A Project Report on

"Design, Fabrication and Control of an Articulated Robotic Arm"

Submitted
In partial fulfillment of the requirements of degree of
Bachelor of Technology- Mechanical Engineering

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(SESSION: 2014-2015)

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CERTIFICATE

This is to certify that this project report entitled ***'DESIGN, FABRICATION AND CONTROL OF AN ARTICULATED ROBOTIC ARM'*** is the bona-fide work of ***MR. SAHIL MAKWANA***, ***MR. DIVYA SHAH*** and ***MR. KAHAAN SHAH***, the students of ***BACHELOR OF TECHNOLOGY- MECHANICAL ENGINEERING, BATCH OF 2015*** at ***SARDAR PATEL COLLEGE OF ENGINEERING***, who carried out the project work under my supervision and have completed it to my satisfaction.

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CERTIFICATE

This is to certify that this project report entitled *‘**DESIGN, FABRICATION AND CONTROL OF AN ARTICULATED ROBOTIC ARM**’* submitted by ***MR. SAHIL MAKWANA***, ***MR. DIVYA SHAH*** and ***MR. KAHAAN SHAH***, is found to be satisfactory and approved for the degree of ***BACHELOR OF TECHNOLOGY- MECHANICAL ENGINEERING***.

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ACKNOWLEDGEMENT

The success and final outcome of this project would not have been possible without the able guidance and help from many people and we are extremely fortunate to have got this throughout the completion of the project work. We hereby take this opportunity to thank and show our gratitude towards everyone who supported us.

We thank our professor, project guide and the Head of Department- Mechanical Engineering, Dr. Rajesh Buktar for guiding us throughout the way and for advising us on various aspects of our project. We thank him for offering much-appreciated and sought-after advice and suggesting thought-provoking ideas throughout the semester. We are indebted to our guide for offering us the freedom to explore and work on challenging aspects of the project. His constant support and guidance has helped us complete our project successfully. We also thank him for supporting us by providing great learning oriented infrastructure coupled with laboratory equipment and plethora of varied literature of scholarly levels incorporated in the Institute's library which made our search and quest for research materials a lot easier.

We would also like to express our sincere thanks to all our professors, colleagues and friends from different fields whose periodic inputs, informal discussions and varied perspectives have given us a better understanding of our progress.

ABSTRACT

The report documents the conceptualization, design, fabrication and control of a six degree of freedom articulated robotic arm by means of design and analysis followed by manufacturing specific to a particular work envelope and payload. The motivation for this project is creating a generalized robotic arm for educational purposes at the Institute which will contribute to acquiring a deeper understanding of theories of robotic arms and at the same time enable research in various applications of robotic manipulators.

The designs implemented through CATIA v5 computer software followed by payload calculations and analysis for materials and stresses have been presented as a part of this project. Manufacturing was implemented by importing designs via the drawing exchange format onto laser-cutting machines. Programming was implemented through Arduino MEGA microcontroller using C++ language. The final prototype will validate and establish the capability of the robotic arm. It will serve as a research platform for extended functionality by adding and improving existing software environments and hardware devices.

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Chapter 1
Introduction

1.1 ROBOTIC MANIPULATORS

A robotic arm is a type of mechanical arm, usually programmable, with similar functions to a human arm; the arm may be the sum total of the mechanism or may be part of a more complex robot. The links of such a manipulator are connected by joints allowing either rotational motion (such as in an articulated robot) or translational (linear) displacement. The links of the manipulator can be considered to form a kinematic chain. The terminus of the kinematic chain of the manipulator is called the end effector and it is analogous to the human hand. The end effector, or robotic hand, can be designed to perform any desired task such as welding, gripping, spinning etc., depending on the application. For example robot arms in automotive assembly lines perform a variety of tasks such as welding and parts rotation and placement during assembly. In some circumstances, close emulation of the human hand is desired, as in robots designed to conduct bomb disarmament and disposal.

The first robotic arm was developed in the 1950s by a scientist named George Devol, Jr., before which robotics were largely the products of science fiction and the imagination. The development of robotics was slow for a while, with many of the most useful applications being involved with space exploration. The use of robots to aid in industrialization weren’t fully realized until the 1980s, when robotic arms began to be integrated in automobile and other manufacturing assembly lines.

While working in a fashion similar to the human arm, robot arms can still have a much wider range of motion since their design can be purely up to the imagination of their creator. The joint that connects the segments of a robotic arm, for example, can rotate as well as moving like a hinge. The end of the robotic arm designed to actually do the work that it was designed for is known as the end effector, and can be designed for practically any task, for example gripping like a hand, painting, tightening screws and more. These robots can be fixed in one place, for example along an assembly line, or they can be mobile so they can be transported to do a variety of tasks in different places.

Autonomous robotic arms are designed to be programmed and then left alone to repeat their tasks independent of human control. Conversely, a robotic arm can also be designed to be.

2.3 CURRENT ROBOTICS RESEARCH

2.3.1 MANIPULATION AND CONTROL

Robotic Manipulation is a major research area in robotics especially for manufacturing applications. For the past five years, research and interest in manipulation has surged. New applications have emerged, from the manipulation of everyday objects in human environments, to the disposal of roadside bombs. Mobile platforms and manipulators and sensory capabilities are improving rapidly. Together all of these factors are pushing manipulation research in interesting directions, and leading us to new perspectives and approaches.

Some of the research in manipulation at the Robotics Institute Pennsylvania is listed below:

Prof. Erdmann’s team found a graph-theoretic technique for modeling planning problems, so that the global capabilities are revealed by the homotopy type of a "strategy complex". A key result is a controllability theorem: A robot can move anywhere in its state graph despite control uncertainty precisely when the graph's strategy complex is homotopic to a sphere of dimension two less than the number of states.

Several other less abstract (but still fundamental) manipulation results have been recently developed. Research on manipulation in human environments has expanded and changed our perspective on everyday manipulation. Led by Prof. Srinivasa, a team have identified interesting new problems and raised our consciousness on issues such as how to deal with clutter, how to hand objects to a human being, and how to plan motions that won't surprise nearby humans. The group has been remarkably successful in proceeding from discovery of new problems to development of new technology.

A high-impact high-visibility "unique mobility" project is the Modular Snake Robots project led by Prof. Choset. The group has developed novel mechanical design elements and planning and control techniques, to demonstrate a remarkable set of capabilities. Among the most remarkable accomplishments is the wide range of applications addressed: from exploration (archaeological forensics), to manufacturing (airplane assembly), and robotic surgery (minimally invasive heart surgery).

Ballbot, led by Prof. Hollis, is another novel approach to mobility. Ballbot balances and moves on a single spherical wheel, a radical departure from traditional quasi-static approaches. This unique approach also brings unique problems straddling the boundary between planning and control. To achieve fast, graceful navigation for dynamically stable mobile robots like the ballbot, Hollis and Kantor and collaborators developed motion planning that is cognizant of the natural dynamics of the system and closed-loop controls that stabilize the system around those trajectories. A hybrid control framework pieces together locally-defined control policies to produce smooth, graceful, energy-efficient motions. The project's high impact is best indicated by the numerous imitations that have appeared since Ballbot's debut.

Prof. Likhachev's group focuses on developing fundamental new graph-search techniques addressing the many unique challenges of mobile manipulation. Prof. Likhachev and his collaborators developed and refined a variety of techniques for the efficient search of nominally high dimensional and complex search spaces, and demonstrated the capabilities on a Willow Garage mobile manipulator.

Other work in manipulation includes:

- Locomotion techniques suitable for a high-centered mobile robot or an inverted turtle.
- Folding of origami
- Manipulation preparatory to grasping
- New approaches to autonomous manipulation with simple hands
- Assembly of consumer electronics
- Design of hands with scale-invariant or pose-invariant contact geometry
- Caging
- Imitation learning of manipulation strategies
- Data-driven approaches to grasp recognition and localization
- RISE climbing robot
- DSAC and DTAR dynamic planar climbing robots

2.3.2 ROBOTICS ARMS

Many robotic manipulators are very expensive, due to high-precision actuators and custom machining of components. We propose that robotic manipulation research can advance more rapidly if robotic arms of reasonable performance were greatly reduced in price. Increased affordability can lead to wider adoption, which in turn can lead to faster progress—a trend seen in numerous other fields. However, drastic cost reduction will require design tradeoffs and compromises. There are numerous dimensions over which robotic arms can be evaluated, such as backlash, payload, speed, bandwidth, repeatability, compliance, human safety, and cost, to name a few.

The arm uses low-cost stepper motors in conjunction with timing belt and cable drives to achieve backlash-free performance, trading off the cost of expensive, compact gear heads with an increased arm volume. To achieve human safety, a series-elastic design was used, in combination with minimizing the flying mass of the arm by keeping the motors close to ground.

There are a number of robotic arms used in robotics research today, many with unique features and design criteria. In this section, we discuss some recent widely-used and/or influential robotic arms.

The **Barrett WAM** is a cable-driven robot known for its high backdrivability and smooth, fast operation. It has high speed (3 m/s) operation and 2 mm repeatability.

The **Meka A2** arm is series-elastic, intended for human interaction; other, custom-made robots with series-elastic arms include **Cog, Domo, Obrero, Twendy-One,** and the **Agile Arm**. The Meka arm and Twendy-One use harmonic drive gearheads, while Cog uses planetary gearboxes and Domo, Obrero, and the Agile Arm use ballscrews; the robots all use different mechanisms for their series elasticity. These arms have lower control bandwidth (less than 5 Hz) due to series compliance, yet that has not appeared to restrict their use in manipulation research.

Several human-safe arms have been developed at Stanford using a macro-mini actuation approach, combining a series elastic actuator with a small motor to increase bandwidth. The **PR2 robot** has a unique system that uses a passive gravity compensation mechanism, so the arms float in any configuration. Because the large mass of the arm is already supported, relatively small motors are used to move the arms and support payloads. These small motors provide human safety, as they can be backdriven easily due to their low gear ratios.

The **DLR-LWR III** arm, **Schunk Lightweight Arm**, and **Robonaut** all use motors directly mounted to each joint, with harmonic drive gearheads to provide fast motion with zero backlash. These arms have somewhat higher payloads than the other arms discussed in this section, ranging from 3-14 kg.

They are not designed for human safety, having relatively large flying masses (close to 14 kg for the DLR-LWR), although demonstrations with the DLR-LWR III have been performed that incorporate a distal force/torque sensor that uses the arm’s high bandwidth to quickly stop when collisions are detected.

Of the robotic arms discussed previously, those that are commercially available are all relatively expensive, with end user purchase prices well above $100,000 USD. However, there are a few examples of low-cost robotic manipulators used in research. The arms on the **Dynamaid robot** are constructed from Robotis Dynamixel robotics servos, which are light and compact. The robot has a human-scale workspace, but a lower payload (1 kg) than the class of arms discussed previously. Its total cost is at least $3500 USD, which is the price of just the Dynamixel servos. In videos of it in operation, it appears to be slightly underdamped.

The **KUKA youBot** arm is a new 5-DOF arm for robotics research. It has a comparatively small work envelope of just over 0:5 m3, repeatability of 0.1 mm, and payload of 0.5 kg. It has custom, compact motors and gearheads, and is sold for 14,000 Euro at time of writing.

Many robot arms have been made using stepper motors. Pierrot and Dombre discuss how stepper motors contribute to the human-safety of the **Hippocrate** and **Dermarob** medical robots, because the steppers will remain stationary in the event of electronics failure, as compared to conventional motors which may continue rotating. Furthermore, they are operated relatively close to their maximum torque, as compared to conventional motors which may have a much higher stall torque than the torque used for continuous operation. ST Robotics offers a number of stepper driven robotic arms, which have sub-mm repeatability.

1.3 PURPOSE AND APPLICATION

An industrial robot is defined by ISO as an automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes. The field of robotics may be more practically defined as the study, design and use of robot systems for manufacturing.

Typical applications of robots include welding, painting, assembly, pick and place (such as packaging, palletizing and SMT), product inspection, and testing; all accomplished with high endurance, speed, and precision.

As of 2005, the robotic arm business is approaching a mature state, where they can provide enough speed, accuracy and ease of use for most of the applications. Vision guidance (aka machine vision) is bringing a lot of flexibility to robotic cells. However, the end effector attached to a robot is often a simple pneumatic, 2-position chuck. This does not allow the robotic cell to easily handle different parts, in different orientations.

Hand-in-hand with increasing off-line programmed applications, robot calibration is becoming more and more important in order to guarantee a good positioning accuracy. Other developments include downsizing industrial arms for light industrial use such as production of small products, sealing and dispensing, quality control, handling samples in the laboratory. Such robots are usually classified as "bench top" robots. Robots are used in pharmaceutical research in a technique called High-throughput screening. Bench top robots are also used in consumer applications (micro-robotic arms). Industrial arms may be used in combination with or even mounted on automated guided vehicles (AGVs) to make the automation chain more flexible between pick-up and drop-off.

Our aim through this project is to study and understand the principles and theory involved in the various aspects of robot manipulation. The prototype robotic arm will help us gain practical experience on the design, fabrication and control of robotic manipulators.

Application:

1. Industrial robots are gaining widespread application for the past few years. The application demonstrated is a robotic arm for sorting of workpieces on a conveyor belt. These robots of different levels of complexity are required at various places in assembly lines and machine shops of manufacturing industries.

2. A robotic arm at SPCE to further research in manipulation, sensors and control. We intend to develop this prototype as a research platform in the college encouraging a collaborative effort in the future years.

1.4 APPROACH

As for any project, the first step was clearly defining the problem statement. A well-defined description of the problem, to be solved by the project, was instrumental in defining the scope of the project and giving way to the further steps to be undertaken. The problem statement is as follow:

Generally robotic manipulators are very expensive, due to high-precision actuators and custom machining of components. We propose the design of a new low cost robotic arm and a prototype for the same. The arm uses six servomotors for movement along six degrees of freedom (DOF), and the gripper is designed to handle one package weighing 200 g. The work envelope is a hemisphere of 40 cm radius, with the center being the base center. The arm is used to demonstrate sorting of objects on a conveyor belt.

After adequately defining the problem statement as above, a strategy plan was made, based on the project scope. A comprehensive description of scope of project comprised of the following aspects:

- Mechanical design, modeling and assembly using CATIA
- Payload calculations using MATLAB
- Analysis using Direct and Inverse Kinematics
- Manufacturing using Laser Cutting
- Coding for running servomotors
- Control using Arduino MEGA

The various parts of the arm – links, brackets, gripper, gears etc. – were designed using CATIA software. Different parts were color coded, and an assembly was made. Animations showed the ideal movement of the arm. The modules used were as follows:

- Sketch
- Part
- Assembly
- Drawing

The payload calculations were used in deciding the lengths of the links and other such criteria. The dimensions of the end effector were decided accordingly. Based on the final arm assembly, a link coordinate diagram was made. This diagram was used in further mathematical calculations.

Using the kinematic parameters and the link coordinate diagram, Direct Kinematics was applied to determine position and orientation of end effector based on movements of links and joints. Using the kinematic parameters and the link coordinate diagram; Inverse Kinematics was applied to determine was movements of the links and joints were needed in order to reach a particular end effector position and orientation. Hence, changing the required variables in the sample Direct Kinematics and Inverse Kinematics calculations, based on the problem statement, different positions and orientations of the end effector can be reached.

For the next step i.e. manufacturing, we decided to use two methods: Laser Cutting. This decision was based on the aim of expanding our practical knowledge and experience of manufacturing processes.

- Laser Cutting:
  - The material used was acrylic.
  - For laser cutting, the .prt files of designs obtained from CATIA software were converted to .cdr files, by exporting to Corel Draw software. These files were then directly fed into the manufacturer's computer software for laser cutting.
  - We approached 'J K Plastics' at Oshiwara for laser cutting of acrylic for manufacturing of parts. All links, base plates, brackets and gripper parts were manufactured here.

For control and manipulation of the arm, we used programming in C++ language, to control the servomotors. This was done using Arduino MEGA board, which uses the open-source Arduino electronics prototyping platform for programming. The board uses ATMEGA 328 Microcontroller

Chapter 2
Literature Survey

2.1 TECHNICAL TERMS

1] SPEED: Speed is the amount of distance per unit time at which the robot can move, usually specified in inches per second or meters per second. The speed is usually specified at a specific load or assuming that the robot is carrying a fixed weight. Actual speed may vary depending upon the weight carried by the robot.

2] LOAD BEARING CAPACITY: Load bearing capacity is the maximum weight-carrying capacity of the robot. Robots that carry large weights, but must still be precise are expensive.

3] ACCURACY: Accuracy is the ability of a robot to go to the specified position without making a mistake. It is impossible to position a machine exactly. Accuracy is therefore defined as the ability of the robot to position itself to the desired location with the minimal error (usually 0.001 inch).

4] REPEATABILITY: Repeatability is the ability of a robot to repeatedly position itself when asked to perform a task multiple times. Accuracy is an absolute concept, repeatability is relative. Note that a robot that is repeatable may not be very accurate. Likewise, an accurate robot may not be repeatable.

5] WORK ENVELOPE: Work envelope is the maximum robot reach, or volume within which a robot can operate. This is usually specified as a combination of the limits of each of the robot's parts. The figure below shows how a work-envelope of a robot is documented.

6] WORKCELLS: Robots seldom function in an isolated environment. In order to do useful work, robots must coordinate their movements with other machines and equipment, and possibly with humans. A group of machines/equipment positioned with a robot or robots to do useful work is termed a workcell. For example, a robot doing welding on an automotive assembly line must coordinate with a conveyor that is moving the car-frame and a laser-positioning / inspection robot that uses a laser beam to locate the position of the weld and then inspect the quality of the weld when it is complete

2.2 ROBOT ANATOMY

As mentioned in the introduction to the chapter, the manipulator or robotic arm has many similarities to the human body. The mechanical structure of a robot is like the skeleton in the human body. The robot anatomy is, therefore, the study of skeleton of robot, that is, the physical construction of the manipulator structure.

The mechanical structure of a manipulator that consists of rigid bodies (links) connected by means of articulations (joints), is segmented into an arm that ensures mobility and reachability, a wrist that confers orientation, and an end- effector that performs the required task. Most manipulators are mounted on a base fastened to the floor or on the mobile platform of an autonomous guided vehicle (AGV). The arrangement of base, arm, wrist, and end-effector is shown in Fig. 2.1.

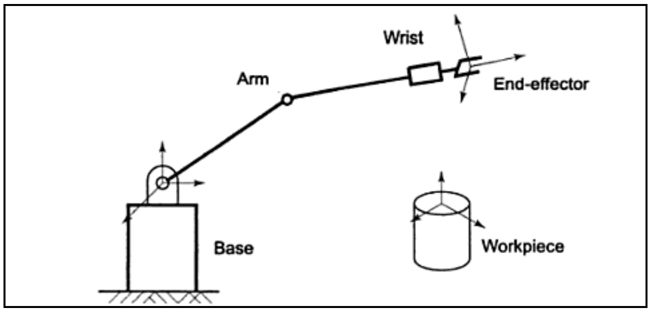


Fig.2.1 The base, arm, wrist, and end effector forming the mechanical structure of a manipulator

2.2.1 LINKS

The mechanical structure of a robotic manipulator is a mechanism, whose members are rigid links or bars. A rigid link that can be connected, at most, with two other links is referred to as a binary link. Figure 2.2 shows two rigid binary "links, 1 and 2, each with two holes at the ends A, B, and C, D, respectively to connect with each other or to other links.

Two links are connected together by a joint. By putting a pin through holes B and C of links 1 and 2, an open kinematic chain is formed as shown in Fig. 2.3. The joint formed is called a pin joint also known as a revolute or rotary joint.

Relative rotary motion between the links is possible and the two links are said to be paired. In Fig. 2.3 links are represented by straight lines and rotary joint by a small circle.

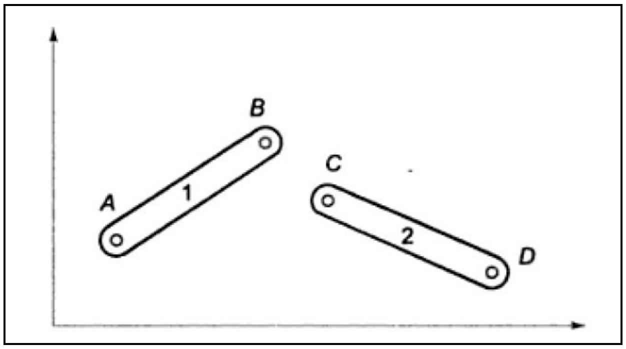


Fig.2.2 Two rigid binary links in free space

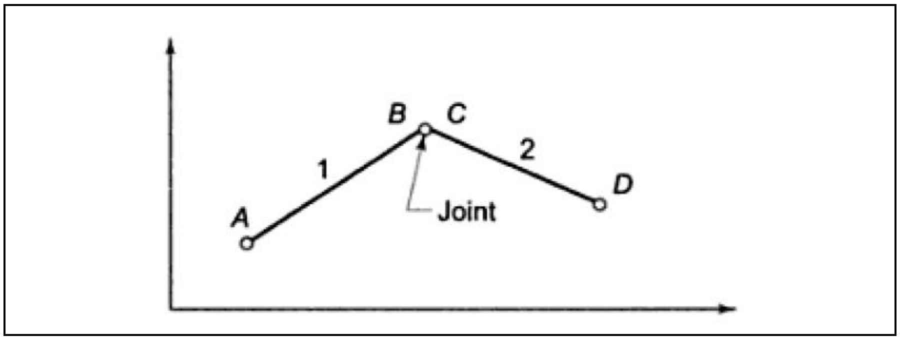


Fig.2.3 An open kinematic chain formed by joining two links

2.2.2 JOINTS AND JOINT NOTATION SCHEME

Many types of joints can be made between two links. However, only two basic types are commonly used in industrial robots. These are

- Revolute (R) and
- Prismatic (P).

The relative motion of the adjoining links of a joint is either rotary or linear depending on the type of joint. Revolute joint: It is sketched in Fig. 2.4(a). The two links are joined by a pin (pivot) about the axis of which the links can rotate with respect to each other. Prismatic join': It is sketched in Fig. 2.4(b). The two links are so jointed that these can slide (linearly move) with respect to each other. Screw and nut (slow linear motion of the nut), rack and pinion are ways to implement prismatic joints.

Other types of possible joints used are: planar (one surface sliding over another surface); cylindrical (one link rotates about the other at 90° angle. Fig. 2.4) and spherical (one link can move with respect to the other in three dimensions). Yet another variant of rotary joint is the 'twist' joint, where two links remain aligned along a straight line but one turns (twists) about the other around the link axis, Fig. 2.4(d).

At a joint, links are connected such that they can be made to move relative to each other by the actuators. A rotary joint allows a pure rotation of one link relative to the connecting link and prismatic joint allows a pure translation of one link relative 10 the connecting link.

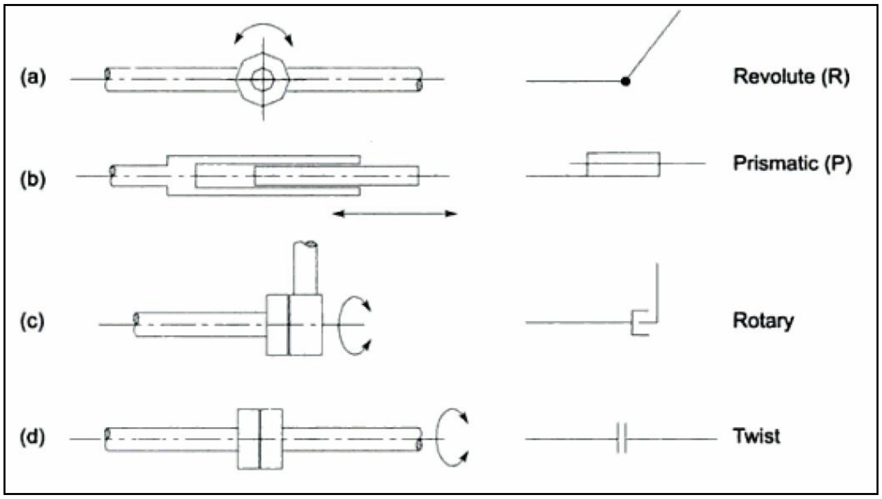


Fig.2.4 Joint types and their symbols

The kinematic chain formed by joining two links is extended by connecting more links. To form a manipulator one end of the chain is connected to the base or ground with a joint. Such a manipulator is an open kinematic chain. The end-effector is connected to the free end of the last link as illustrated ill Fig. 1.5. Closed kinematic chains are used in special purpose manipulators such as parallel manipulators to create certain kind of motion of the end-effector. The kinematic chain of the manipulator is characterized by the degrees of freedom it has and the space its end-effector can sweep. These parameters are discussed in next sections.

2.2.3 DEGREES OF FREEDOM (DOF)

The number of independent movements that an object can perform in a 3-D space is called the number of degrees of freedom (DOF). Thus a rigid body free in space has six degrees of freedom- three for position and three for orientation.
These six independent movements pictured in Fig. 2.5 are:

(i) Three translations *(T*1, *T2, T3),* representing linear motions along three perpendicular axes, specify the position of the body in space.
(ii) Three rotations *(R1, R2, R3),* which represent angular motions about the three axes specify the orientation of the body in space.

Note from the above that six independent variables are required to specify the location (position and orientation) of an object in 3-D space, that is. 2 x 3 = 6. Nevertheless, in a 2-D space (a plane), an object has 3-DOF-two translator and one rotational. For instance, link 1 and link 2 in Fig. 2.2 have 3-DOF each.

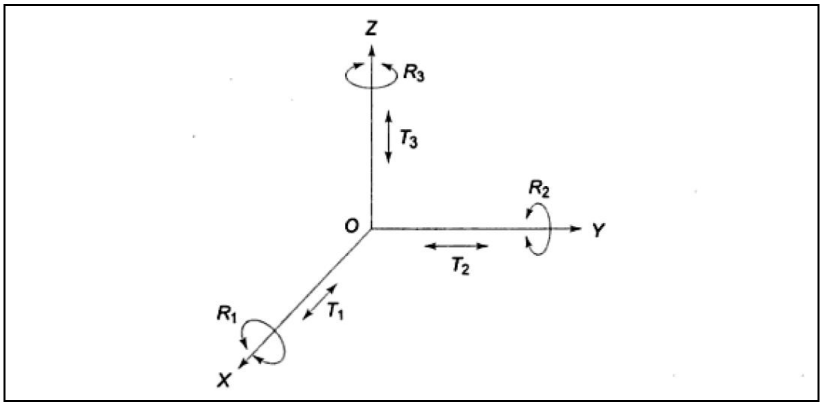


Fig.2.5 Representation of six degrees of freedom with respect to a coordinate frame

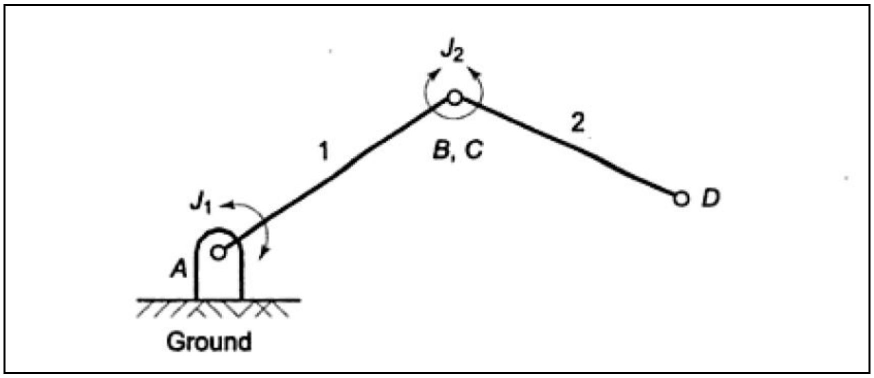


Fig.2.6 A two DOF planar manipulator-two links, two joints

Consider an open kinematic chain of two links with revolute joints at A and B (or C), as shown in Fig. 2.6. Here, the first link is connected to the ground by a joint at A. Therefore, link I can only rotate about joint I (J I) with respect to ground and contributes one independent variable (an angle), or in other words, it contributes one degree of freedom. Link 2 can rotate about joint 2 (12 respect to link 1, contributing another independent variable and so another DOF.

Thus, by induction, conclude that an open kinematic chain with one end connected to the ground by a joint and the farther end of the last link free has as many degrees of freedom as the number of joints in the chain. It is assumed that each joint has only one DOF.

The DOF is also equal to the number of links in the open kinematic chain. For example, in Fig. 2.6, the open kinematic chain manipulator with two DOF has two links and two joints.

The variable defining the motion of a link at a joint is called a joint-link variable. Thus, for an n-DOF manipulator n independent joint-link variables are required to completely specify the location (position and orientation) of each link (and joint), specifying the location of the end-effector in space. Thus, for the two-link, in turn, 2-DOF manipulator in Fig. 2.6, two variables are required to define location of end-point, point D.

2.2.4 REQUIRED DOF IN A MANIPULATOR

It is concluded from Section 2.1.3 that to position and orient a body freely in 3-D space, a manipulator with 6-DOF is required. Such a manipulator is called a spatial manipulator. It has three joints for positioning and three for orienting the end-effector.

A manipulator with less than 6-DOF bas constrained motion in 3-D space. There are situations where five or even four joints (DOF) are enough to do the required job. There are many industrial manipulators that have five or fewer DOF. These are useful for specific applications that do not require 6·DOF. A planar manipulator can only sweep a 2-D space or a plane and can have any number of degrees of freedom. For example, a planar manipulator with three joints (3-DOF) - may be two for positioning and one for orientation-can only sweep a plane.

Spatial manipulators with more than 6-DOFhave surplus joints and are known as redundant manipulators. The extra DOF may enhance the performance by adding to its dexterity. Dexterity implies that the manipulator can reach a subspace, which is obstructed by objects, by the capability of going around these.

However, redundant manipulators present complexities in modelling and coordinate frame transformations and therefore in their programming and control. The DOF of a manipulator are distributed into subassemblies of arm and wrist. The arm is used for positioning the end-effector in space and, hence, the three positional DOF, as seen in Fig. 2.5, are provided to the arm. The remaining 3-DOF is provided in the wrist, whose task is to orient the end-effector. The type and arrangement of joints in the arm and wrist can vary considerably. These are discussed in the next section.

2.3 ARM CONFIGURATION

The mechanics of the arm with 3-DOF depends on the type of three joints employed and their arrangement. The purpose of the arm is to position the wrist in the 3-D space and the arm bas following characteristic requirements.

- Links are long enough to provide for maximum reach in the space.
- The design is mechanically robust because the arm has to bear not only the load of workpiece but also has to carry the wrist and the end-effector.

According to joint movements and arrangement of links, four well-distinguished basic structural configurations are possible for the arm. These are characterized by the distribution of three arm joints among prismatic and rotary joints, and arc named according to the coordinate system employed or the shape of the space they sweep. The four basic configurations arc:

(i) Cartesian (rectangular) configuration - all three P joints.
(ii) Cylindrical configuration - one R and two P joints.
(iii) Polar (spherical) configuration - two R and one P joint.
(iv) Articulated (Revolute or Jointed-arm) Configuration - all three R-joints.
Each of these arm configurations is now discussed briefly.

2.3.1 CARTESIAN (RECTANGULAR) CONFIGURATION

This is the simplest configuration with all three prismatic joints, as shown in Fig. 1. 11. It is constructed by three perpendicular slides, giving only linear motions along the three principal axes. There is an upper and lower limit for movement of each link. Consequently, the endpoint of the arm is capable of operating in a cuboidal space, called workspace. The workspace represents the portion of space around the base of the manipulator that can be accessed by the arm endpoint. The shape and size of the workspace depends on the arm configuration, structure, degrees of freedom, size of links, and design of joints. The physical space that can be swept by a manipulator (with wrist and end-effector) may be more or less than the arm endpoint workspace. The volume of the space swept is called work volume; the surface of the workspace describes the work envelope.

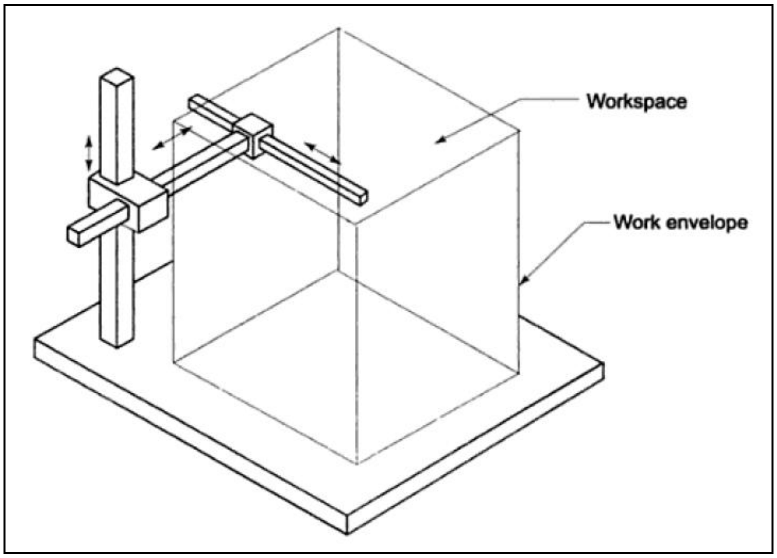


Fig.2.7 A 3 DOF Cartesian arm configuration and its workspace

The workspace of Cartesian configuration is cuboidal and is shown in Fig. 2.7. Two types of constructions are possible for Cartesian arm: a Cantilevered Cartesian as in Fig. 2.7, and a Gantry or box Cartesian. The latter one has the appearance of a gantry-type crane and is shown in Fig. 2.8.

Despite the fact that Cartesian arm gives high precision and is easy to program, it is not preferred for many applications due to limited manipulatability. Gantry configuration is used when heavy loads must be precisely moved. The Cartesian configuration gives large work volume but has a low dexterity.

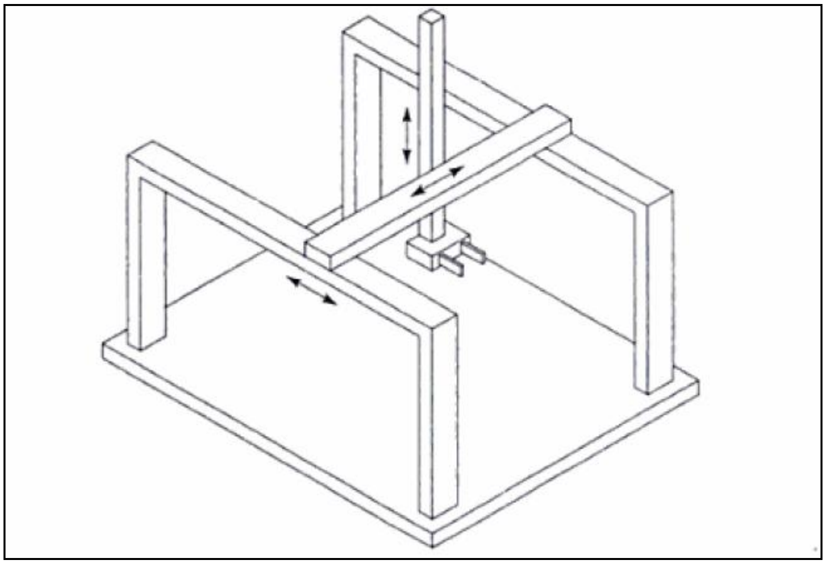


Fig.2.8 Gantry or box configuration Cartesian manipulator

2.3.2 CYLINDRICAL CONFIGURATION

The cylindrical configuration pictured in Fig. 2.9, uses two perpendicular prismatic joints and a revolute joint. The difference from the Cartesian one is that one of the prismatic joint is replaced with a revolute joint. One typical construction is with the first joint as revolute. The rotary joint may either have the column rotating or a block revolving around a stationary vertical cylindrical column. The vertical column carries a slide that can be moved up or down along the column. The horizontal link is attached to the slide such that it can move linearly, in or out, with respect to the column. This results in a RPP configuration. The arm endpoint is thus capable of sweeping a cylindrical space. To be precise, the workspace is a hollow cylinder as shown in Fig. 2.9. Usually a full 360° rotation of the vertical column is not permitted due to mechanical restrictions imposed by actuators and transmission elements.

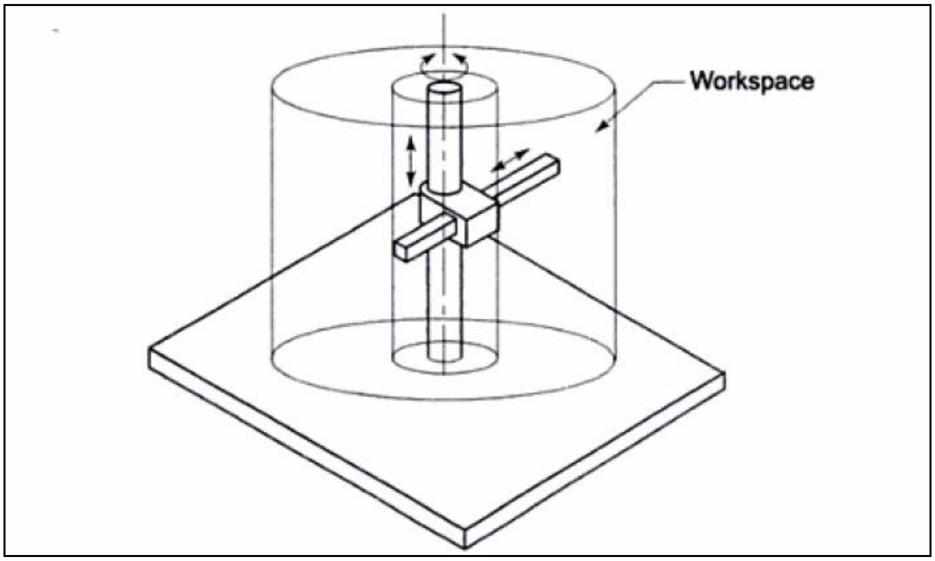


Fig.2.9 A 3-DOF cylindrical arm configuration and its workspace

Many other joint arrangements with two prismatic and one rotary joint are possible for cylindrical configuration, for example, a PRP configuration. Note that all combinations of 1R and 2P are not useful configurations as they may not give suitable workspace and some may only sweep a plane. Such configurations are called non-robotic configurations. It is left for the reader to visualize as to which joint combinations are robotic arm configurations.

The cylindrical configuration offers good mechanical stiffness and the wrist positioning accuracy decreases as the horizontal stroke increases. It is suitable to access narrow horizontal cavities and. hence is useful for machine-loading operations.

2.3.3 POLAR (SPHERICAL) CONFIGURATION

The polar configuration is illustrated in Fig. 2.10. It consists of a telescopic link (prismatic joint) that can be raised or lowered about a horizontal revolute joint. These two links are mounted on a rotating base. This arrangement of joints, known as RRP configuration, gives the capability of moving the arm end-point within a partial spherical shell space as work volume, as shown in Fig. 2.10.

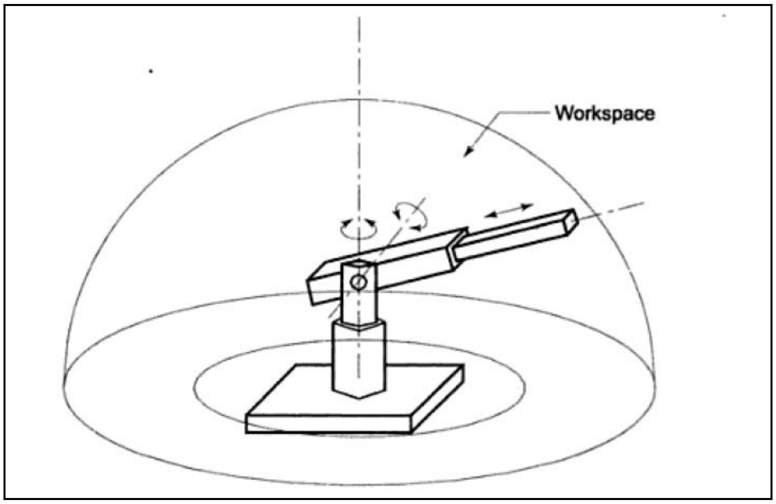


Fig.2.10 A 3 DOF polar arm configuration and its workspace

This configuration allows manipulation of objects on the floor because its shoulder joint allows its end-effector to go below the base. Its mechanical stiffness is lower than Cartesian and cylindrical configurations and the wrist positioning accuracy decreases with the increasing radial stroke. The construction is more complex. Polar arms are mainly employed for industrial applications such as machining, spray painting and so on. Alternate polar configuration can be obtained with other joint arrangements such as RPR, but PRR will not give a spherical work volume.

2.3.4 ARTICULATED (REVOLUTE OR JOINTED-ARM) CONFIGURATION

The articulated arm is the type that best simulates a human arm and a manipulator with this type of an arm is/often referred as an anthropomorphic manipulator. It consists of two straight links, corresponding to the human "forearm" and "upper arm" with two rotary joints corresponding to the "elbow" and "shoulder" joints. These two links are mounted on a vertical rotary table corresponding to the human wrist joint. Figure 2.11 illustrates the joint-link arrangement for the articulated arm. This configuration (RRR) is also called revolute because three revolute joints are employed. The work volume of this configuration is spherical shaped, and with proper sizing of links and design of joints, the arm endpoint can sweep a full spherical space. The arm endpoint can reach the base point and below the base, as shown in Fig. 2.11. This anthropomorphic structure is the most dexterous one, because all the joints are revolute, and the positioning accuracy varies with arm endpoint location in the workspace. The range of industrial applications of this arm is wide.

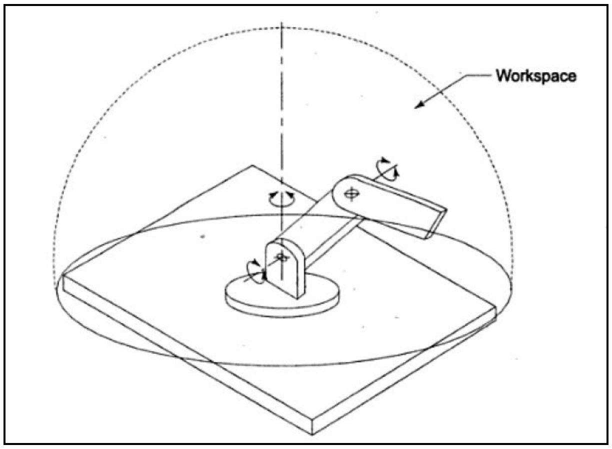


Fig.2.11 A 3 DOF articulated configuration and its workspace

2.3.5 OTHER CONFIGURATIONS

New arm configurations can be obtained by assembling the links and joints differently, resulting in properties different from those of basic arm configurations outlined above. For instance, if the characteristics of articulated and cylindrical configurations are combined, the result will be another type of manipulator with revolute motions, confined to the horizontal plane. Such a configuration is called SCARA, which stands for Selective Compliance Assembly Robot Arm.

The SCARA configuration has vertical major axis rotations such that gravitational load, Coriolis, and centrifugal forces do not stress the structure as much as they would if the axes were horizontal. This advantage is very important at high speeds and high precision. This configuration provides high stiffness to the arm in the vertical direction, and high compliance in the horizontal plane, thus making SCARA congenial for many assembly tasks. The SCARA configuration and its workspace are presented pictorially in Fig. 2.12.

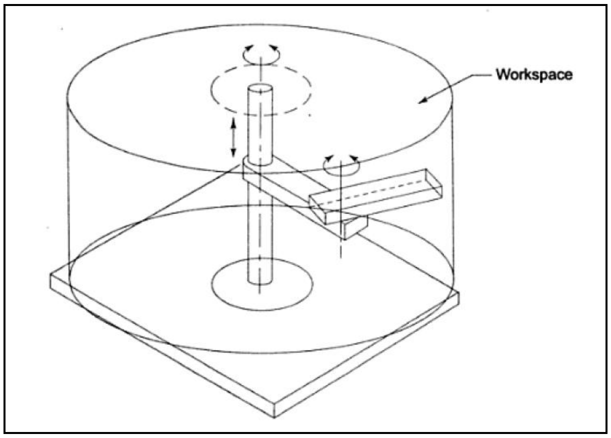


Fig.2.12 The SCARA configuration and its workspace

2.3.6 WRIST CONFIGURATION

The arm configurations discussed above carry and position the wrist, which is the second part of a manipulator that is attached to the endpoint of the arm. The wrist subassembly movements enable the manipulator to orient the end-effector to perform the task properly, for example, the gripper (an end-effector) must be oriented at an appropriate angle to pick and grasp a workpiece. For arbitrary orientation in 3-D space, the wrist must possess at least 3-DOF to give three rotations about the three principal axes. Fewer than 3-00F may be used in a wrist, depending on requirements. The wrist has to be compact and it must not, diminish the performance of the arm.

The wrist requires only rotary joints because its sole purpose is to orient the lend-effector. A 3-DOF wrist permitting rotation about three perpendicular axes provides for roll (motion in a plane perpendicular to the end of the arm), pitch (motion in vertical plane passing through the arm), and yaw (motion in a horizontal plane that also passes through the arm) motions. This type of wrist is called roll-pitch-yaw or RPY wrist and is illustrated in Fig. 2.13. A wrist with the highest dexterity is one where three rotary joint axes intersect at a point. This complicates the mechanical design.

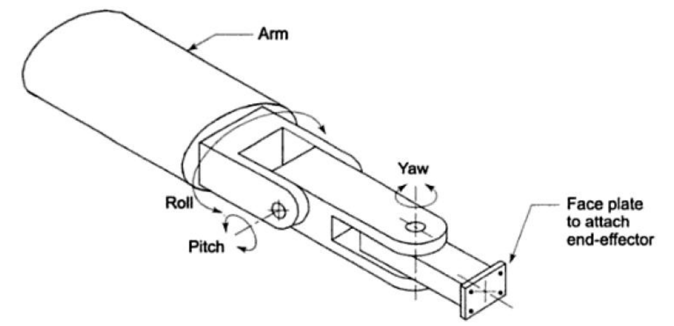


Fig.2.13 A DOF RPY wrist with three revolute joints

2.3.7 THE END-EFFECTOR

The end-effector is external to the manipulator and its DOF do not combine with the manipulator's DOF, as they do not contribute to manipulatability. Different end-effectors can be attached to the end of the wrist according to the task to be executed. These can be grouped into two major categories:

1. Grippers
2. Tools

Grippers are end-effectors to grasp or hold the workpiece during the work cycle. The applications include material handling, machine loading-unloading, pelletizing, and other similar operations. Grippers employ mechanical grasping or other alternative ways such as magnetic, vacuum, bellows, or others for holding objects. The proper shape and size of the gripper and the method of holding are determined by the object to be grasped and the task to be performed.

Some typical mechanical grippers are shown in Fig. 2.14.

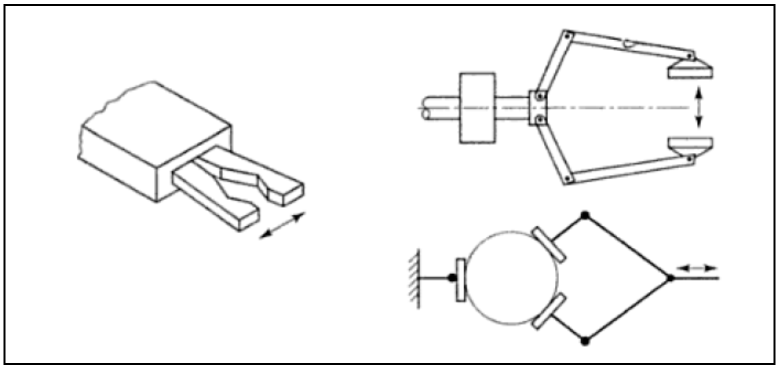


Fig.2.14 Some fingered grippers for holding different types of jobs

For many tasks to be performed by the manipulator, the end-effector is a tool rather than a gripper. For example, a cutting tool, a drill. a welding torch. a spray gun, or a screwdriver is the end-effector for machining, welding, painting, or assembly task, mounted at the wrist endpoint The tool is usually directly attached to the end of the wrist. Sometimes, a gripper may be used to hold the tool instead of the workpiece. Tool changer devices can also be attached to the wrist end for multi-tool operations in a work cycle.

Chapter 3
Design

3.1 OVERVIEW

3.1.1 ARTICULATED ROBOTIC ARM

An articulated robot is a robot which is fitted with rotary joints. Rotary joints allow a full range of motion, as they rotate through multiple planes, and they increase the capabilities of the robot considerably. An articulated robot can have one or more rotary joints, and other types of joints may be used as well, depending on the design of the robot and its intended function.

With rotary joints, a robot can engage in very precise movements. Articulated robots commonly show up on manufacturing lines, where they utilize their flexibility to bend in a variety of directions. Multiple arms can be used for greater control or to conduct multiple tasks at once, for example, and rotary joints allow robots to do things like turning back and forth between different work areas.

These robots can also be seen at work in labs and in numerous other settings. Researchers developing robots often work with articulated robots when they want to engage in activities like teaching robots to walk and developing robotic arms. The joints in the robot can be programmed to interact with each other in addition to activating independently, allowing the robot to have an even higher degree of control. Many next generation robots are articulated because this allows for a high level of functionality.

Articulated robots can have arms and legs which allow them to move and manipulate a wide variety of objects. Some are designed as console units with arms, where the unit remains in place in a fixed position and the arms are used to perform tasks. Others may wheel, slide, or move in other ways so that they can navigate spaces of varying sizes. In a medical lab, for example, an articulated robot might be used to deliver and carry samples around the lab.

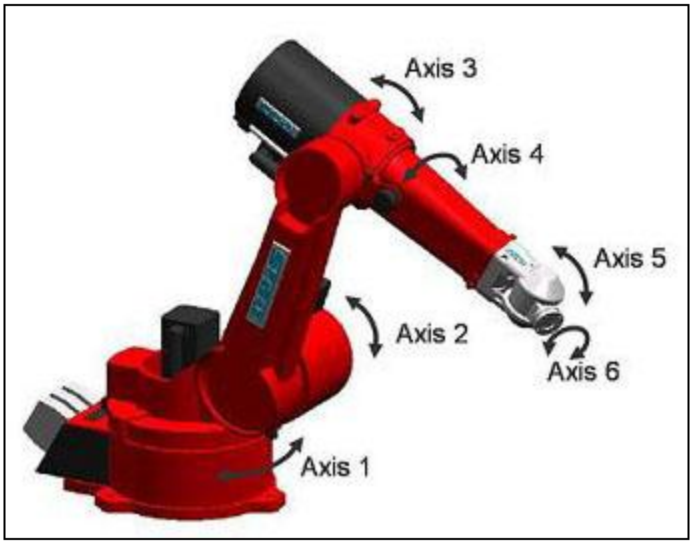


Fig.3. 1 An articulated robotic arm

3.1.2 OUR DESIGN

The robotic arm is a vertical articulated robot, made of the following components:
i. Six revolute joints
ii. Six links
iii. End gripper

The arm has six degrees of freedom, with the gripper attached. The movements of the joints are tabulated below:

Axis No.	Name of Joint	Motion	Motor No.
1	Base	Rotates the entire assembly	1
2	Shoulder	Rotates the upper arm	2
3	Elbow	Rotates the forearm	3
4	Wrist Pitch	Rotates the gripper	4
5	Wrist Roll	Rotates the gripper	5
6	Wrist Yaw	Rotates the gripper	6

Table 3. 1 : Joint and functions

The seventh motor is used for the gripping mechanism.

3.2 TORQUE CALCULATIONS

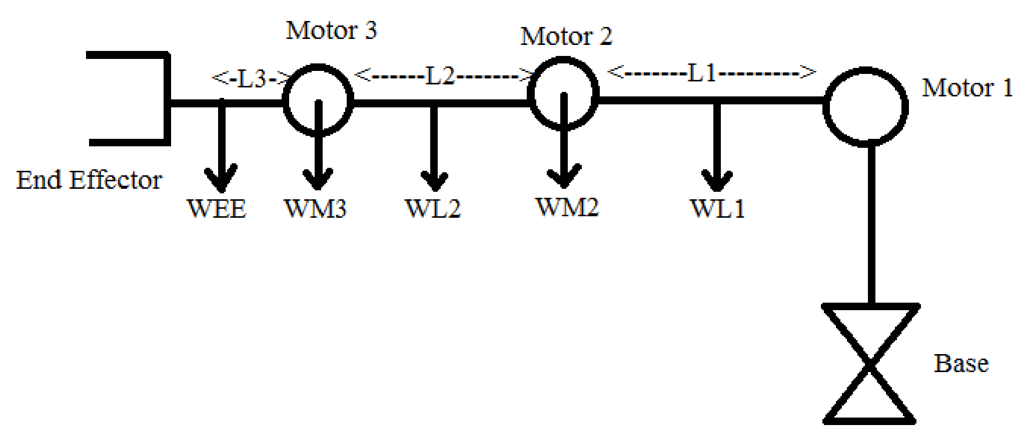


Fig. 3 1 Link Diagram

Available data:

- Weight of servo motor(15 kg-cm): 56 gms
- Weight of servo motor(9 kg-cm): 56 gms
- Weight of servo motor(6 kg-cm): 40 gms
- Weight of servo motor(15 kg-cm): 6 gms
- Weight of universal bracket: 38 gms
- Weight of C bracket: 37 gms
- Density of acrylic: 1.18 gms/cm^3
- Length of link1 (L1) = 9.5 cm
- Length of Link (L2) = 9.5 cm
- Length L3 = 9.5 cm

Assumed data:

- Weight of M4 nut and bolt: 2.5 gms
- Weight of M2 nut and bolt: 1.5 gms

Calculations:

Mass of acrylic link = 9.5*3*0.4*1.18
= 13.45 gms

Mass of Servo Motor M2 considering four M4 nut bolts, one C bracket and one Universal bracket (WM2) = 56 + 37 + 38 + 4*2.5 = 141 gms

Mass of link L1 (WL1) = 2*Mass of Acrylic link + 8*Mass of M2 Nut bolt
= 2*13.45 + 1.5*8 gms
= 38.9 gms

Since link L2 is same as link L1, Mass of link L2 (WL2) = 38.9 gms

Mass of Servo Motor 3 considering four M4 nut bolts, one C bracket and one Universal bracket (WM3) = 56 + 37 + 38 + 4*2.5 = 141 gms

Mass of end effector (WEE) = 230 gms

Torque acting on motor M1 (T1) = (WL1*L1)/2 + WM2*L1 + WL2*(L2/2 + L1) + WM3*(L2 + L1) + WEE*(L1 + L2 + L3)

T1= {9.5*38.9)/2} + {10.5*141} + {15.25*38.9} + {20.25*141} + {30*230}
= 13.67 kg-cm

Hence standard available metal gear servo motor of 15 kg-cm torque is selected.

Torque acting on motor M2 (T2) = (WL2*L2)/2 + WM3*L2 + WEE*(L2 + L3)
T2 = {9.5(38.9)/2} + {10.5*141} + {20*230}
= 6.265 kg-cm

Hence standard available metal gear servo motor of 9 kg-cm torque is selected.

Torque acting on motor M3 (T3) = WEE*L3
T3= {9.5*230}
= 2.185 kg-cm

Hence standard available metal gear servo motor of 9 kg-cm torque is selected since metal gear motors can sustain higher loads as compared to plastic gear motors and metal gear motor range starts from 9 kg-cm torque.

3.3 COMPONENTS

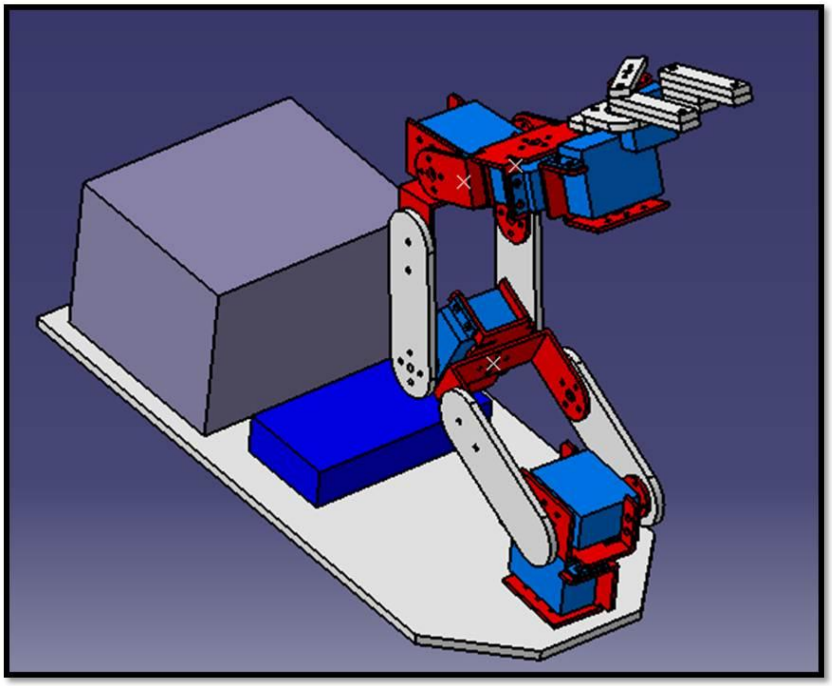


Fig. 3 2 Picture of Assembly 1

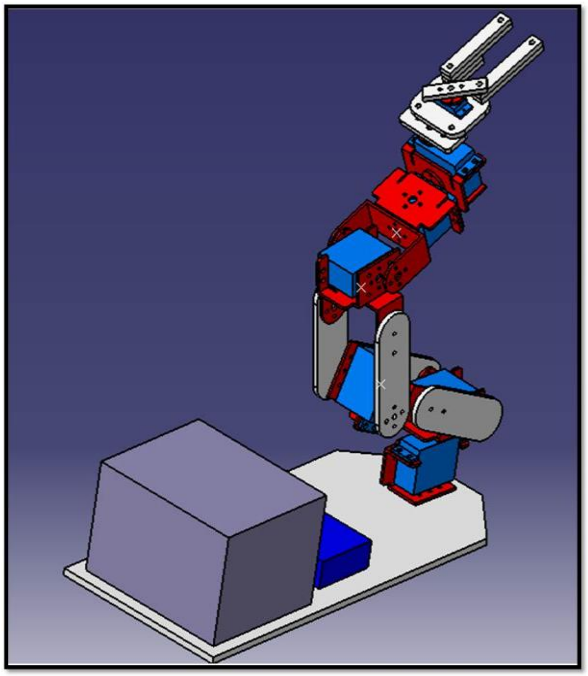


Fig. 3 3 Picture of Assembly 2

3.3.1 LINKS & BASEPLATE

1. Links: It is a prismatic link. It connects the shoulder & the elbow and the elbow & the wrist.
Material: Acrylic, 4 mm thickness

2. Base Plate: It provides the base for the entire assembly. The battery, motor driver circuit and the Arduino board is also mounted on it.
Material: Acrylic, 4 mm thickness

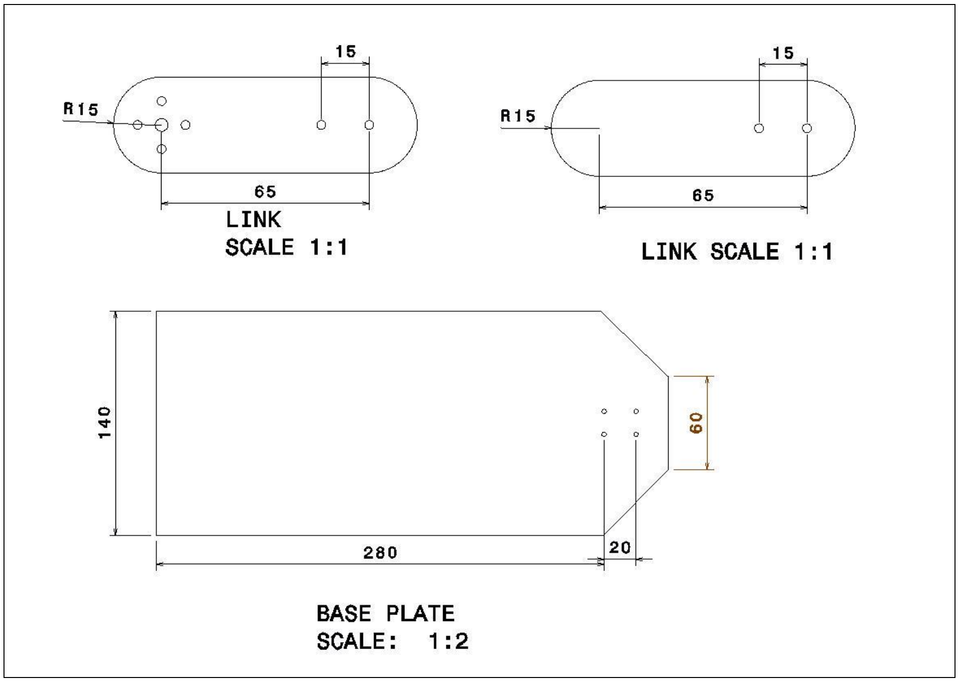


Fig. 3 4 Links & Base Plate

3.3.2 BRACKETS

1. Universal Bracket: It holds the servomotor.
Material: Anodized aluminum, 2 mm thickness

2. C-Bracket: It joints the two links for pitch motion.
Material: Anodized aluminum, 2 mm thickness

3. Circular Horn: It joins the servo motor shaft to the adjacent link.
Material: Plastic

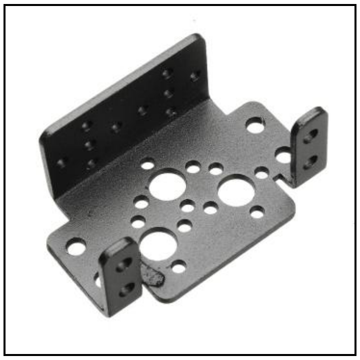


Fig. 3 5 Universal Bracket

Fig. 3 6 C- Bracket

Fig. 3 7 Circular Horn

3.3.3 SERVO MOTORS

Standard servo motors used with torque ratings as follows:

1) 15 kg.cm: for base and shoulder rotation
2) 9 kg.cm: for elbow rotation and wrist pitch
3) 6 kg.cm: for wrist roll and wrist yaw
4) 0.8 kg.cm: micro servo motor for gripper

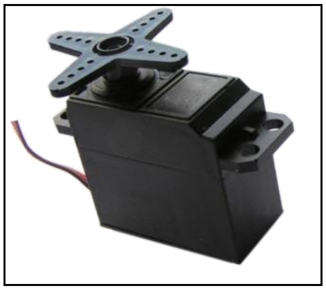


Fig. 3 8 Servo Motor

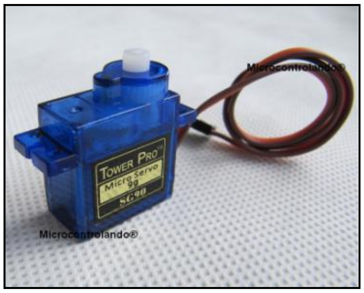
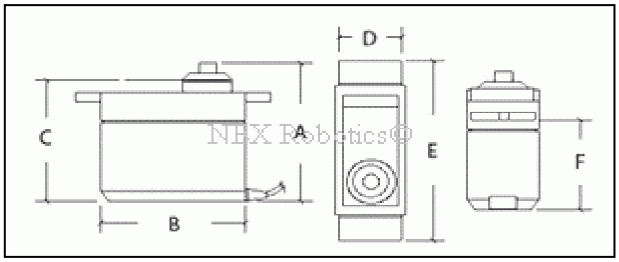


Fig. 3 9 Micro Servo Motor



Notation	Dimension	Notation	Dimension
A	46 mm	D	20 mm
B	40 mm	E	55 mm
C	41 mm	F	29 mm

Table 3. 2 Servo motor dimension

Chapter 4
Analysis

A robotic manipulator is designed to perform a task in the 3-D space. The tool or end-effector is required to follow a planned trajectory to manipulate objects or carry out the task in the workspace. This requires control of position of each link and joint of the manipulator to control both the position and orientation of the tool. To program the tool motion and joint-link motions, a mathematical model of the manipulator is required to refer to all geometrical and/or time-based properties of the motion. Kinematic model describes the spatial position of joints and links, and position and orientation of the end-effector. The derivatives of kinematics deal with the mechanics of motion without considering the forces that cause it. The relationships between the motions and the forces and torques that cause them, is the dynamics problem. In designing a robot manipulator, kinematics and dynamics play a vital role. The mathematical tools of spatial descriptions developed in the previous chapter are used in the modeling of robotic manipulators. The *kinematic model* gives relations between the position and orientation of the end-effector and spatial positions of joint-links. The *differential kinematics* of manipulators refers to differential motion, that is, velocity, acceleration, and all higher order derivatives of position variables. The problem of completely describing the position and orientation of a manipulator, the kinematic model, is considered in this and the next chapter.

With the definition of fixed and variable kinematic parameters for each link kinematic models can be defined. This model is the analytical description of the spatial geometry of motion of the manipulator with respect to a fixed (inertial) reference frame as a function of time. In particular, the relation between the joint-variables and the position and orientation of the end-effector is the kinematic model. It is required to control position and orientation of the end-effector in 3-D space, so that it can follow a defined trajectory or manipulate objects in the workspace. The kinematic modelling problem is split into two problems as:

1. Given the set of joint-link parameters the problem of finding the position and orientation of the end-effector with respect to a known (immobile or inertial) reference frame for an n-DOF manipulator is the first problem. This is referred to as *direct (or forward) kinematic model* or *direct kinematics.* This model gives the position and orientation of the end-effector as a function of the joint variables and other joint-link constant parameters.

2. For a given position and orientation of the end-effector (of the n-DOF manipulator), with respect to an immobile or inertial reference frame it is required to find a set of joint variables that would bring the end-effector in the specified position and orientation. This is the second problem and is referred to as the *inverse kinematic model* or *inverse kinematics.*

The problem of manipulator control requires both the direct and inverse kinematic models of the manipulator. The block diagram for both the models is illustrated in Fig. 3.7 wherein the commonality is the joint-link fixed and variable parameters. The task to be performed by a manipulator is stated in terms of the end-effector location in space. The values of joint variables required to accomplish the task are computed using the inverse kinematic model. To find the location of end-effector in space, at any instant of time, the joint variable values are substituted in the direct kinematic model. This chapter addresses the problem of formulation of direct kinematic model. The inverse kinematic model formulation will be discussed in the next chapter.

For kinematic modelling frames are assigned to each link of the manipulator starting from the base to the end-effector. The homogeneous transformation matrices relating the frames attached to successive links describe the spatial relationship between adjacent links. The composition of these individual transform matrices determines the overall transformation matrix describing tool frame with respect to base frame.

4.1 DIRECT KINEMATICS

4.1.1 DENAVIT &HARTENBERG (D-H) NOTATION

The definition of a manipulator with four joint-link parameters for each link and a systematic procedure for assigning right-handed orthonormal coordinate frames, one to each link in an open kinematic chain was proposed by Denavit and Hartenberg (1955) and is known as *Denavit-Hartenberg (DH) notation*. This notation is presented in this section and followed throughout the text. A frame {i} is rigidly attached to distal end of link i and it moves with link i. An n-DOF manipulator will have (n + I) frames with the frame {O} or base frame acting as the reference inertial frame and frame *{n}* being the *"tool frame"*.

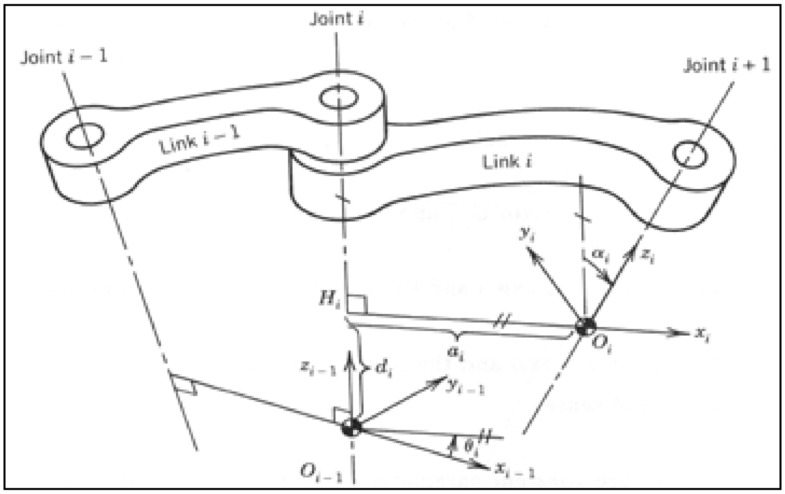


Fig.4. 1 D-H parameters

Figure 4.1 shows a pair of adjacent links, link (i-1) and link i, their associated joints, joints (i-1), i and (i+ 1), and axes (;-2), (i-1), and *i*, respectively. Line AB, in the figure, is the common normal to (i-2)- and (i-1)-axes and line CD is the common normal to (i-l)- and i-axes. A frame {i} is assigned to link *i* as follows:

(i) The Z-axis is aligned with axis *i*, its direction being arbitrary. The choice of direction defines the positive sense of joint variable Θ,.

(ii) The x;-axis is perpendicular to axis Zi-1 and Zi and points away from axis Zi-1 'that is, Xi axis is directed along the common normal CD.

(iii) The origin of the ith coordinate frame, frame {i} is located at the intersection of axis of joint (i+ 1), that is, axis i, and the common normal between axes (i-1) and i (common normal is CD), as shown in the figure.

(iv) Finally, y;-axis completes the right-hand orthonormal coordinate frame {i}.

Note that the frame {i} for link i is at the distal end of link i and moves with the link.

With respect to frame *{i-1}* and frame {i}, the four DH-parameters – two link parameters (ai. αi) and two joint parameters (di, Θi) - are defined as:

(a) Link Length (aj) - distance measured along "'Xi-axis from the point of intersection of Xi-axis with Zi-1-axis (point C) to the origin of frame {i}, that is distance CD.

(b) Link twist (αi) - angle between Zi-1 and Zi-axes measured about *Xi-axis* in the right-hand sense.

(c) Joint distance *(di)* - distance measured along Zi-1-axis from the origin of frame {i-1} (point B) to the intersection of *xi*-axis with Zi-l-axis (point C), that is distance BC.

(d) Joint angle (Θj) - angle between *Xi-1*and Xi axes measured about the Zi-l-axis in the right-hand sense.

The convention outlined above does not result in a unique attachment 'of frames to links because alternative choices are available. For example, joint axis *i* has two choices of direction to point z.-axis, one pointing upward (as in Fig. 3.8) and other pointing downward. To minimize such options and get a consistent set of frames an algorithm is presented below to assign frames to all links of a manipulator.

4.1.2 ARTICULATED ARM KINEMATIC MODEL

The arm matrix is divided into three parts, which is,

- First partitioned matrix
- Second partitioned matrix
- Final arm matrix

A 3-DOF articulated arm is considered for obtaining the transformation matrix for the endpoint,

An articulated arm is a 3-DOF-manipulator with three revolute joints that is an RRR arm configuration as shown in Fig. 4.2. The axes of joint 2 and joint 3 are parallel and axis of joint 1 is perpendicular to these two. At the end of the arm, a faceplate is provided to attach the wrist.

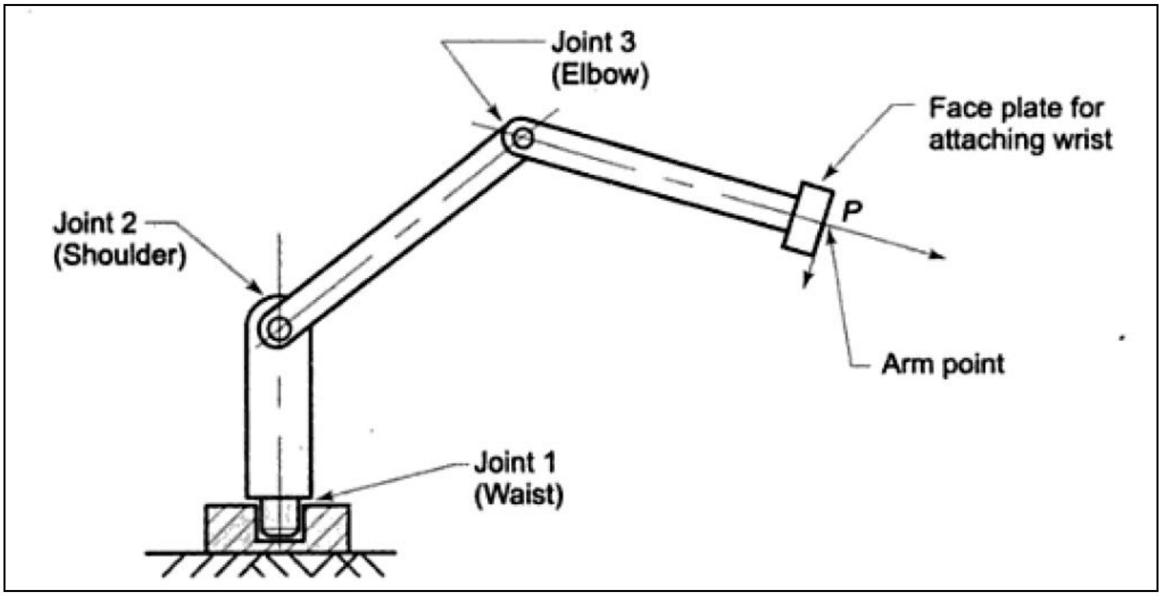


Fig 4. 2 3 DOF manipulator

To determine the "arm point" transformation matrix, the frames are assigned first. The resulting joint-link parameters are tabulated. For all the three joints, joint-offsets are assumed to be zero.

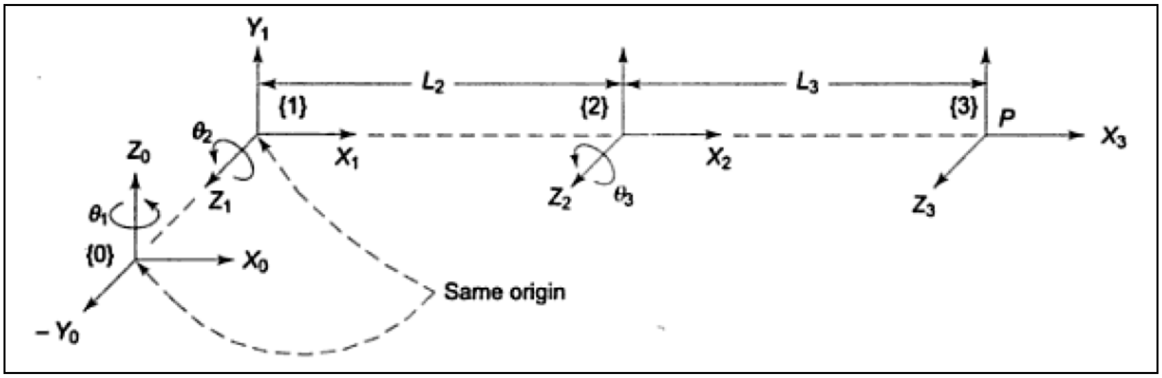


Fig 4. 3 Link

The link transformation matrices are

$$
{}^0T_1(\theta_1) = \begin{bmatrix} C_1 & 0 & S_1 & 0 \\ S_1 & 0 & -C_1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}
$$

$$
{}^1T_2(\theta_2) = \begin{bmatrix} C_2 & -S_2 & 0 & L_2C_2 \\ S_2 & C_2 & 0 & L_2S_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}
$$

$$
{}^2T_3(\theta_3) = \begin{bmatrix} C_3 & -S_3 & 0 & L_3C_3 \\ S_3 & C_3 & 0 & L_3S_3 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}
$$

The overall transformation matrix for the endpoint of the arm is, therefore,

$$
{}^0T_1 = {}^0T_1{}^1T_2{}^2T_3 = \begin{bmatrix} C_1C_{23} & -C_1S_{23} & S_1 & C_1(L_3C_{23} + L_2C_2) \\ S_1C_{23} & -S_1S_{23} & -C_1 & S_1(L_3C_{23} + L_2C_2) \\ S_{23} & C_{23} & 0 & L_3S_{23} + L_2S_2 \\ 0 & 0 & 0 & 1 \end{bmatrix}
$$

Where C_{23} and S_{23} refer to $\cos(\Theta2+\Theta3)$ and $\sin(\Theta2+\Theta3)$ respectively.

For Pick up Position substituting Servo motor angles in the above matrix as-
$\Theta_1=45^0$
$\Theta_2=85^0$
$\Theta_3=110^0$

The Joint Link parameter table for the arm is-

Link i	ai	αi	di	Θi
1	0	90	0	45
2	10	0	0	85
3	10	0	0	110

Table 4. 1 Joint link parameter table

Substituting the values of link lengths and Joint angles we get the position of the Wrist as-
X= 6.3cm
Y=-6.21cm
Z= 7.7cm
According to this position the object is placed for pick up.

Similarly position for placing of the object is determined.

Chapter 5
Fabrication

5.1 MATERIALS

5.1.1 ACRYLIC

Poly(methyl methacrylate) (**PMMA**) is a transparent thermoplastic often used as a lightweight or shatter-resistant alternative to soda-lime glass. We used acrylic to make gripper links, gripper plate and arm links for its excellent aesthetic properties, strength and durability.

Although not a type of familiar silica-based glass, the substance, like many thermoplastics, is often technically a type of glass (a non-crystalline vitreous substance) and historically has often been called **acrylic glass**. Chemically, it is the synthetic polymer of methyl methacrylate. The material was developed in 1928 in several different laboratories by many chemists such as William Chalmers, Otto Röhm and Walter Bauer and was first brought to market in 1933 by the Rohm and Haas Company, under the trademark ***Plexiglas***.It has since been sold under many different names, including ***Acrylite***, ***Lucite***, and ***Perspex***.

PMMA is an economical alternative to polycarbonate (PC) when extreme strength is not necessary. Additionally, PMMA does not contain the potentially harmful bisphenol-A subunits found in polycarbonate. It is often preferred because of its moderate properties, easy handling and processing, and low cost. Non-modified PMMA behaves in a brittle manner when loaded, especially under an impact force, and is more prone to scratching than conventional inorganic glass, but modified PMMA can achieve high scratch and impact resistance.

PHYSICAL PROPERTIES

Tensile Strength		
Yield, 73°F	5420 to 10700	Psi
Yield, 73°F	5370 to 12100	Psi
Break, 73°F	2800 to 10900	Psi
Break, 73°F	7100 to 11200	Psi
73°F	5340 to 11500	Psi
73°F	5190 to 11600	Psi
Tensile Elongation		
Yield, 73°F	2.4 to 5.2	%
Yield, 73°F	3.6 to 25	%

Break, 73°F	0.20 to 15	%
Break, 73°F	1.8 to 7.2	%
Nominal Tensile Strain at Break (73°F)	9.9 to 27	%
Surface Resistivity		
--	5.0E+10 to 1.0E+16	Ohm
--	1.0E+13 to 1.0E+16	Ohm
Volume Resistivity		
73°F	5.5E+9 to 2.5E+15	ohm·cm
73°F	1.0E+13 to 1.0E+15	ohm·cm
Dielectric Strength		
73°F	380 to 510	V/mil
73°F	510 to 610	V/mil
Density	1.18	g/cm^3

Table 5. 1 Physical properties of acrylic

WHY ACRYLIC?

Uniting incredible strength with aesthetic beauty, acrylic is the material of choice for thousands of products in many industries.

Acrylic is a polymer created when giant carbon molecules combine chemically. Finished acrylic sheet exhibits glass-like qualities – clarity, brilliance, transparency, translucence – but at half the weight and up to 10 times the impact resistance. It can be tinted or coloured, mirrored or made opaque. A number of coatings can be applied to a sheet or finished part for performance enhancing characteristics such as scratch resistance, anti-fogging, glare reduction and solar reflective.

Because it's a thermoplastic and softens under extremely high temperatures, acrylic can be formed to virtually any shape. Incredibly durable, acrylic is a suitable solution over a broad temperature range, and has superior weathering properties compared to other plastics. Today Plaskolite acrylic sheet is specified for use in thousands of products thanks to its ease of fabrication, low heat loss and attractive clear edge colour. From point-of-purchase displays to signage, lighting and dozens of other applications, Plaskolite acrylic sheet is an ideal design solution.

5.1.2 ANODIZED ALUMINIUM

Hard Anodising is an alternative form of anodising where high levels of hardness and abrasion resistance are important. Typical uses are working parts on machinery and street hardware items such as cable duct and water stopcock covers. The hard anodising process provides a method of increasing the thickness of the naturally occurring oxide film on aluminium and its alloys, to give a coating which may be considered in many ways analogous to the case hardening of steel. It is distinguished from 'decorative' or 'architectural' anodising in that the process is operated in a manner, which gives optimum technical properties without regard to aesthetic effect; thus, the coatings may be grey or tinged with yellow or brown, according to the alloy and coating thickness. Colouring may be carried out by dyeing after anodising, but the colours so obtained will be diluted by the 'natural' colour of the coating. Dichromate sealing also imparts a colour to the film. Anodising lowers the fatigue strength of alloys but this reduction is said to be restored to some extent by hot sealing. We used Hard Anodized Aluminium in Motor Brackets due to its excellent strength and availability.

WHY ANODIZED ALUMINIUM?

Aluminium anodizing enhances the advantageous characteristics of aluminium in several ways:

- *Durability*: Since anodized aluminium extrusion products have a protective layer, they are more resistant to wear from normal handling and usage.
- *Finishing*: The process creates a more aesthetically pleasing finish, with either a clear or colourized appearance.
- Corrosion resistance: The thick outer coating produced, along with proper sealing, increases the corrosion resistivity of the surface as it prevents further oxidization.
- *Lasting Color*: The color finish added to anodized aluminium is more enduring due to the surface obtaining more adhesive and porous qualities during the anodizing process. The resulting anodic film coating allows for effective dyeing processes to be applied.
- *Strength*: The anodized aluminium surface is harder than pure aluminium, second only to diamonds with respect to its hard crystalline structure.

5.2 MANUFACTURING- LASER CUTTING

Laser cutting is a technology that uses a laser to cut materials, and is typically used for industrial manufacturing applications, but is also starting to be used by schools, small businesses, and hobbyists. Laser cutting works by directing the output of a high-power laser, by computer, at the material to be cut. The material then melts, burns, vaporizes away, or is blown away by a jet of gas, leaving an edge with a high-quality surface finish. Industrial laser cutters are used to cut flat-sheet material as well as structural and piping materials.

Laser cutting works by exciting a gaseous medium, commonly carbon dioxide, causing it to amplify light reflected back and forth multiple times within the laser chamber. The light emerges from an aperture and is focused by a lens onto a specific point.

A typical process laser has a beam about a 1/5 of a millimeter in width, focusing 1000 to 2000 watts of energy. This is enough to melt most common materials. Because lasers become less focused and lose energy as they penetrate through a material, there is a limit of about 20 mm for the deepness of the cut. Laser cutting machines are integrated into a larger CAD/CAM (computer-aided-design, computer-aided-manufacturing) system that takes a design file and implements it on a workpiece. These machines represent a stepping stone in the continuing trend away from hands-on manufacturing, putting human workers in a more removed, creative design role.

Because a laser is made up of photons, parts of its energy can be reflected away by materials such as aluminum and copper alloys. These materials are also thermal conductors, meaning they distribute incoming heat more evenly throughout their volume. For this reason, carbon alloy and stainless steel are popular workpiece materials for laser cutting. They are poor at absorbing heat, so heat is concentrated into the laser's path more readily.

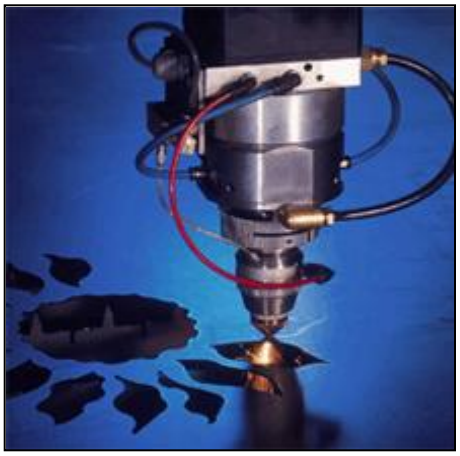


Fig.5. 1 Laser cutting

5.2.1 KEY FEATURES

- Laser light can be well focused from 2" (50 mm) to .007" (.2 mm)
- Laser radiation: coherent, monochromatic, high energy
- Very high power density (some MW/cm2)
- The light melts or partially vaporizes the material and an additional gas stream blows it away
- High to medium cut quality (roughness)
- Smooth to rough, vertical planes of cut
- Metallurgical perfect surfaces (oxidized) or metallic blank surfaces (high pressure inert gas cutting)
- Low heat input
- High to low cutting speeds
- Hardening within the area of the Heat-Affected-Zone (HAZ) (small)
- Dust as well as UV and IR-radiation

Fig.5. 2 Laser cutting

5.2.2 TYPES

There are three main types of lasers used in laser cutting. The CO_2 laser is suited for cutting, boring, and engraving. The neodymium (Nd) and neodymium yttrium-aluminium-garnet (Nd- YAG) lasers are identical in style and differ only in application. Nd is used for boring and where high energy but low repetition is required. The Nd-YAG laser is used where very high power is needed and for boring and engraving. Both CO_2 and Nd/ Nd-YAG lasers can be used for welding.

Common variants of CO$_2$ lasers include fast axial flow, slow axial flow, transverse flow, and slab.CO$_2$ lasers are commonly "pumped" by passing a current through the gas mix (DC-excited) or using radio frequency energy (RF-excited). The RF method is newer and has become more popular. Since DC designs require electrodes inside the cavity, they can encounter electrode erosion and plating of electrode material on glassware and optics. Since RF resonators have external electrodes they are not prone to those problems.

Fig.5. 3 CO2 Laser Machine

CO$_2$ lasers are used for industrial cutting of many materials including mild steel, aluminium, stainless steel, titanium, paper, wax, plastics, wood, and fabrics. YAG lasers are primarily used for cutting and scribing metals and ceramics.

In addition to the power source, the type of gas flow can affect performance as well. In a fast axial flow resonator, the mixture of carbon dioxide, helium and nitrogen is circulated at high velocity by a turbine or blower. Transverse flow lasers circulate the gas mix at a lower velocity, requiring a simpler blower. Slab or diffusion cooled resonators have a static gas field that requires no pressurization or glassware, leading to savings on replacement turbines and glassware.

The laser generator and external optics (including the focus lens) require cooling. Depending on system size and configuration, waste heat may be transferred by a coolant or directly to air.

Water is a commonly used coolant, usually circulated through a chiller or heat transfer system.

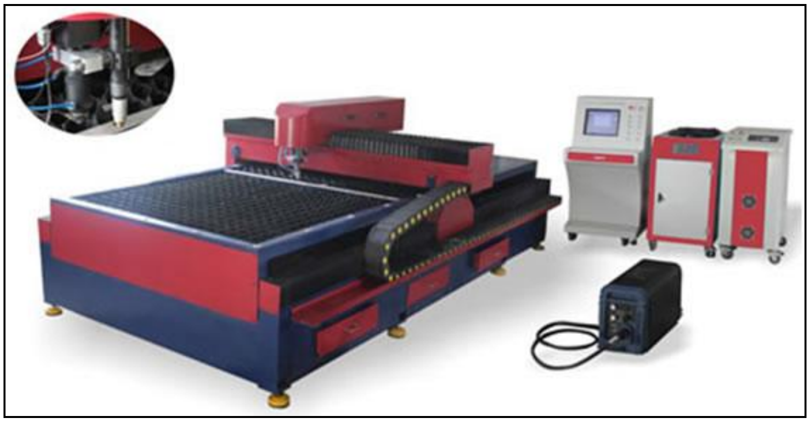


Fig.5. 4 Neodymium (Nd) Laser Machine

5.2.3 PROCESS

Generation of the laser beam involves stimulating a lasing material by electrical discharges or lamps within a closed container. As the lasing material is stimulated, the beam is reflected internally by means of a partial mirror, until it achieves sufficient energy to escape as a stream of monochromatic coherent light. Mirrors or fiber optics are typically used to direct the coherent light to a lens, which focuses the light at the work zone. The narrowest part of the focused beam is generally less than 0.0125 inches (0.32 mm) in diameter. Depending upon material thickness, kerf widths as small as 0.004 inches (0.10 mm) are possible. In order to be able to start cutting from somewhere else than the edge, a pierce is done before every cut. Piercing usually involves a high-power pulsed laser beam which slowly makes a hole in the material, taking around 5–15 seconds for 0.5-inch-thick (13 mm) stainless steel, for example.

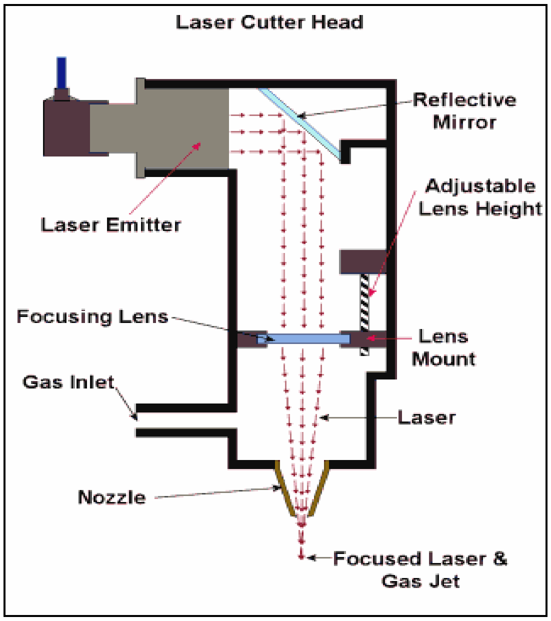


Fig.5. 5 Process of Laser cutting

The parallel rays of coherent light from the laser source often fall in the range between 0.06– 0.08 inch (1.5–2.0 mm) in diameter. This beam is normally focused and intensified by a lens or a mirror to a very small spot of about 0.001 inches (0.025 mm) to create a very intense laser beam. In order to achieve the smoothest possible finish during contour cutting, the direction of beam polarization must be rotated as it goes around the periphery of a contoured workpiece. For sheet metal cutting, the focal length is usually 1.5–3 inches (38–76 mm).

There are many different methods in cutting using lasers, with different types used to cut different material. Some of the methods are vaporization, melt and blow, melt blow and burn, thermal stress cracking, scribing, cold cutting and burning stabilized laser cutting.

5.2.4 MACHINE CONFIGURATIONS

There are generally three different configurations of industrial laser cutting machines: moving material, hybrid, and flying optics systems. These refer to the way that the laser beam is moved over the material to be cut or processed. For all of these, the axes of motion are typically designated X and Y axis. If the cutting head may be controlled, it is designated as the Z-axis.

Moving material lasers have a stationary cutting head and move the material under it. This method provides a constant distance from the laser generator to the workpiece and a single point from which to remove cutting effluent. It requires fewer optics, but requires moving the workpiece. This style machine tends to have the fewest beam delivery optics, but also tends to be the slowest. In moving material machines, the laser beam remains stationary while the material is moved using an automatically mobile surface located beneath the laser.

The advantage of using this type of machine is that the opening of the laser and the surface of the material are kept apart at a constant distance Hybrid lasers provide a table which moves in one axis (usually the X-axis) and move the head along the shorter (Y) axis. This results in a more constant beam delivery path length than a flying optic machine and may permit a simpler beam delivery system. This can result in reduced power loss in the delivery system and more capacity per watt than flying optics machines.

Flying optics lasers feature a stationary table and a cutting head (with laser beam) that moves over the workpiece in both of the horizontal dimensions. Flying optics cutters keep the workpiece stationary during processing and often do not require material clamping. The moving mass is constant, so dynamics are not affected by varying size of the workpiece. Flying optics machines are the fastest type, which is advantageous when cutting thinner workpieces. One disadvantage of the flying optics option is that the constant mobility of the laser head leads to a constantly changeable beam length. This can be adjusted by aligning the optics or by using tools specially designed to keep the distance between the laser opening and material constant.

Flying optic machines must use some method to take into account the changing beam length from near field (close to resonator) cutting to far field (far away from resonator) cutting. Common methods for controlling this include collimation, adaptive optics or the use of a constant beam length axis.

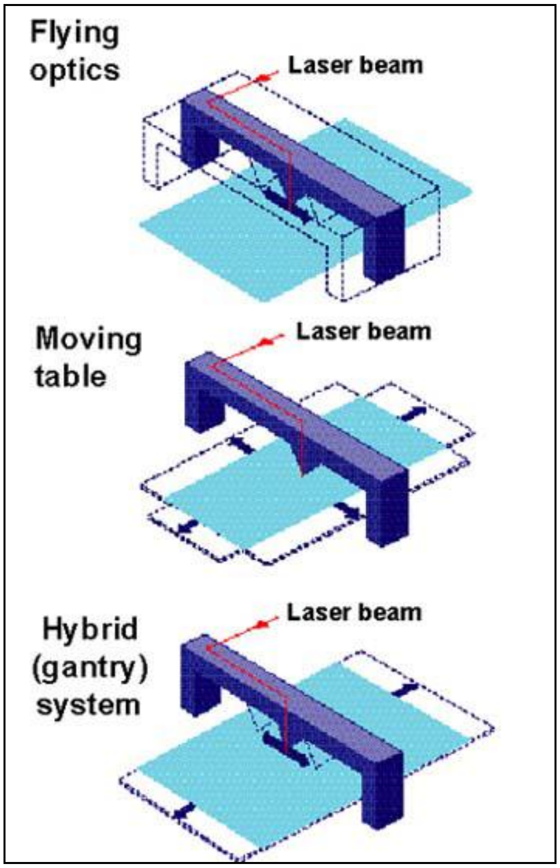


Fig.5. 6 Machine configuration

5.2.5 ADVANTAGES OF CO_2 LASER CUTTING

- The laser creates a beam of light that is used to cut through the material, so there is no part of the laser system in contact with the material
- For thinner materials, all Epilog laser systems include an Integrated Vacuum Table to hold down papers, fabrics, and thin plastics as you cut through the material
- It is amazingly precise, following the pattern you've drawn on screen
- Cut several patterns from the same piece of material
- You can print to the laser from a variety of programs, including CorelDRAW,
- AutoCAD and Adobe software
- Easier work holding and reduced contamination of workpiece (since there is no cutting edge which can become contaminated by the material or contaminate the material)
- Precision may be better, since the laser beam does not wear during the process.
- There is also a reduced chance of warping the material that is being cut, as laser systems have a small heat-affected zone

5.2.6 DISADVANTAGES OF CO_2 LASER CUTTING

- The main disadvantage of laser cutting is the high power consumption
- Industrial laser efficiency may range from 5% to 15%
- The power consumption and efficiency of any particular laser will vary depending on output power and operating parameters
- This will depend on type of laser and how well the laser is matched to the work at hand
- The amount of laser cutting power required, known as heat input, for a particular job depends on the material type, thickness, process (reactive/inert) used, and desired cutting rate

Chapter 6
Control

6.1 ACTUATORS

The actuators are used in the robots for providing the *power* to the *robot joints*. It can be powered by anyone of the following sources:

- Hydraulic – pressurized fluid
- Pneumatic – compressed air
- Electric – electricity

6.1.1 SERVO MOTORS

A servomotor is a rotary actuator that allows for precise control of angular position. It consists of a motor coupled to a sensor for position feedback, through a reduction gearbox. The servomotor is actually an assembly of four things: a normal DC motor, a gear reduction unit, a position-sensing device (usually a potentiometer—a volume control knob), and a control circuit.

The function of the servomotor is to receive a control signal that represents a desired output position of the servo shaft, and apply power to its DC motor until its shaft turns to that position. It uses the position-sensing device to determine the rotational position of the shaft, so it knows which way the motor must turn to move the shaft to the commanded position.

We have used the servo motors procured from VEGAROBOKIT with the following specifications:-

1. V0006 MICRO SERVO MOTOR

Operating Voltage : 4.8-6.0V
PWM Input Range : Pulse Cycle 20±2ms, Positive Pulse 1~2ms
STD Direction : Counter Clockwise / Pulse Traveling 1500 to 1900μsec
Stall Torque : 0.8 kg (11 oz/in) at 4.8V, 1 Kgf.cm (12 oz/in) at 6V
Operating Speed : 0.14 sec/ 60° at 4.8V, 0.16 sec/ 60° at 6V at no load
Weight : 9 g (0.2 oz)
Size : 22*12.5*20*26.6
Plug Available : FUT, JR
Special Feature : Heavy Duty Plastic Gears, Economy Servo

2. V0150 SERVO MOTOR

Operating Voltage : 4.8-6.0V
PWM Input Range : Pulse Cycle 20±2ms, Positive Pulse 1~2ms
STD Direction : Counter Clockwise / Pulse Traveling 1500 to 1900µsec
Stall Torque : 15 kg-cm (206.3 oz/in) at 4.8V, 16.1 Kg-cm (221.4 oz/in) at 6V

Operating Speed : 0.18 sec/ 60° at 4.8V, 0.16 sec/ 60° at 6V at no load
Weight : 56 g (1.98 oz)
Size : 41.3*20.3*38.7*48.5*10
Plug Available : FUT, JR
Special Feature : Heavy Duty Metal Gears, Economy Servo

3. V0090F SERVO MOTOR

Operating Voltage : 4.8-6.0V
PWM Input Range : Pulse Cycle 20±2ms, Positive Pulse 1~2ms
STD Direction : Counter Clockwise / Pulse Traveling 1500 to 1900µsec
Stall Torque : 9 kg-cm (123.7 oz/in) at 4.8V, 10.2 Kg-cm (140.2 oz/in) at 6V
Operating Speed : 0.18 sec/ 60° at 4.8V, 0.16 sec/ 60° at 6V at no load
Weight : 56 g (1.98 oz)
Size : 41.3*20.3*38.7*48.5*10
Plug Available : FUT, JR
Special Feature : Heavy Duty Metal Gears, Economy Servo

4. V3006 SERVO MOTOR

Operating Voltage : 4.8-6.0V
PWM Input Range : Pulse Cycle 20±2ms, Positive Pulse 1~2ms
STD Direction : Counter Clockwise / Pulse Traveling 1500 to 1900µsec
Stall Torque : 6 kg-cm (82.6 oz/in) at 4.8V, 7.1 Kg-cm (97.3 oz/in) at 6V
Operating Speed : 0.18 sec/ 60° at 4.8V, 0.16 sec/ 60° at 6V at no load
Weight : 40g (1.41 oz)
Size : 41.3*20.3*38.7*48.5*10
Plug Available : FUT, JR
Special Feature : Heavy Duty Plastic Gears, Economy Servo

6.1.2 ELECTRICAL CIRCUIT

IC 7806

7806 is a voltage regulator integrated circuit. It is a member of 78xx series of fixed linear voltage regulator ICs. The voltage source in a circuit may have fluctuations and would not give the fixed voltage output. The voltage regulator IC maintains the output voltage at a constant value. The xx in 78xx indicates the fixed output voltage it is designed to provide. 7806 provide +6V regulated power supply Capacitors of suitable values can be connected at input and output pins depending upon the respective voltage levels. The operating range of servo motors is 4.8V to 6V; hence IC 7806 is used to convert the power supply into 6V.

Pin Description:

Pin No.	Function	Name
1	Input voltage (5V-18V)	Input
2	Ground (0V)	Ground
3	Regulated output; 6V (5.75V-6.25V)	Output

Table 6. 1 Pin description of IC 7806

Motor Pins

Brown cable ---- Gnd
Red cable ---- 5V Supply Voltage
Orange cable ---- PWM Signal

6.2 MICROCONTROLLER- ARDUINO MEGA

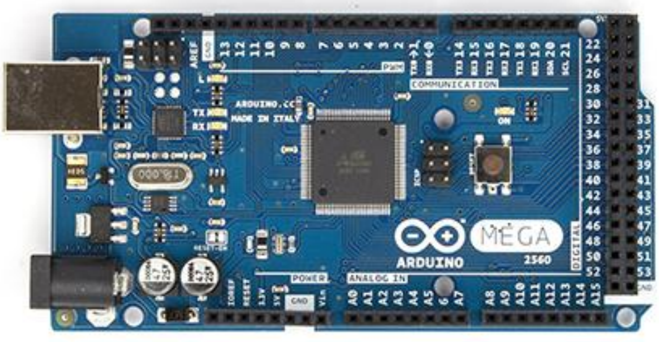


Fig 6. 1 Ardiuno mega

Overview

The Arduino Mega is a microcontroller board based on the ATmega1280. It has 54 digital input/output pins (of which 14 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started. The Mega is compatible with most shields designed for the Arduino Duemilanove or Diecimila.

Summary

Microcontroller	ATmega1280
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	54 (of which 15 provide PWM output)
Analog Input Pins	16
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	128 KB of which 4 KB used by bootloader
SRAM	8 KB
EEPROM	4 KB
Clock Speed	16 MHz

Table 6. 2 Ardiuno summary

Power

The Arduino Mega can be powered via the USB connection or with an external power supply. The power source is selected automatically.

External (non-USB) power can come either from an AC-to-DC adapter (wall-wart) or battery. The adapter can be connected by plugging a 2.1mm center-positive plug into the board's power jack. Leads from a battery can be inserted in the Gnd and Vin pin headers of the POWER connector.

The board can operate on an external supply of 6 to 20 volts. If supplied with less than 7V, however, the 5V pin may supply less than five volts and the board may be unstable. If using more than 12V, the voltage regulator may overheat and damage the board. The recommended range is 7 to 12 volts.

The power pins are as follows:

- VIN. The input voltage to the Arduino board when it's using an external power source (as opposed to 5 volts from the USB connection or other regulated power source). You can supply voltage through this pin, or, if supplying voltage via the power jack, access it through this pin.
- 5V. The regulated power supply used to power the microcontroller and other components on the board. This can come either from VIN via an on-board regulator, or be supplied by USB or another regulated 5V supply.
- 3V3. A 3.3 volt supply generated by the on-board FTDI chip. Maximum current draw is 50 mA.
- GND. Ground pins.

Memory

The ATmega1280 has 128 KB of flash memory for storing code (of which 4 KB is used for the bootloader), 8 KB of SRAM and 4 KB of EEPROM (which can be read and written with the EEPROM library).

Input and Output

Each of the 54 digital pins on the Mega can be used as an input or output, using pinMode(), digitalWrite(), anddigitalRead() functions. They operate at 5 volts. Each pin can provide or receive a maximum of 40 mA and has an internal pull-up resistor (disconnected by default) of 20-50 kOhms. In addition, some pins have specialized functions:

- Serial: 0 (RX) and 1 (TX); Serial 1: 19 (RX) and 18 (TX); Serial 2: 17 (RX) and 16 (TX); Serial 3: 15 (RX) and 14 (TX). Used to receive (RX) and transmit (TX) TTL serial data. Pins 0 and 1 are also connected to the corresponding pins of the FTDI USB-to-TTL Serial chip.
- External Interrupts: 2 (interrupt 0), 3 (interrupt 1), 18 (interrupt 5), 19 (interrupt 4), 20 (interrupt 3), and 21 (interrupt 2). These pins can be configured to trigger an interrupt on a low value, a rising or falling edge, or a change in value. See the attachInterrupt()function for details.
- PWM: 2 to 13 and 44 to 46. Provide 8-bit PWM output with the analogWrite() function.
- SPI: 50 (MISO), 51 (MOSI), 52 (SCK), 53 (SS). These pins support SPI communication, which, although provided by the underlying hardware, is not currently included in the Arduino language. The SPI pins are also broken out on the ICSP header, which is physically compatible with the Duemilanove and Diecimila.
- LED: 13. There is a built-in LED connected to digital pin 13. When the pin is HIGH value, the LED is on, when the pin is LOW, it's off.

- I^2C: 20 (SDA) and 21 (SCL). Support I^2C (TWI) communication using the Wire library (documentation on the Wiring website). Note that these pins are not in the same location as the I^2C pins on the Duemilanove or Diecimila.

The Mega has 16 analog inputs, each of which provide 10 bits of resolution (i.e. 1024 different values). By default they measure from ground to 5 volts, though is it possible to change the upper end of their range using the AREF pin and analogReference() function.

There are a couple of other pins on the board:

- AREF. Reference voltage for the analog inputs. Used with analog Reference().
- Reset. Bring this line LOW to reset the microcontroller. Typically used to add a reset button to shields which block the one on the board.

Communication

The Arduino Mega has a number of facilities for communicating with a computer, another Arduino, or other microcontrollers. The ATmega1280 provides four hardware UARTs for TTL (5V) serial communication. An FTDI FT232RLon the board channels one of these over USB and the FTDI drivers (included with the Arduino software) provide a virtual com port to software on the computer. The Arduino software includes a serial monitor which allows simple textual data to be sent to and from the Arduino board. The RX and TX LEDs on the board will flash when data is being transmitted via the FTDI chip and USB connection to the computer (but not for serial communication on pins 0 and 1).

A Software Serial library allows for serial communication on any of the Mega's digital pins.

The ATmega1280 also supports I2C (TWI) and SPI communication. The Arduino software includes a Wire library to simplify use of the I2C bus; see the documentation on the Wiring website for details. To use the SPI communication, please see the ATmega1280 datasheet.

Programming

The Arduino Mega can be programmed with the Arduino software. The ATmega1280 on the Arduino Mega comes preburned with a bootloader that allows you to upload new code to it without the use of an external hardware programmer. It communicates using the original STK500 protocol (reference, C header files).

You can also bypass the bootloader and program the microcontroller through the ICSP (In-Circuit Serial Programming) header; see these instructions for details.

6.3 PROGRAMMING

The Arduino software comes with ‘Servo’ library for the programming of servo motors. This library allows an Arduino board to control RC (hobby) servo motors. Servos have integrated gears and a shaft that can be precisely controlled. Standard servos allow the shaft to be positioned at various angles, usually between 0 and 180 degrees. Continuous rotation servos allow the rotation of the shaft to be set to various speeds.

The Servo library supports up to 12 motors on most Arduino boards and 48 on the Arduino Mega. On boards other than the Mega, use of the library disables analogWrite() (PWM) functionality on pins 9 and 10, whether or not there is a Servo on those pins. On the Mega, up to 12 servos can be used without interfering with PWM functionality; use of 12 to 23 motors will disable PWM on pins 11 and 12.

Servo motors have three wires: power, ground, and signal. The power wire is typically red, and should be connected to the 5V pin on the Arduino board. The ground wire is typically black or brown and should be connected to a ground pin on the Arduino board. The signal pin is typically yellow, orange or white and should be connected to a digital pin on the Arduino board.

6.3.1 FUNCTIONS

attach()

Description: Attach the Servo variable to a pin.
Syntax: servo.attach(pin)
servo.attach(pin, min, max)
Parameters:
servo: a variable of type Servo
pin: the number of the pin that the servo is attached to
min (optional): the pulse width, in microseconds, corresponding to the minimum (0-degree)
angle on the servo (defaults to 544)
max (optional): the pulse width, in microseconds, corresponding to the maximum (180-degree) angle on the servo (defaults to 2400)

Example:

```
#include <Servo.h>
Servo myservo;
void setup()
{
myservo.attach(9);
}
void loop() {}
```

write()

Description: Writes a value to the servo, controlling the shaft accordingly. On a standard servo, this will set the angle of the shaft (in degrees), moving the shaft to that orientation. On a continuous rotation servo, this will set the speed of the servo (with 0 being full-speed in one direction, 180 being full speed in the other, and a value near 90 being no movement).
Syntax: servo.write(angle)
Parameters:
servo: a variable of type Servo
angle: the value to write to the servo, from 0 to 180

Example:

```
#include <Servo.h>
Servo myservo;
void setup()
{
myservo.attach(9);
myservo.write(90); // set servo to mid-point
}
void loop() {}
```

writeMicroseconds()

Description: Writes a value in microseconds (uS) to the servo, controlling the shaft accordingly. On a standard servo, this will set the angle of the shaft. On standard servos a parameter value of 1000 is fully counter-clockwise, 2000 is fully clockwise, and 1500 is in the middle.

Note that some manufactures do not follow this standard very closely so that servos often respond to values between 700 and 2300. Feel free to increase these endpoints until the servo no longer continues to increase its range. Note however that attempting to drive a servo past its endpoints (often indicated by a growling sound) is a high-current state, and should be avoided. Continuous-rotation servos will respond to the writeMicrosecond function in an analogous manner to the write function.

Syntax: servo.writeMicroseconds(uS)
Parameters:
servo: a variable of type Servo
uS: the value of the parameter in microseconds (int)

Example:

```
#include <Servo.h>
Servo myservo;
void setup()
```

```
{
myservo.attach(9);
myservo.writeMicroseconds(1500); // set servo to mid-point
}
void loop() {}
```

read()

Description: Read the current angle of the servo (the value passed to the last call to write()).
Syntax: servo.read()
Parameters:
servo: a variable of type Servo
Returns the angle of the servo, from 0 to 180 degrees.

attached()

Description: Check whether the Servo variable is attached to a pin.
Syntax: servo.attached()
Parameters:
servo: a variable of type Servo
Returns true if the servo is attached to pin; false otherwise.

detach()

Description: Detach the Servo variable from its pin. If all Servo variables are detached, then pins 9 and 10 can be used for PWM output with analogWrite().
Syntax: servo.detach()
Parameters:
servo: a variable of type Servo

Example:

```
#include <Servo.h>
Servo myservo; // create servo object to control a servo
// a maximum of eight servo objects can be created
int pos = 0; // variable to store the servo position
void setup()
{
myservo.attach(9); // attaches the servo on pin 9 to the servo object
}
void loop()
{
for(pos = 0; pos < 80; pos += 1) // goes from 0 degrees to 180 degrees
{ // in steps of 1 degree
myservo.write(pos); // tell servo to go to position in variable 'pos'
```

```
delay(15); // waits 15ms for the servo to reach the position
}
for(pos = 80; pos>=1; pos-=1) // goes from 180 degrees to 0 degrees
{
myservo.write(pos); // tell servo to go to position in variable 'pos'
delay(15); // waits 15ms for the servo to reach the position
}
}
```

6.3.2 PULSE WIDTH MODULATION

Pulse width modulation (PWM) is a fancy term for describing a type of digital signal. Pulse width modulation is used in a variety of applications including sophisticated control circuitry. A common way to use them is to control a servo motor. We can accomplish a range of results in both applications because pulse width modulation allows us to vary how much time the signal is high in an analog fashion. While the signal can only be high (usually 5V) or low (ground) at any time, we can change the proportion of time the signal is high compared to when it is low over a consistent time interval.

Duty Cycle

When the signal is high, we call this “on time”. To describe the amount of “on time” , we use the concept of duty cycle. Duty cycle is measured in percentage. The percentage duty cycle specifically describes the percentage of time a digital signal is on over an interval or period of time. This period is the inverse of the frequency of the waveform.

If a digital signal spends half of the time on and the other half off, we would say the digital signal has a duty cycle of 50% and resembles an ideal square wave. If the percentage is higher than 50%, the digital signal spends more time in the high state than the low state and vice versa if the duty cycle is less than 50%. Here is a graph that illustrates these three scenarios:

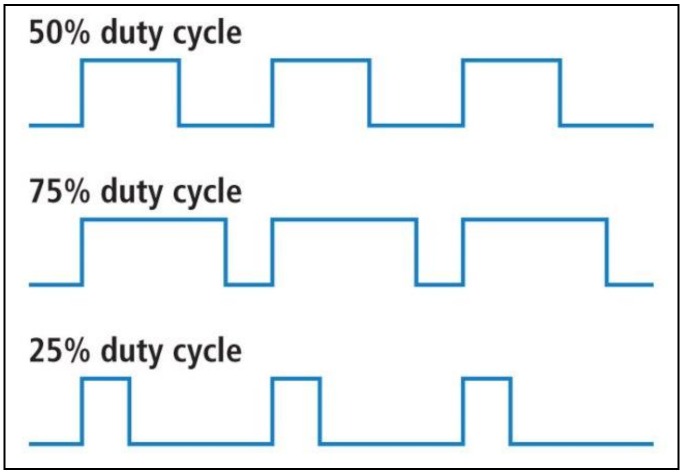


Fig 6. 2 *50%, 75%, and 25% Duty Cycle Examples*

100% duty cycle would be the same as setting the voltage to 5 Volts (high). 0% duty cycle would be the same as grounding the signal.

Frequency/period are specific to controlling a specific servo. A typical servo motor expects to be updated every 20 ms with a pulse between 1 ms and 2 ms, or in other words, between a 5 and 10% duty cycle on a 50 Hz waveform. With a 1.5 ms pulse, the servo motor will be at the natural 90 degree position. With a 1 ms pulse, the servo will be at the 0 degree position, and with a 2 ms pulse, the servo will be at 180 degrees. You can obtain the full range of motion by updating the servo with any value in between.

Chapter 7
Applications & Conclusion

7.1 APPLICATIONS

Robot is general are designed to help people with tasks that would be difficult, unsafe, or boring for real people to do alone. Robots are now widely used in factories to perform high-precision job such as welding and riveting. They are also used in special situation that would be dangerous for human, for example in cleaning toxic waste or defusing bombs.

Robots are used in underwater recover efforts, particularly in water too deep for human exploration. Machine loading, where robots supply parts to or remove parts from other machines. In this type of work, the robot may not even perform any operation on the part, but only a means of handling parts within a set of operation.

Pick and place, where the robot picks up parts and place them elsewhere. This may include palletizing, placing cartridges, simple assembly where two parts are put together (such as placing tablets into the bottle), placing parts in an oven and removing the treated part from the oven, or other similar routines.

These robot arms offer the greatest level of flexibility due to their serial articulation and increased numbers of degrees of freedom. This type of robot allows for an arbitrarily placing of a work piece in space using six parameters; three for the specification of the location (x, y, z) and three for the specification of the orientation (yaw, roll, pitch). Because of this ability it is the largest segment of robots available on the market and therefore offers a very wide range of solutions from tabletops to very large 1300 kg plus solutions.

Articulated robots are frequently applied to process intensive applications where they can utilize their full articulation and dexterity for applications such as spot and arc welding, painting, dispensing, loading and unloading, assembly and material handling. When articulated robots are today being applied to a wide variety of applications, their first usage was in the car industry. This first practical mass use of articulated robots was driven by the ever growing output volume in the car industry and the need for cost reduction. Big names like GM, Renault etc had their own divisions for robotics. Modern car factories can use up to 1000 articulated robots whilst having only 5000 workers, a ratio of 1 to 5! In car factories the main application for these types of robots is spot welding, arc welding and handling of car body and parts. Later more advanced applications like underbody sealing and laser welding were introduced using articulated robots, and more often than not using vision systems. Robots improve the productivity of these expensive production lines by ensuring that manufacturing operations move at a constant pace with minimal machine idle time. A robot is a mere component of any production line, albeit a highly flexible and reliable one. Hard automation might fulfill a dedicated function, but comes at a high price: the grouping of various valves, cylinders, B. STRUIJK: Robots in human societies and industry AARMS 10(1) (2011) 191 sensors, motors and controls come not even close to the reliability of a robot, with uptimes of 99.99%! Robots allow faster and easier set-up when change-over occur at the line. And it is not only the big automakers that use robots. Robots have been in factories since 1962 and are a mature technology.

Industrial applications include
- Manipulation (pick-and-place)
- Assembly
- Spray painting and coating
- Arc welding
- Spot welding with pneumatic or servo-controlled gun
- Laser cutting and welding
- Gluing and sealing
- Mechanical finishing operations (deburring, grinding)

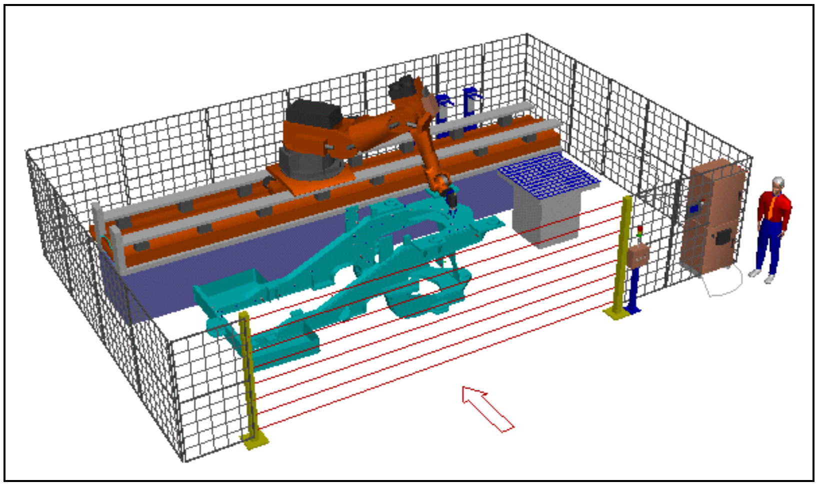


Fig 7. 1 Stud welding

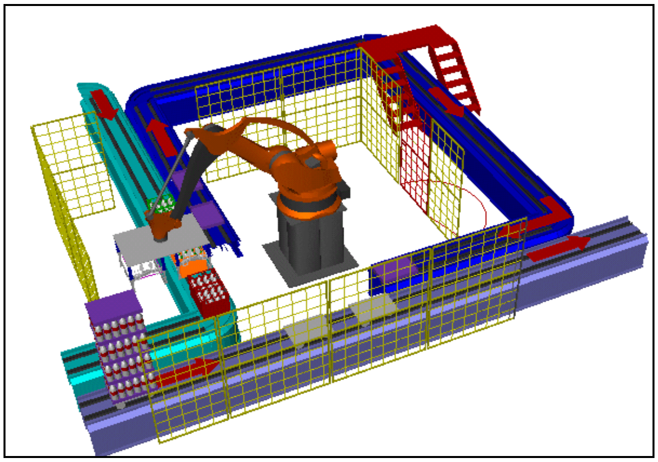


Fig 7. 2 Palletizing

In medical robot are used to conduct operations. Recent technological advances in surgery have resulted in the development of a range of new techniques that have reduced patient trauma, shortened hospitalization, and improved diagnostic accuracy and therapeutic outcome. Despite many appreciated benefits of Minimally Invasive Surgery (MIS) compared to traditional approaches, there are still significant drawbacks including poor instrument control and ergonomics caused by rigid instrumentation and its associated fulcrum effect. The use of surgical robots has helped to realise the full potential of MIS with improved consistency, safety and accuracy. The development of articulated, precision tools to enhance the surgeon's dexterity has evolved in parallel with advances in imaging and human robot interaction. This has improved hand-eye coordination and manual precision, with the capability of navigating through complex anatomical pathways.

Fig 7. 3 Medical applications

7.2 CONCLUSION

Robotics is the technology for the future and with a future. The current research goals and trends indicate that the industrial robots of the future will be more robust, more accurate, more flexible, with more than one arm, more mobile, and will have many more capabilities. The robots will be human friendly and intelligent, capable of responding to voice commands and will be easy to program.

With this project, a 6-DOF articulated robotic arm has been designed and constructed giving priority to cost effectiveness and enabling robotic manipulator research to be more accessible. General movements such as pick and place have been implemented to demonstrate the range of motions of the arm. Gripper is modular to enable various gripper designs to be implemented as the end effector.

7.3 THE FUTURE SCOPE

We intend to extend this project so as to include:

1] Inverse Kinematics approach for design and analysis.
2] Sensors and feedback system to make the arm fully autonomous.
3] Different end-effectors to demonstrate different applications.

We intend to further manipulation research and transform the arm into a research platform for continued work.

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- Websites:
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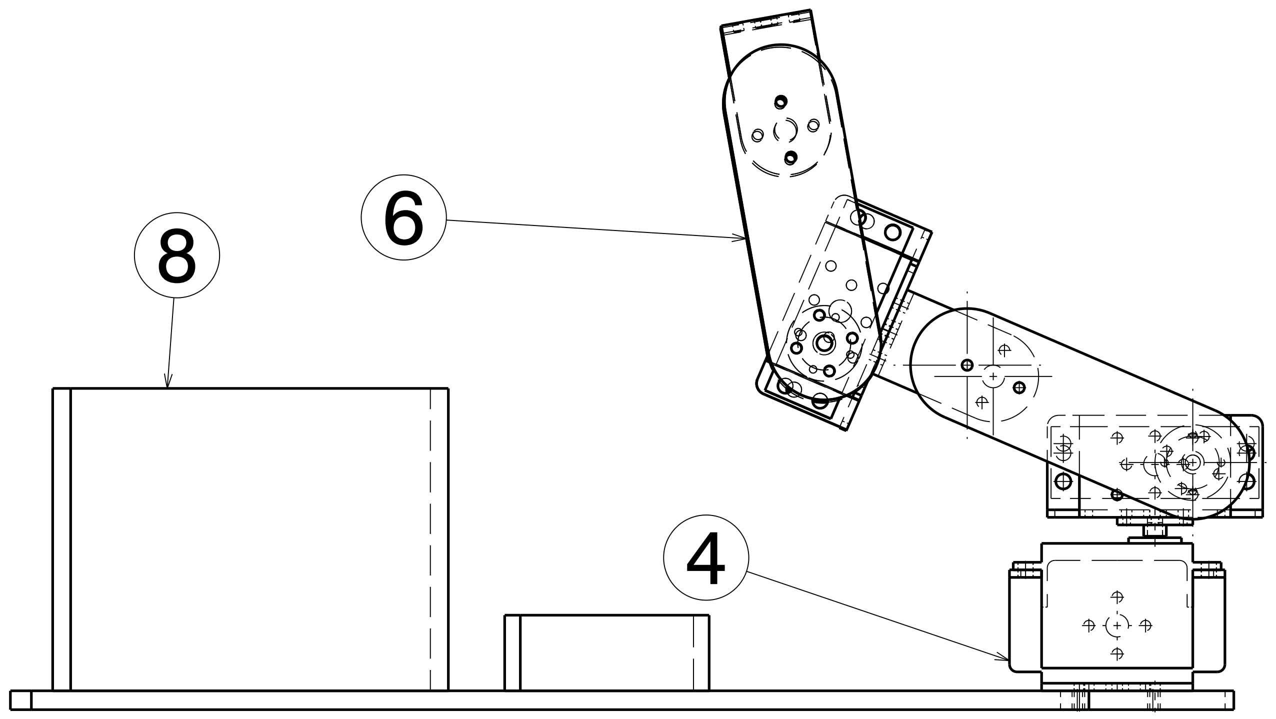
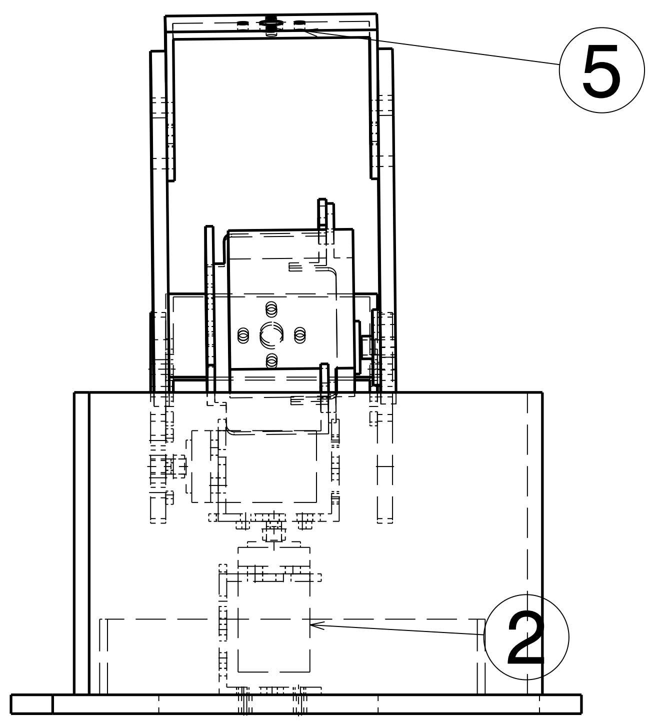
ANNEXURE A- CAD DRAFT FILES

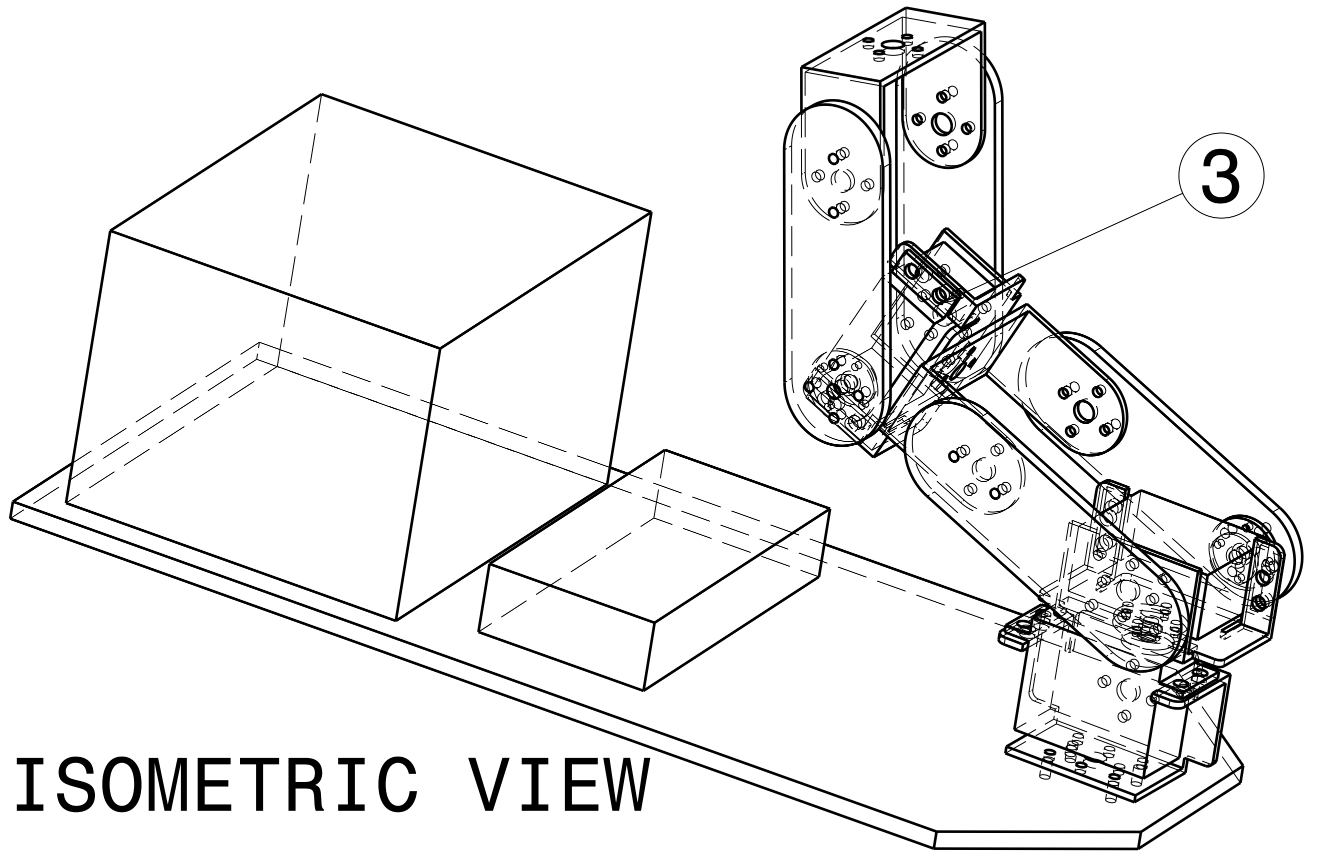
The computer aided model was generated of the prototype of the arm using CATIA v5. The drafting files of the sub-assemblies of arm, wrist and the gripper have been attached under this section as follows:



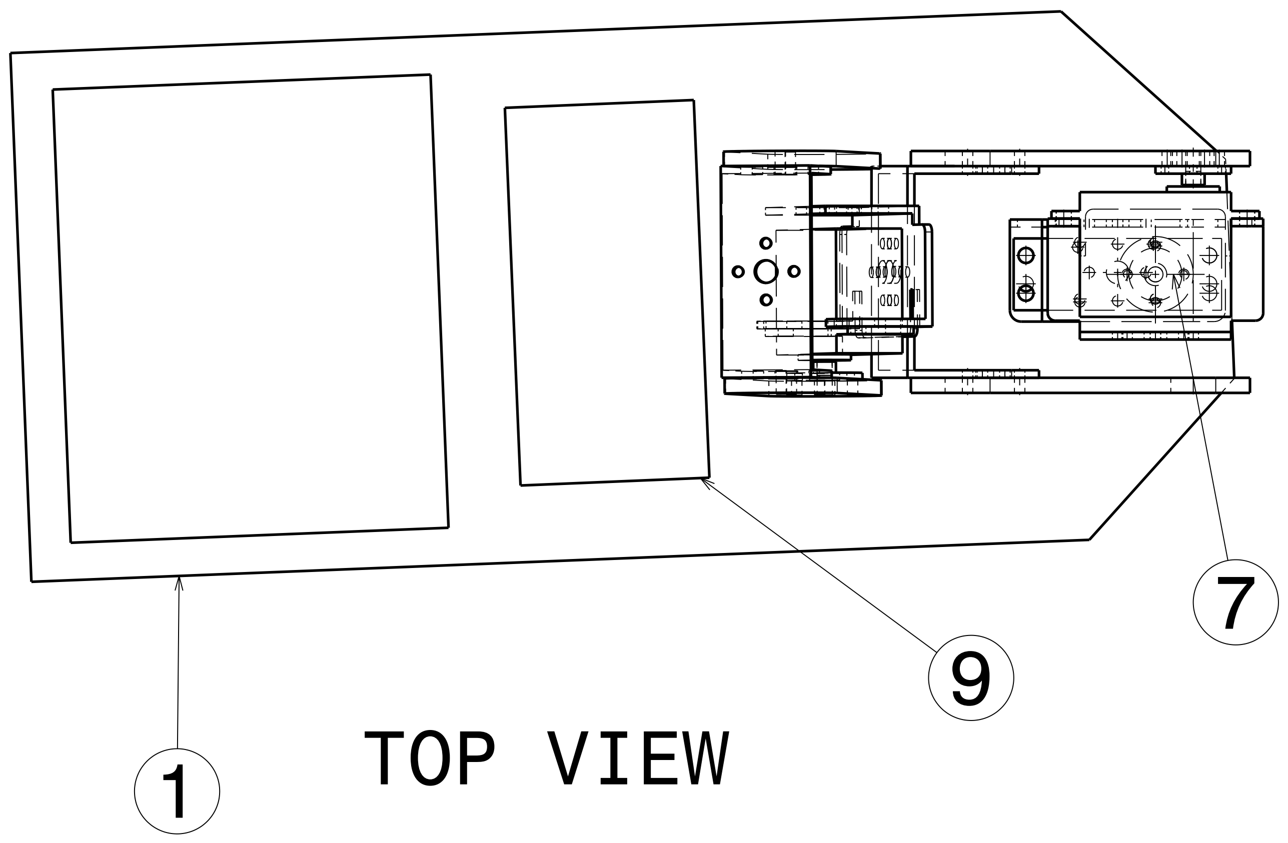
FRONT VIEW



LEFT VIEW



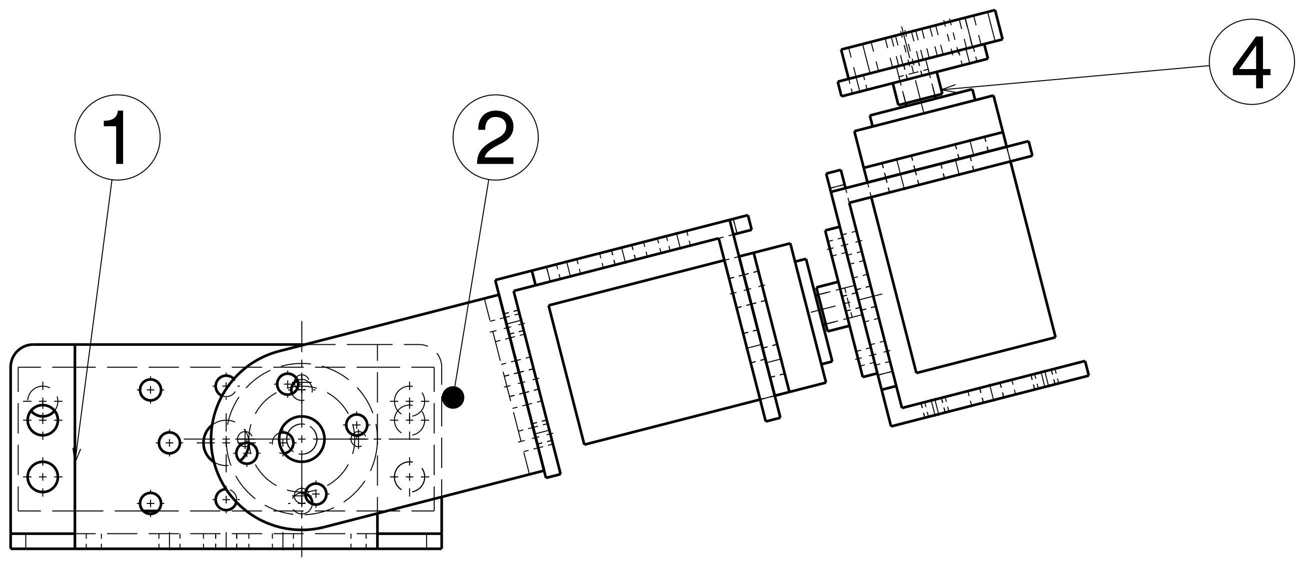
ISOMETRIC VIEW



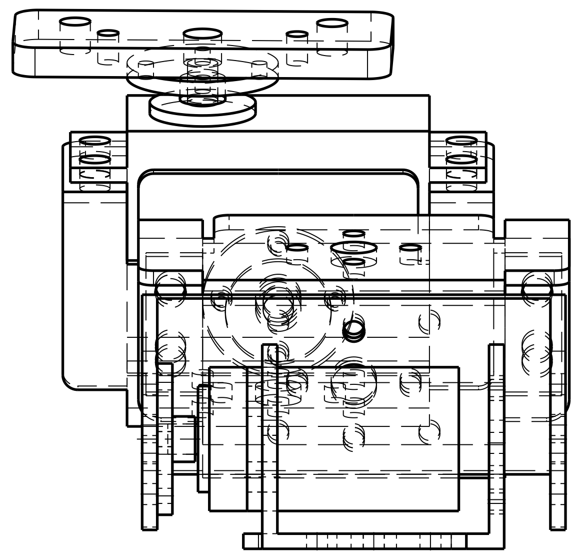
TOP VIEW

SR. NO.	PART	MATERIAL/MAKE	QUANTITY
1	BASE PLATE	ACRYLIC	1
2	SERVO MOTOR	VEGAROBOKIT 15KGCM	2
3	SERVO MOTOR	VEGAROBOKIT 9KGCM	1
4	UNIVERSAL BRACKET	ANODIZED ALUMINIUM	3
5	C- BRACKET	ANODIZED ALUMINIUM	3
6	LINKS	ACRYLIC	4
7	CIRCULAR HORN	PLASTIC	3
8	BATTERY	12 V	1
9	CIRCUIT	IC 7806 & ARDUINO	1

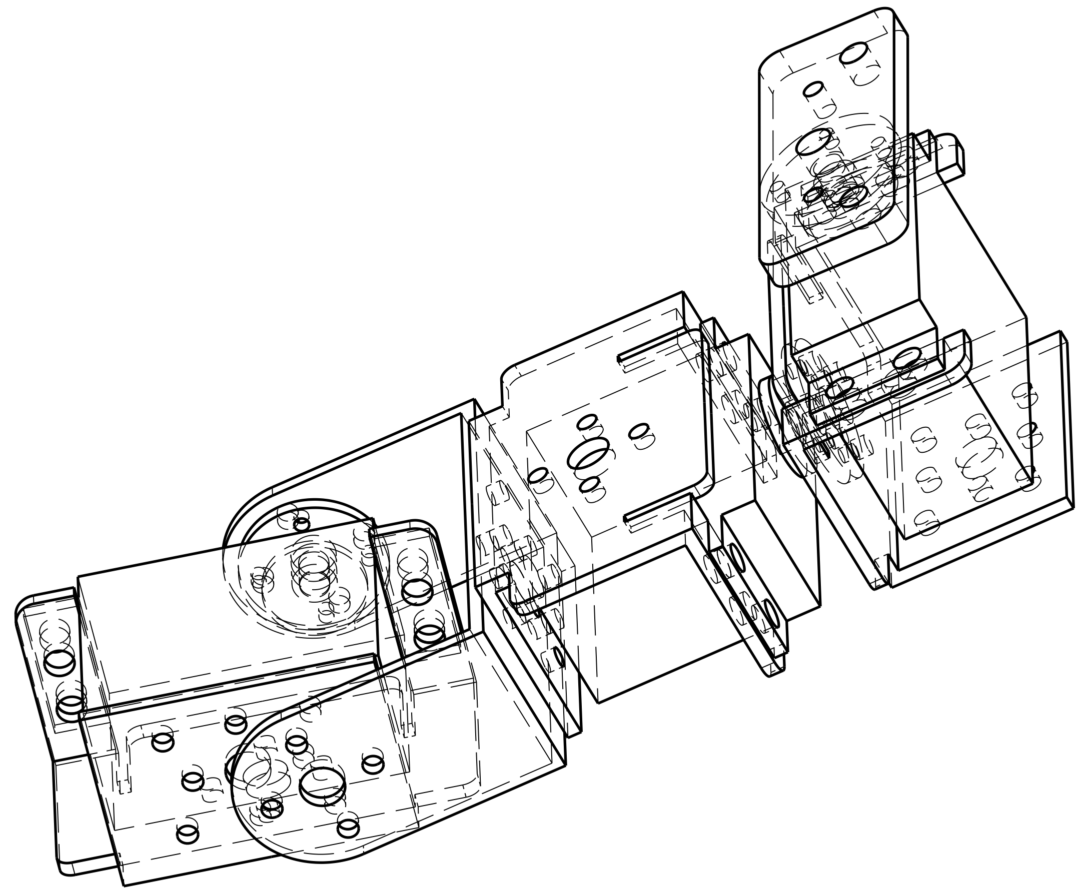
SARDAR PATEL COLLEGE OF ENGINEERING
FYP- ARTICULATED ROBOTIC ARM
TOPIC: ARM ASSEMBLY
DRAWING NO.: 01
DATE: 15/03/2015
SCALE: 1:2



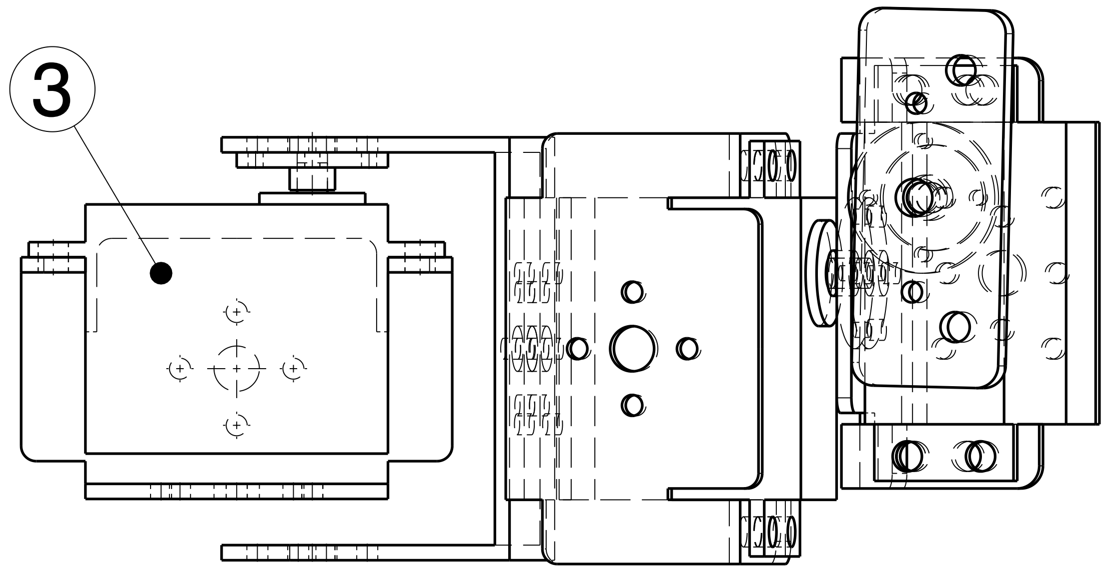
FRONT VIEW



LEFT VIEW



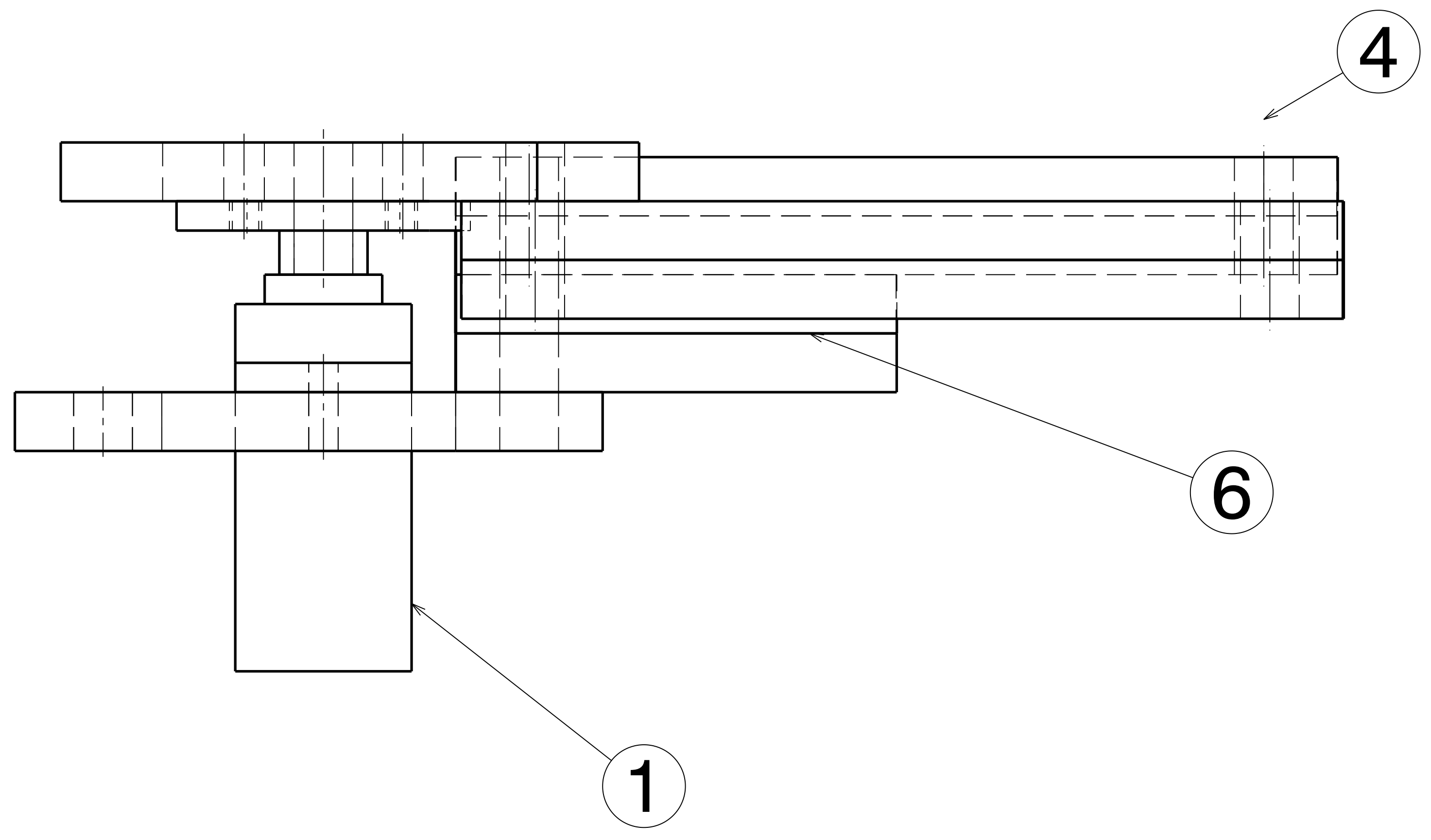
ISOMETRIC VIEW



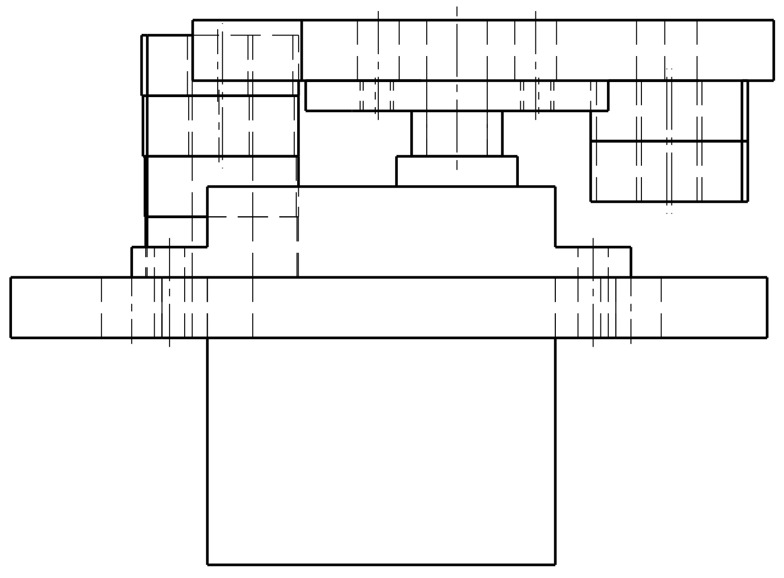
TOP VIEW

SR. NO.	PART	MATERIAL/MAKE	QUANTITY
1	UNIVERSAL BRACKET	ANODIZED ALUMINIUM	3
2	C- BRACKET	ANODIZED ALUMINIUM	1
3	SERVO MOTOR	VEGAROBOKIT 9KGCM	3
4	CIRCULAR HORN	PLASTIC	3

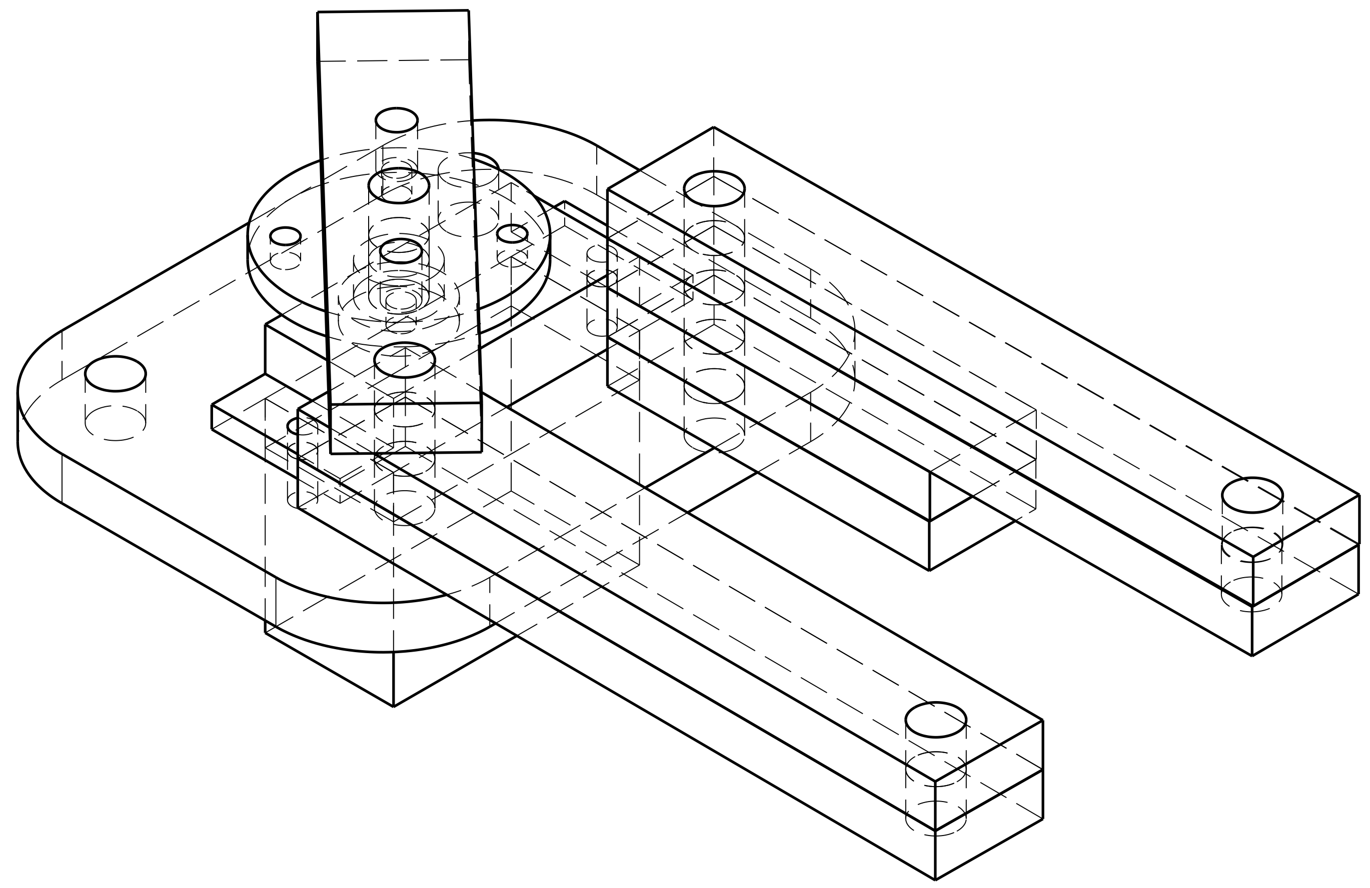
SARDAR PATEL COLLEGE OF ENGINEERING
FYP- ARTICULATED ROBOTIC ARM
TOPIC: WRIST ASSEMBLY
DRAWING NO.: 02
DATE: 15/03/2015
SCALE: 1:1



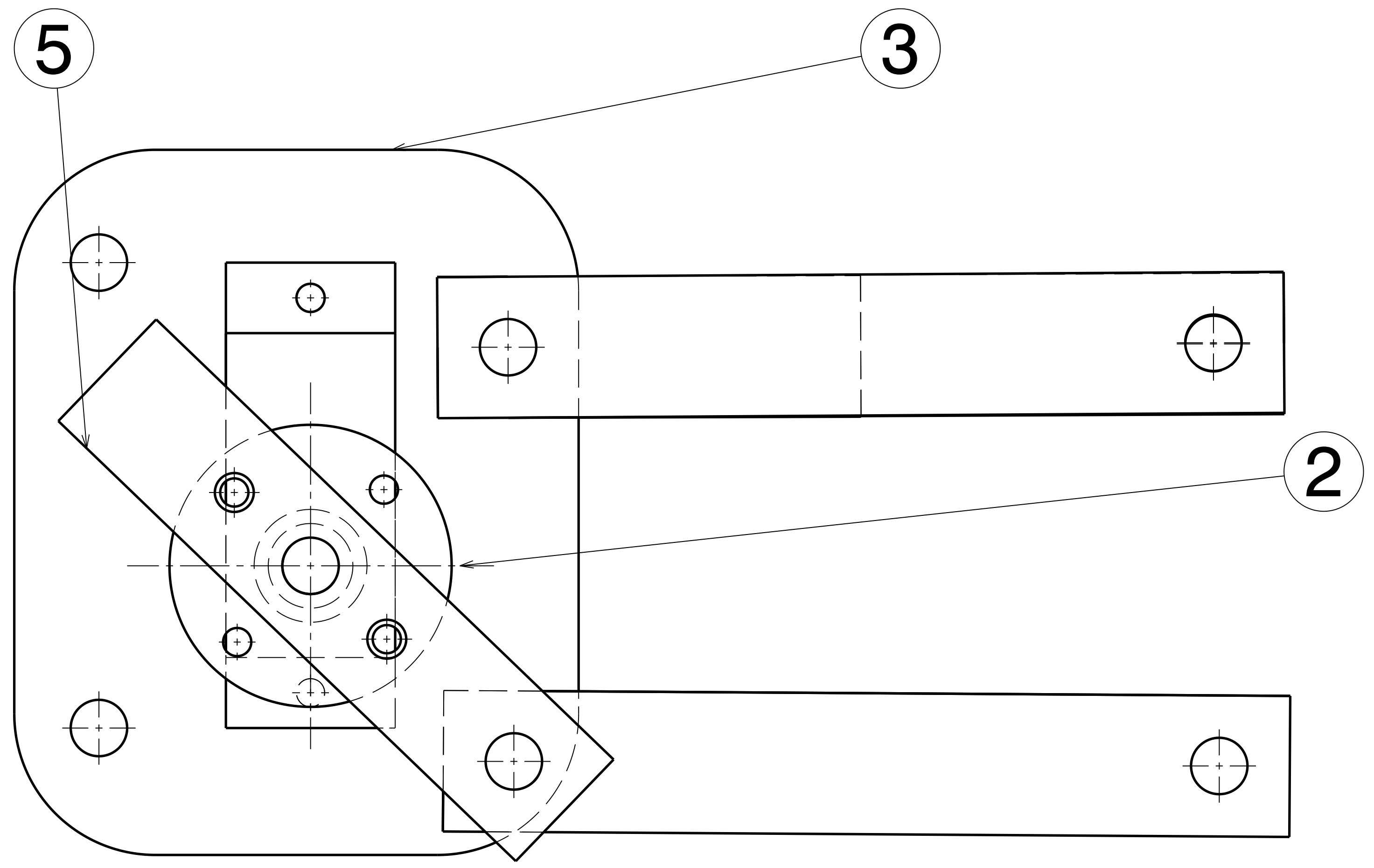
FRONT VIEW



LEFT VIEW



ISOMETRIC VIEW



TOP VIEW

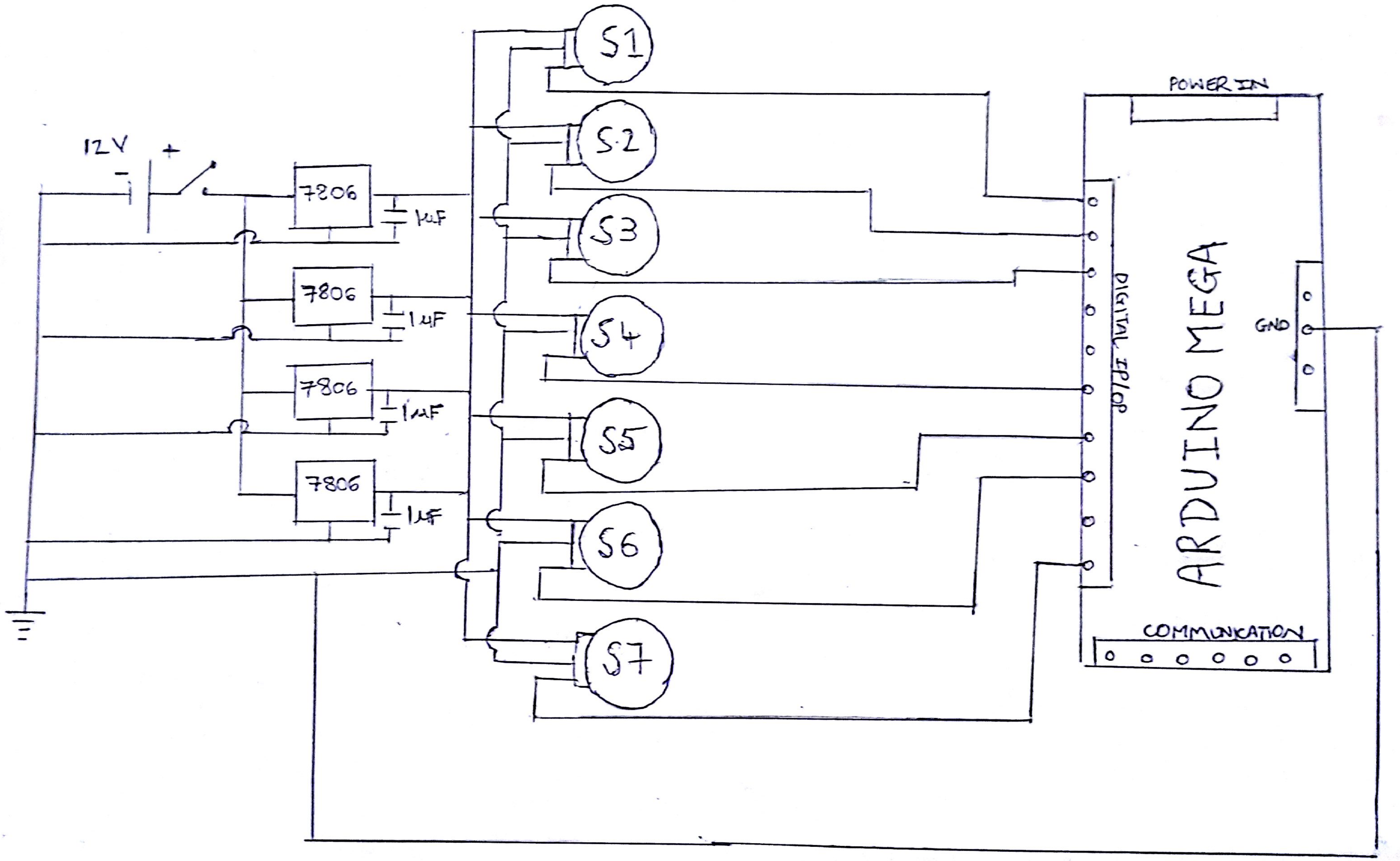
SR. NO.	PART	MATERIAL/MAKE	QUANTITY
1	MICRO SERVO MOTOR	VEGAROBOKIT 0.8KGCM	1
2	CIRCULAR HORN	PLASTIC	1
3	GRIPPER BASE	ACRYLIC	1
4	BIG LINKS	ACRYLIC	4
5	ROTARY LINK	ACRYLIC	1
6	SMALL LINKS	ACRYLIC	2

SARDAR PATEL COLLEGE OF ENGINEERING
FYP- ARTICULATED ROBOTIC ARM
TOPIC: GRIPPER ASSEMBLY
DRAWING NO.: 03
DATE: 15/03/2015
SCALE: 2:1

ANNEXURE B- CIRCUIT DIAGRAM

The diagram of the circuit used for the control of servo motors for the arm is attached under this section as follows:

ANNEXURE B- CIRCUIT DIAGRAM



ANNEXURE C- ARDUINO PROGRAM

The following C++ program was used to demonstrate the working of articulated robotic arm for pick and place application.

```
#include <Servo.h> //In built Servo library
void setup()
{
//define servo variables for each motor and other variables to store different positions of
servo motors
Servo axis1,axis2,axis3,axis4,axis5,axis6,ee7;
int home1,home2,home3,home4,home5,home6,home7;
int pick1,pick2,pick3,pick4,pick5,pick6,pick7;
int place1,place2,place3,place4a,place4b,place5,place6,place7;
int return1,return2,return3a,return3b,return4a,return4b,return5,return6,return7;
//attach the digital input pins on Arduino Mega to each of the Servo motor
axis1.attach(2);
axis2.attach(3);
axis3.attach(4);
axis4.attach(5);
axis5.attach(6);
axis6.attach(7);
ee7.attach(8);
// taking the end effector to the home position
home7=50;
  ee7.write(home7);
  delay(500);
home6=90;
  axis6.write(home6);
  delay(500);
home5=180;
  axis5.write(home5);
  delay(500);
home4=0;
  axis4.write(home4);
  delay(500);
home3=180;
  axis3.write(home3);
```

```
  delay(500);
home2=150;
  axis2.write(home2);
  delay(500);
home1=90;
  axis1.write(home1);
  delay(500);
 // the angles corresponding to home position for each motor are: 90-150-180-0-180-90-
50
// taking the end effector from home to pick up position
for (pick4=0;pick4<=50;pick4+=1)
{
  axis4.write(pick4);
  delay (20);
}
for (pick2=150;pick2>=75;pick2-=1)
{
  axis2.write(pick2);
  delay (20);
}
for (pick3=180;pick3>=150;pick3-=1)
{
  axis3.write(pick3);
  delay (20);
}
for (pick6=90;pick6<=140;pick6+=1)
{
  axis6.write(pick6);
  delay (20);
}
for (pick1=90;pick1<=135;pick1+=1)
{
  axis1.write(pick1);
  delay (20);
}
ee7.write(5);
delay (500);
//the angles corresponding to pick up position for each motor are: 135-75-150-50-180-
140-5
// taking the end effector from pick up to place position
```

```
for (place4a=50;place4a<=100;place4a+=1)
{
axis4.write(place4a);
delay(20);
}
for(place1=135;place1>=0;place1-=1)
{
  axis1.write(place1);
  delay(20);
}
for(place3=150;place3<=170;place3+=1)
{
 axis3.write(place3);
delay(20);
}
for(place5=180;place5>=0;place5-=1)
{
  axis5.write(place5);
  delay(20);
}
for(place6=140;place6>=90;place6-=1)
{
  axis6.write(place6);
  delay(20);
}
for(place4b=100;place4b>=80;place4b-=1)
{
  axis4.write(place4b);
  delay(20);
}
for(place7=5;place7<=50;place7+=1)
{
  ee7.write(place7);
  delay(30);
}
//the angles corresponding to the place position for each motor are: 0-75-170-80-0-90-50

// taking the end effector from place to home position
for(return4a=80;return4a<=100;return4a+=1)
{
```

```
  axis4.write(return4a);
  delay(20);
 }
 for(return3a=170;return3a>=140;return3a-=1)
 {
  axis3.write(return3a);
  delay(20);
 }
 for(return5=0;return5<=180;return5+=1)
 {
  axis5.write(return5);
  delay(20);
 }
 for(return4b=100;return4b>=0;return4b-=1)
 {
  axis4.write(return4b);
  delay(20);
 }
 for(return1=0;return1<=90;return1+=1)
 {
  axis1.write(return1);
  delay(20);
 }
 for (return2=75;return2<=150;return2+=1)
 {
  axis2.write(return2);
  delay(20);
 }
 for(return3b=140;return3b<=180;return3b+=1)
 {
  axis3.write(return3b);
  delay(20);
 }
 //the angles corresponding to home position for each motor are: 90-150-180-0-180-90-50
 }
 void loop()
 {
  // put your main code here, to run repeatedly:
 }
```

ANNEXURE D-TEAM DETAILS

SR. NO.	NAME	DESIGNATION	CONTACT
1	Dr. Rajesh Buktar Project Guide	HOD- Mechanical, S.P.C.E.	r_buktar@spce.ac.in
2	Mr. Sahil Makwana Team Member	B.Tech Mechanical, S.P.C.E.	sahilmakwana93@gmail.com
3	Mr. Divya Shah Team Member	B.Tech Mechanical, S.P.C.E.	divyashah.2801@gmail.com
4	Mr. Kahaan Shah Team Member	B.Tech Mechanical, S.P.C.E.	shahkahaan@gmail.com

Table A: Team members