. In various applications of IOT ESP 32 CAM is used. It is used for wireless monitoring, smart devices, industrial wireless control, and QR wireless identification and IOT applications. For IOT applications ESP 32 CAM is ideal solution.

It provides customers with high-reliability connection mode. The ESP 32 CAM supports image Wi-Fi upload, TF card, multiple sleep modes, built in flash lamp. It also has micro SD card slot which can be used for storing images taken with the camera to store files to serve to clients.

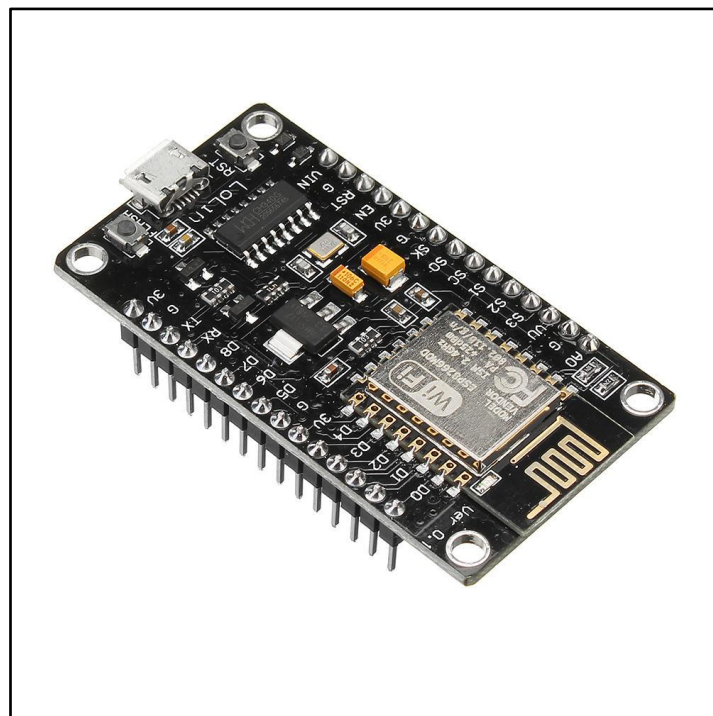


**Fig 3.15**

We used it for real time monitoring the operation. It is mounted on top of the gripper for better view of work place.

### **ESP 8266/NodeMCU(WIFI MODULE)**

This WIFI module has self-contained SOC with integrated TCP/IP protocol stack that can give microcontroller access to your WIFI network. The ESP8266 is used for hosting an application or offloading all WIFI networking functions from another application processor. It is an extremely cost-effective board with a node and ever-growing community. The ESP8266 or NodeMCU has a powerful on-board processing and storage capability that allows it to be integrated with the sensors and other applications specific devices through its GPIOs with minimal development up-front and minimal loading during runtime. The ESP8266 contains a self-calibrated RF allowing to work under all operating conditions and requires no external RF parts.

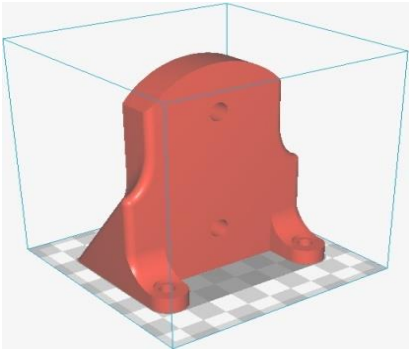
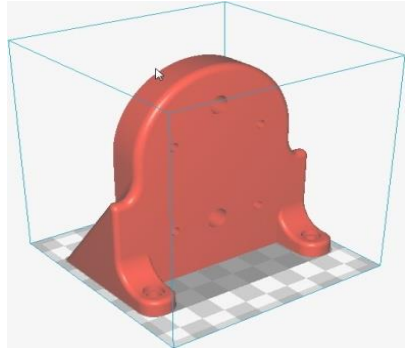
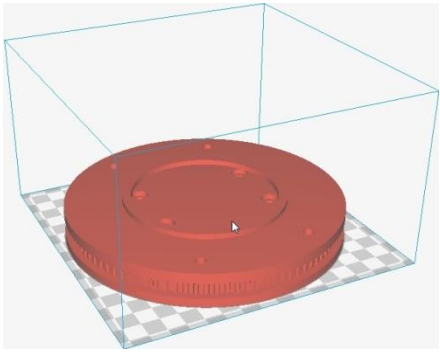


**Fig 3.16**

This is one of the main circuits of the project. It sends potentiometer data i.e. values of joint angles from puppet controller to the Robot through wireless data transmission with a negligible time lag.

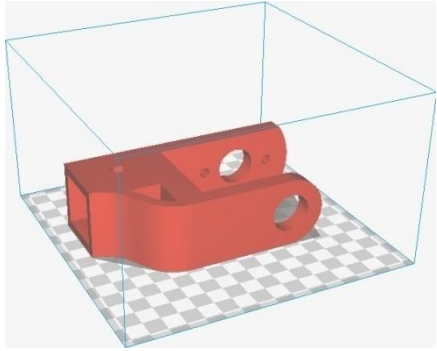
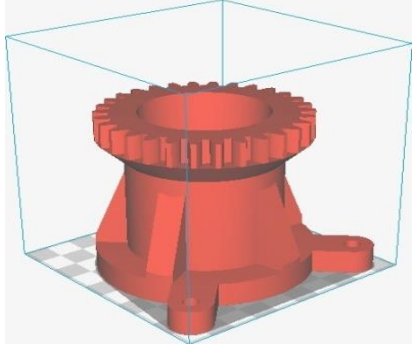
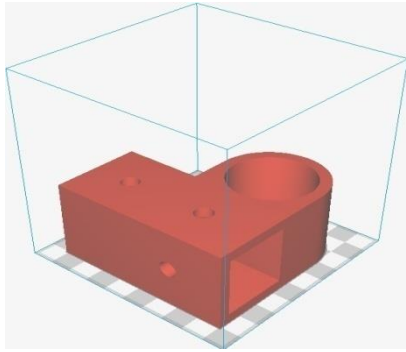
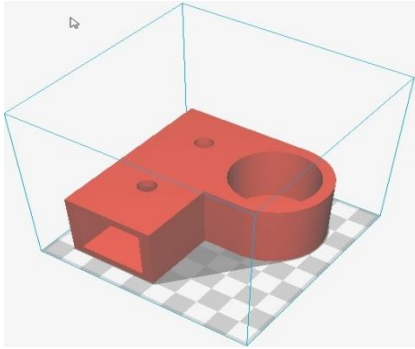
**3.6 3-D PRINTING MODELS**

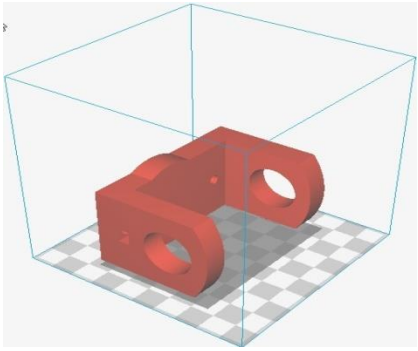
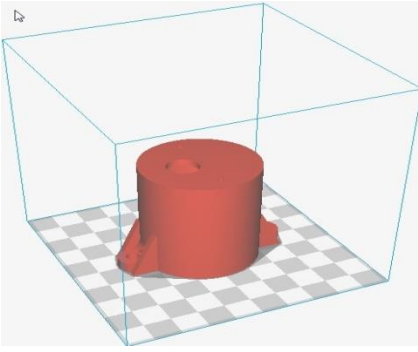
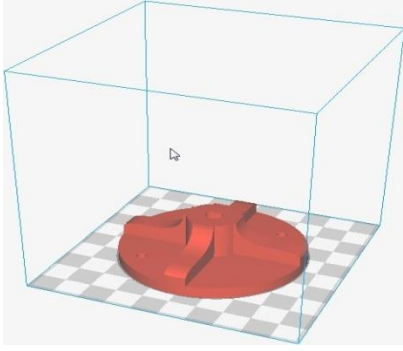
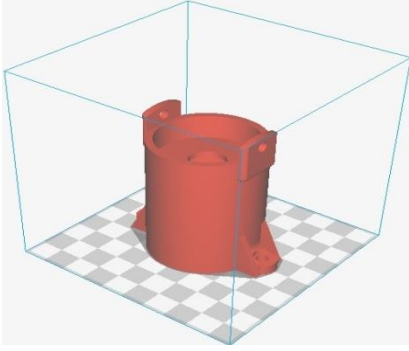
**Table 3.5 Printed Models**

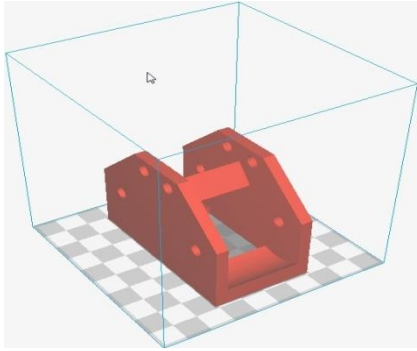
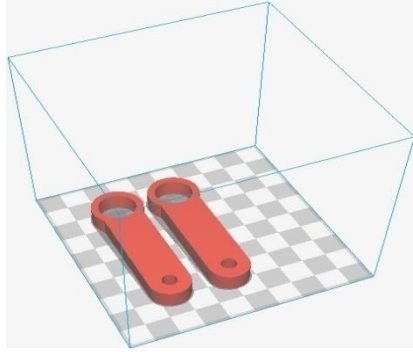
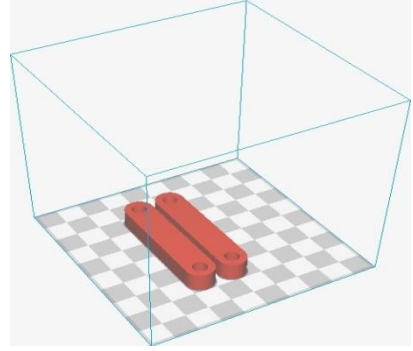
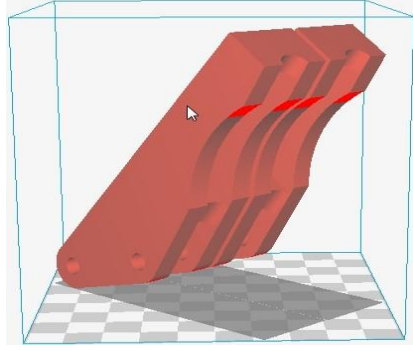
| SR. NO | PRINTED PART  | TIME FOR PRINTING | PART WEIGHT | FILAMENT LENGTH |
|--------|---|-------------------|-------------|-----------------|
| 1      |    | 06h38min          | 51g         | 17.37m          |
| 2      |   | 07h29min          | 57g         | 19.27m          |
| 3      |  | 22h37min          | 178g        | 59.88m          |

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|   |   |          |     |        |
|---|---|----------|-----|--------|
| 4 |    | 10h30min | 75g | 25.19m |
| 5 |    | 12h10min | 86g | 28.99m |
| 6 |   | 10h11min | 74g | 24.86m |
| 7 |  | 09h57min | 72g | 24.42m |

|    |   |          |     |        |
|----|---|----------|-----|--------|
| 8  |    | 04h47min | 33g | 11.25m |
| 9  |    | 03h17min | 20g | 6.99m  |
| 10 |   | 02h57min | 20g | 6.82m  |
| 11 |  | 04h15min | 27g | 9.10m  |

|    |   |          |     |        |
|----|---|----------|-----|--------|
| 12 |    | 04h45min | 31g | 10.63m |
| 13 |    | 01h48min | 12g | 4.22m  |
| 14 |   | 01h00min | 10g | 3.00m  |
| 15 |  | 10h21min | 70g | 23.52m |

### **3.7 BILL OF MATERIAL (BOM)**

Table below shows the overall amount spent on this project. Some abstract amounts are spent on prototyping. Some of which caused due to trial and replacements while development phase.

**Table 3.6 Bill of Material**

| <b>SR. NO.</b> | <b>ITEM</b>               | <b>SPECIFICATIONS</b> | <b>QUANTITY</b> | <b>TOTAL COST (RS)</b> |
|----------------|---------------------------|-----------------------|-----------------|------------------------|
| 1              | Arduino mega              | -                     | 1               | 790                    |
| 2              | 10k Potentiometer         | -                     | 5               | 450                    |
| 3              | Small 9g Servo            | -                     | 4               | 560                    |
| 4              | Electric wires            | -                     | 2               | 70                     |
| 5              | L298N motor driver module | -                     | 4               | 760                    |
| 6              | Shoulder DC motor         | 30 rpm, 30 kg-cm      | 1               | 2200                   |
| 7              | DC Motor for Platform     | 30 rpm, 20 kg-cm      | 2               | 2400                   |
| 8              | Elbow DC motor            | 60 rpm, 12.5 kg-cm    | 1               | 490                    |
| 9              | Wrist DC motor            | 10 rpm, 8kg-cm        | 2               | 780                    |
| 10             | Gripper dc motor          | -                     | 1               | 190                    |
| 11             | Various gears             | -                     | -               | 650                    |
| 12             | Timing belt               | -                     | 1               | 75                     |
| 13             | 8mm ID Bearing            | -                     | 8               | 80                     |
| 14             | 20mm ID Bearing           | -                     | 2               | 20                     |

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|                                      |                               |           |   |                 |
|--------------------------------------|-------------------------------|-----------|---|-----------------|
| 15                                   | 1k Potentiometer              | -         | 5 | 100             |
| 16                                   | Wheels                        | -         | 4 | 500             |
| 17                                   | Base motor                    | -         | 1 | 190             |
| 18                                   | Soldering wire                | -         | 1 | 70              |
| 19                                   | Shaft coupler                 | -         | 2 | 20              |
| 20                                   | NodeMCU                       | -         | 2 | 600             |
| 21                                   | Plywood                       | 20kg      | - | 590             |
| 22                                   | PLA filament                  | 1.5kg     | - | 1500            |
| 23                                   | T-Slot Aluminum Channel       | 30x301m   | - | 1000            |
| 24                                   | Rectangular Aluminum Channels | 50x2512ft | - | 200             |
| 25                                   | Miscellaneous hardware        | -         | - | 300             |
| 26                                   | Amount spent on prototyping   | -         | - | 2100            |
| 27                                   | Billing                       | -         | - | 2000            |
| <b>Total amount spent on project</b> |                               |           |   | <b>18685 RS</b> |

### **3.8 WORKING PRINCIPLE**

This is the most exciting thing about this project.

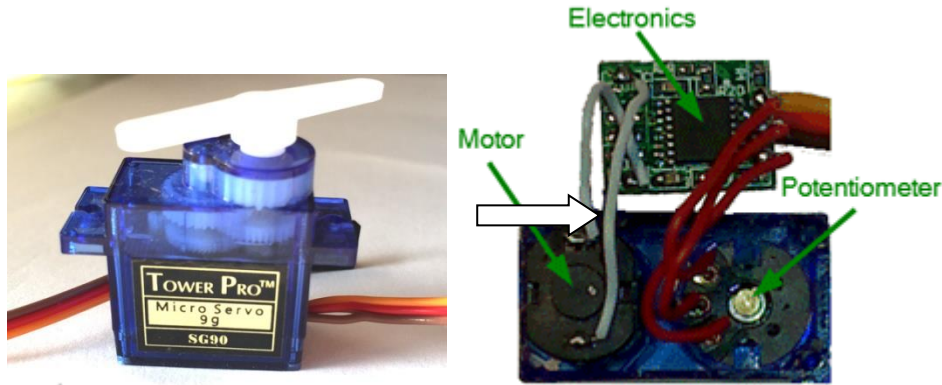
We have seen cheap Robots with servo motors which are just for demonstration and don't produce beneficial output. On the other hand, there are costly stepper motor robots with planetary gearbox etc. But this robot is a balance between them.

So, how is it different?

#### **3.8.1 Construction:**

Instead of using lower power and high cost stepper motor we used DC motors which are relatively quite powerful are economic but as we know DC motors don't have feedback control system and cannot be used directly for position control. So we converted them into servo motors by adding a potentiometer as a feedback/position sensor.

Now for simplicity of work what we did was disassembled cheap 9g “**Fig. 3.17**” servos strip out its circuitry and replaced its DC motor with high torque DC motor and its small pot with what we had for the robot (refer section 3.6, potentiometer). Doing this enabled us to use default library in Arduino which simplified the coding process a lot!



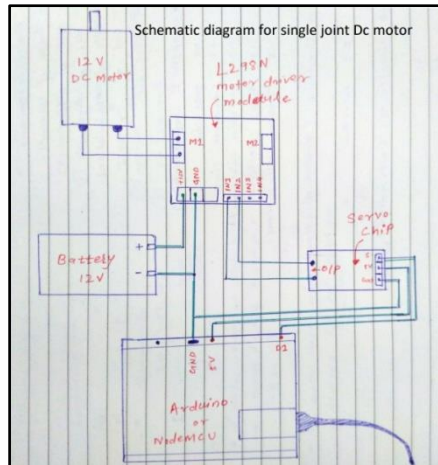
**Fig. 3.17**

For driving 12V DC motor with 5V servo chip we used L298N motor driver module(refer section 3.6, L298N motor driver module) which can drive 2 motors simultaneously. The module has 4 input pins IN1 to IN4 which decides the direction of motor rotation. Where IN1 and IN2 corresponds to 1st motor and IN3, IN4 to 2nd motor. Hence output terminals (2) of servo chip (originally to small dc motor) are connected to IN1 and IN2 of L298N module output of which is connected to 12V Dc motor.

### **3.8.2 Working:**

By this way when motor shaft is not on target position potentiometer send angle value to servo chip which commands L298N module to drive either clock wise or counter clockwise in turn 12V DC motor turns according to command received from microcontroller.

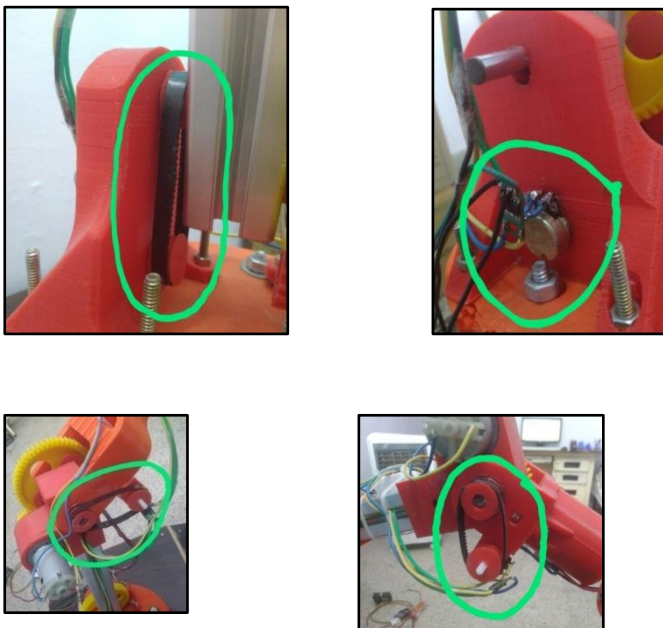
Schematic is shown in “**Fig. 3.18**” (only for 1 motor)



**Fig. 3.18**

In our case command (joint angle values) is sent through puppet controller which is 10 times scaled down copy of actual robot and has potentiometer connected at each joint through NodeMCU (ESP8266) over Wi-Fi to the robot. These values are then sent to each robot joint to which each joint motor try to occupy.

At each joint a potentiometer is connected to the joint shaft via belt pulley mechanism. When joint rotates the potentiometer rotates accordingly and gives feedback about current position of joint angle “**Fig. 3.19**”



**Fig. 3.19**

### **3.9 FABRICATION AND ASSEMBLY OF ROBOT**

#### **3.9.1 Puppet controller**

As discussed Earlier this is an uncommon and efficient control method we adapted for our Robot. Puppet controller is a 10 times smaller desktop model of robot arm fitted with sensors at the joints which senses and gives joint angle values when operator moves the links of puppet controller.

**STEP 1:** Design and 3d printing the model.

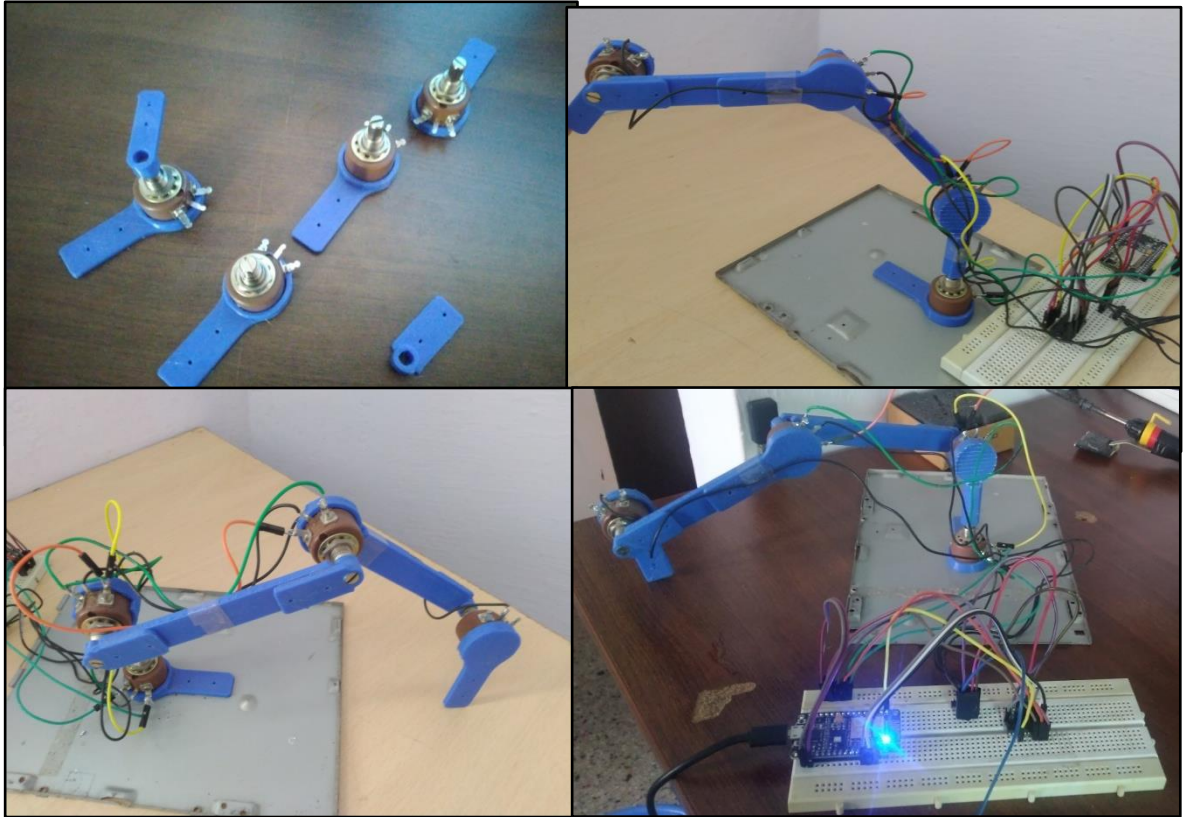


**Fig 3.20**

All these parts are designed in Catia v5 and printed on Easythread -X1 3D printer.

Once parts gets 3D printed we had to do some finishing work to clear any unwanted plastic left while printing, filing extra portions etc.

**STEP 2:** Installing electronics on the controller



All these potentiometers are **Fig 3.21** connected at the joints takes position (Angle) values. These values are continuously received by ESP8266 which is also called NodeMCU microcontroller through a multiplexer. NodeMCU then send these values to another microcontroller which is mounted on Robot over Wi-Fi.

**STEP3:** Coding

Coding for Both the systems i.e. Controller (Transmitter) and Robot n vehicle (Receiver) is attached in appendix section.

References are also provided in the same section.

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### 3.9.2 Robot Arm

#### STEP 1: Shoulder joint.

Shoulder joint is made up of 3 parts. 1<sup>st</sup> is Bearing mount “**Fig 3.22**” which consists of a pair of bearing through which a central shaft mounted on platform passes.

This part supports whole arm assembly and enables it to rotate freely about vertical axis.



**Fig 3.22**



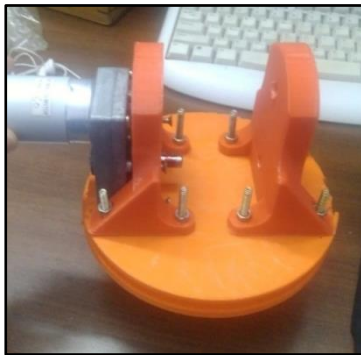
**Fig 3.23**

3<sup>rd</sup> is the motor mount and support plate “**Fig 3.24**” one of which holds motor and feedback sensor while other supports the shaft of the joint.



**Fig 3.24**

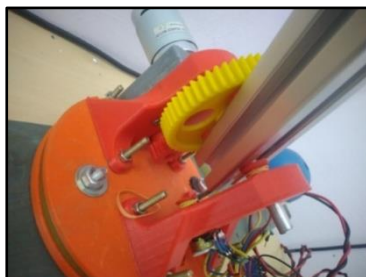
Combining all this together through 3mm diameter nut & bolts looks like this.



**Fig 3.25**

(**Note:** Bearing mount in above picture is older version which was replaced with newer version in future which is shown in “**Fig 3.24**”).

After mounting motor, feedback sensor (potentiometer) and link aluminum channel, the shoulder joint look like this.



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**STEP 2: Elbow joint**

Elbow joint has 2 parts. 1<sup>st</sup> part **Fig 3.27** mounted on the end of link 1 on which shoulder joint is attached.

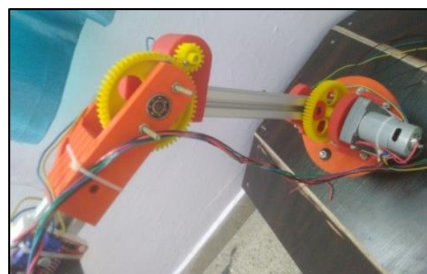


2<sup>nd</sup> part **Fig 3.28** is preceding part of elbow joint which connects link 1 and link 2 together and grows towards end effectors.



**Fig 3.28**

When combined together and mounted with motor and electronics this looks like as shown in “**Fig 3.29**”



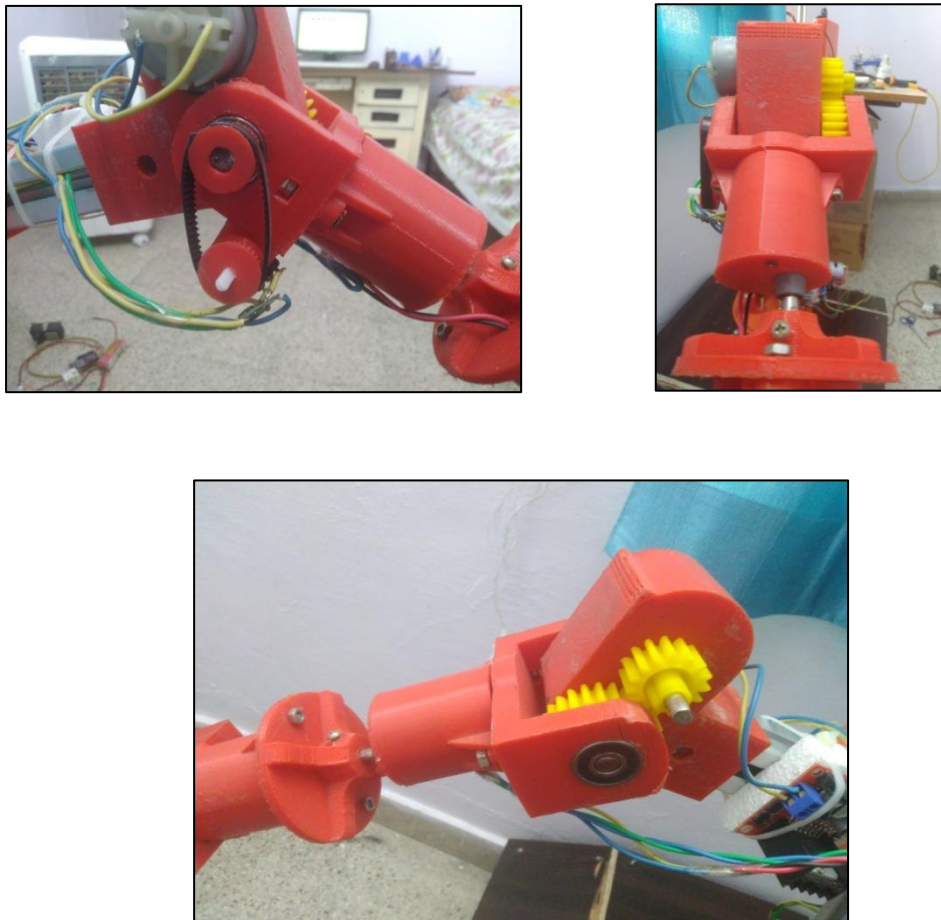
**Fig 3.29**

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**STEP 3: Wrist joint.**

Similar to Elbow joint wrist joint is also a 2<sup>nd</sup> part joint one connecting to previous link and another to gripper. Final assembly of wrist joint is shown in “**Fig 3.30**”.



**Fig 3.30**

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**STEP 4: End-effector (Gripper)**

This was one of the toughest tasks to design. It was designed such that it can pick most of the objects as well as can grip to most of the stuff around us like door latches, handles, bars etc.

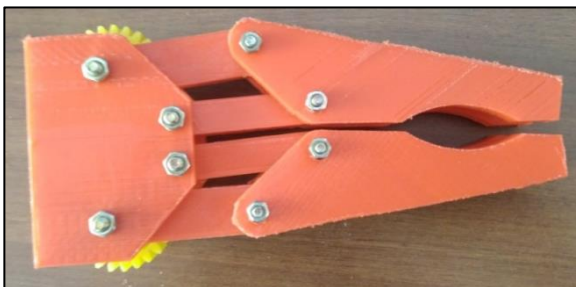
As shown in picture a helical gear attached to motor drives the gears inside the gripper casing clockwise or counters clockwise which are connected to fingers to open and close them.



**Fig3.31 Weight of gripper components**



**Fig 3.32 Motor with helical gear which drives spur gears**



**Fig 3.33 Fingers in fully closed state**



**Fig 3.34 Gripper in middle range**

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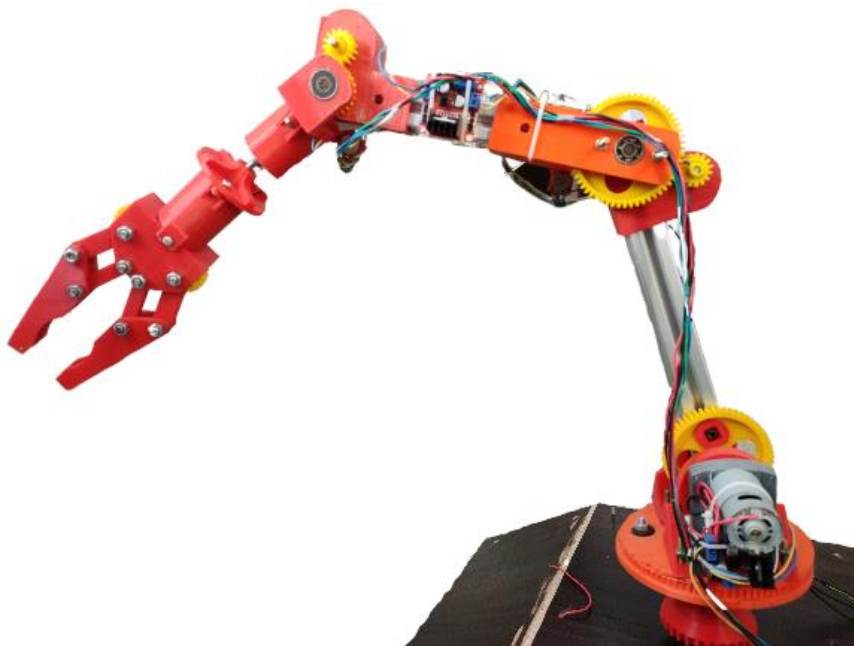
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**STEP 5:** Full Robot Arm assembly and electronics.

All the joints discussed earlier are assembled together. The parts are designed such that they all can just transition fit on a 30x30 aluminum profile. So each joint easily slides along the profile and can be tightened by nuts and t-bolts.



**Fig 3.35**



**Fig 3.36**

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Doing electronics include wiring the whole system i.e. motors, potentiometers and L298N motor driver module and microcontroller. The schematic diagram of major components is as shown in following figure.

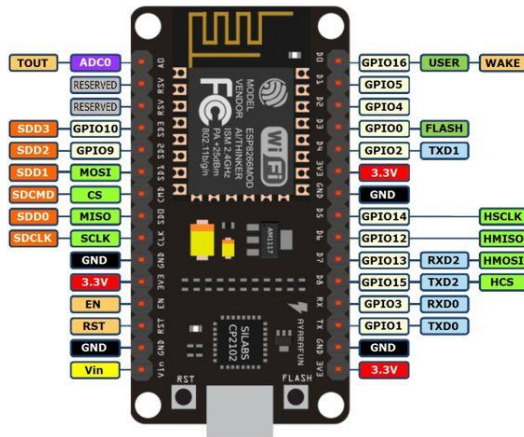


Fig 3.37 ESP8266

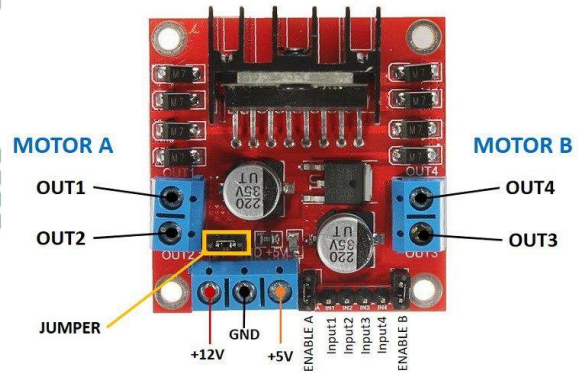


Fig 3.38 L298N Motor Driver Module

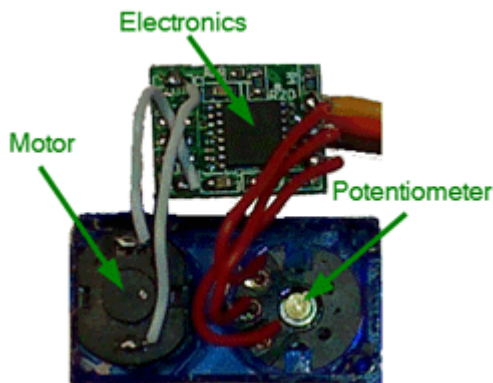


Fig 3.39 Small 9g Servo Motor

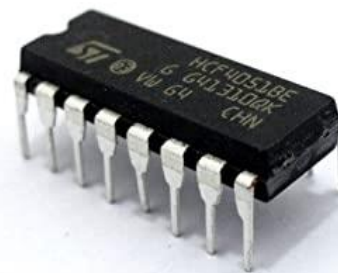


Fig 3.40 4051 Multiplexer

“Fig 3.37” shows the pinout diagram of microcontroller “Fig 3.38” shows pin out diagram for L298N motor driver module. “Fig 3.39” is the internal view of small 9g servo motor which clearly shows the chip which controls the servo. That’s the same chip we used to convert bigger DC motor to servo motor. “Fig 3.40” is a multiplexer which is used in ESP8266 to make it able to take multiple analog inputs rather than only one (as it has only 1 analog pin).

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## **CHAPTER 4**

### **SUMMARY AND CONCLUSION**

## **CHAPTER 4: SUMMARY AND CONCLUSION**

### **4.1 CONCLUSION**

The system developed and discussed in this thesis work demonstrates that readily available low-cost components can be used to build an efficient and easy to learn tele-operative control system.

Maintaining low cost is the key to widespread distribution of this advantage. We achieved the aim of developing and making this project open source so that individuals can make, modify & explore it their own.

As we are aware of the fact that unfortunately, accessibility of robotic technology which is revolutionizing modern world is limited to certain institutions only which are restricting the students in some capacity to learn and apply the knowledge. Using this approach, we could provide an economic alternative to his situation.

### **4.2 FUTURE SCOPE**

- 1) Current feedback system could be improved a lot by using optical sensors mounted onto motor shaft itself without much affecting the cost. This will improve Robot accuracy, precision and control.
- 2) Better console could be designed with Video streaming service for better control.
- 3) The robot vehicle currently has its own controller separate from the control for the arm. It is difficult for an operator to handle multiple tasks such as driving the mobile platform while manipulating the arm. Integration of the robotic arm controller with the robot vehicle motion control would provide additional ease-of-use and learning benefits and will be considered for future work.
- 4) Internet of things (IOT) technology could be utilized for long ranged control.
- 5) Use of other sensors like image recognition, proximity sensor, feedback, collision detection etc would greatly increase the robot performance