5 DOF Wireless Hand Motion Controlled Robotic Arm

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Abstract

Now a days, there is an enormous requirement for the development of robotic arms having different number of Degrees of Freedom (DOF), which can be employed in human conditions. Robots are work profiles that have somehow become a replica to humans. In this project, a robotic arm is designed with 5 DOF's (3 translational and 2 rotational movements) which imitates human hand. Motion sensors are used to detect hand movements. A wireless communication module is used for transmission of hand gestures to the robotic arm. The parts of the Robotic arm were designed by using CATIA (V5 R21) software. Acrylonitrile Butadiene Styrene (ABS) is the material choosen for 3D printing of Robotic arm in order to obtain the required parts. A suction cup is used as the end-effector, which holds the objects with the help of vacuum motor. Vacuum mechanism works on the principle of Chameleon tongue. In order to acquire movement of Robotic arm as human sensitivity, Arduino programming is used. The usage of robots has been increasing gradually. Many industries and online marketers widely use robotic labour. This arm has its application in picking and placing objects of delicate and sensitive objects.

Keywords
Degree of Freedom (DOF), Robotic Arm, CATIA, 3D Printing, Arduino.

1. Introduction
Robotics is an era of machine science. Human work is deliberately done efficiently by robots. Robotics is a combination of science, technology and engineering, that produce`s machines that replicate human actions.
Robot: The term 'Robot' is taken from a Czech word 'robota', that means forced labourer. A robot is simply a machine resembling a human being that can replicate certain human movements. Different robots are used for different tasks.
Robotic Arm: A robotic arm is a kind of mechanical arm that is in general programmable. It consists of a series of joints, articulations, and manipulators that work together in order to closely resemble the movements and functionality of a human arm, at the least from a mechanical perspective. The arm itself can be the complete mechanism or just a part of a much more complex robot. Robotic arms are now often being used across a broad range of industries and sectors that include manufacturing, automated assembly, industrial automation, laboratories, machine feeding, testing & sample handling etc. A robotic arm consists of links connected through joints that resemble the shoulder, elbow, and wrist of a human hand, forming an open kinematic chain. End effectors are devices that are fitted to the end of robot arms in order to perform various tasks. These may be Grippers or Tools.

Various components of a robotic arm system:
The components used for robotic arm were displayed in Figure 1.

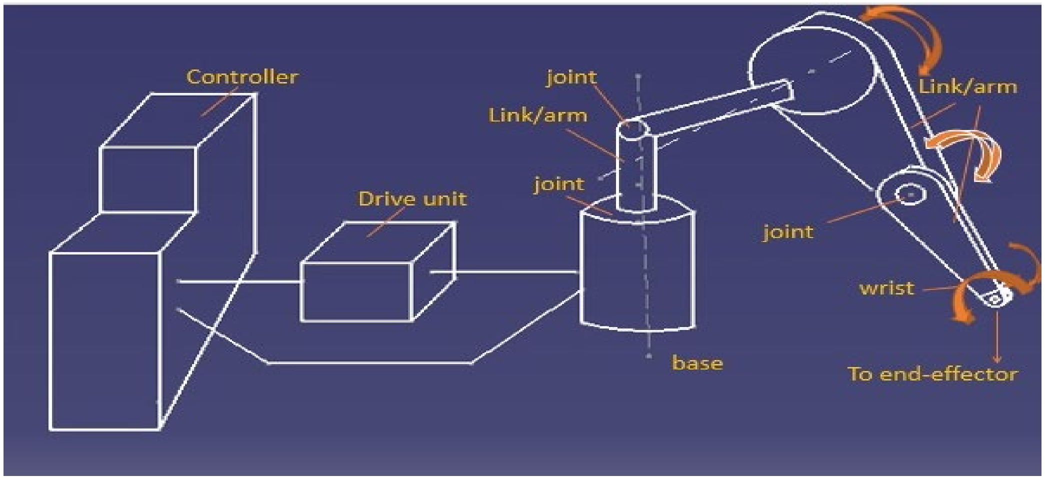


Figure 1. Components of a robotic arm system

Degrees of freedom: The DOF of a robotic arm refers to its movement in the transverse and rotational axis. Figure 2 represents the DOF and representation of pitch, roll & yaw were in Figure 3.

DOF of a robotic arm:

The number of independent parameters/ variables /coordinates needed to describe a system completely is called Degrees of Freedom. DOF of a robotic arm refers to its movement in the transverse and rotational axis. Generally, we have 6 DOF, i.e., 3 Translational and 3 Rotational movements. The three rotational movements can be classified as roll, pitch, and yaw based on the axis about which rotation takes place.

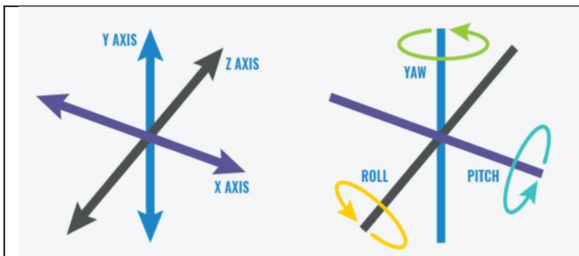


Figure. 2 Degrees of freedom

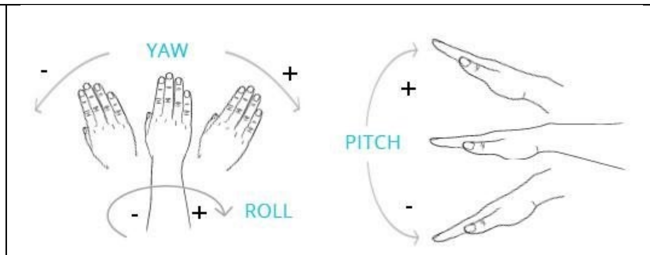


Figure. 3 Representation of pitch, roll & yaw

Roll is used for X-axis rotation, **Pitch** is used for Y-axis rotation, **and Yaw** is used for Z-axis rotation. In a robotic arm, shoulder can be given pitch motion (up and down movement) or yaw (left and right movement); Elbow can be given only pitch movement; Wrist motion can be given pitch or yaw; Rotation (roll) is also possible for shoulder and wrist. Generally, an end effector is added to a robotic arm to increase its degrees of freedom.

Types of joints:

1. Linear joint or prismatic joint (P): This joint possesses one degree of freedom. In this joint, two links will be in parallel, input will be relative motion, and output link will have translational sliding motion.
2. Rotational joint or revolute joint(R): This joint possesses one degree of freedom. It is used to describe rotational movements between links i.e., it is a type of rotary joint. If the axis of rotation is perpendicular to the axis of the output link, such a joint is called as Rotational joint.
3. Twisting joint (T): This joint possesses one degree of freedom. A joint in which the axis of rotation coincides with the axis of the output link is called as a twisting joint.
4. Cylindrical joint (C): This joint possesses two degrees of freedom i.e., one rotary and one translational (sliding) motion along a joint axis.
5. Universal joint/ Hooke joint (U): This joint possesses two degrees of freedom. It is a combination of two revolute joints. This joint is generally used in parallel manipulators.
6. Spherical joint or ball & socket joint (S'): This joint possesses three degrees of freedom and is used to describe three rotational movements between links.

Figure 4 shows the representation of joints which were explained above.

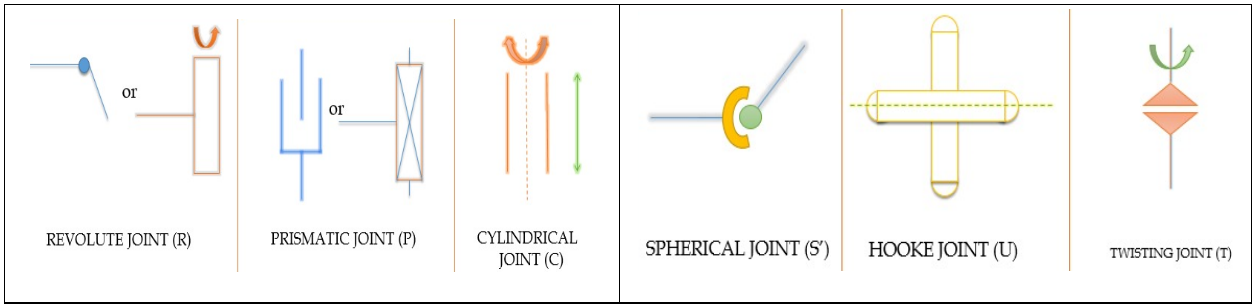


Figure. 4 Representation of Joints

Sample Figure and calculation of DOF:
5 DOF articulated serial (open loop) under-actuated spatial robotic arm: Representing of links, joints and their motions were shown in Figure 5.

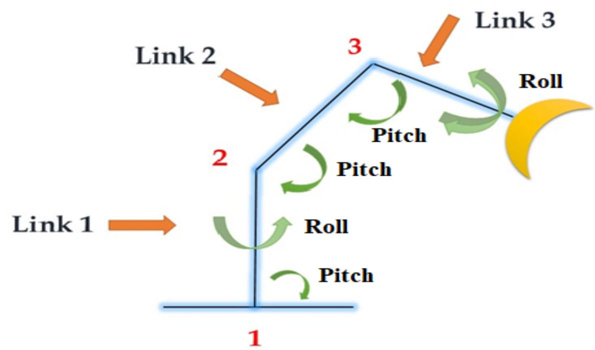


Figure. 5 Sample Figure representing links, joints and their motions

2. Literature Review

Yagna Jadeja and Bhavesh Pandya (2019) dealt with design of a 5 Degrees of Freedom robotic arm using Cortex ARM M3 LPC1768 Microcontroller, including an ultrasonic sensor with servo motors situated at each joint. Pulse Width Modulation (PWM) signals are used in order to control the servo motors. Radio frequency module and an ultrasonic sensor are used to detect the object and determine its distance, respectively. The payload of the robotic arm is proposed to be 100g.
A.O. Oluwajobi & A. A Oridate (2019) dealt with design of a 5 DOF robotic arm with a gripper. The model was designed in AUTOCAD software. The kinematic analysis and stimulation were done in MAT lab software. Pulse Width Modulation (PWM) signals were used to control the servomotors. The material used for the robotic arm was an Acrylic Plastic sheet with a thickness of 3mm. For controlling and generating the coordinates of the robotic arm GUI software was used. The payload of the robotic arm was proposed to be 100g.
Sakshi Sharma et.al (2017) focused on the design of a 3 DOF, 5 fingered Wireless gesture controlled robotic hand with vision that provides a simple reflexive grasp of the objects and places it. The system has been equipped with IP-based camera that streams real-time video wirelessly. To recognize motion, a microcontroller is used. A MEMS Accelerometer sensor embedded in a hand glove is used to detect the hand gesture. Artificial Neutral Networks (ANNs) system is used to recognize and replicate the hand gestures to the robotic hand. Gripper movement is acquired through flex sensors.
Dilshad A. Sulaiman, Akash B. Pandey (2008) dealt with design of a 3 Degrees of Freedom anthropometric robotic arm using delay-based operation of DC motors with a microcontroller-based system for pick and place applications. Pulse Width Modulation (PWM) signals have been used to control the RPM of DC motors. The design of the arm is done using Solid Works. Integrated Development Environment (IDE) is used to compile a C program for the microcontroller. Polypropylene or Acrylic sheet or Aluminium with a thickness of 5mm were proposed as the materials used for the arm body.
Auday A. H. Mohamad et al., (2017) evaluated the methods and techniques that are essential to build a Gesture Robotic Arm by using sensor fusion technique of Gyroscope, Magneto sensors (MEMS sensors), and Accelerometers, for pick

and place applications, especially in the medical field. The arm was developed in the Arduino platform in which all the mentioned, are interfaced with each other by using Bluetooth wireless communication.
T. Asfour and R. Dillmann (2003) assesses the problem of generation of human-like motions from kinematics point of view. It describes the kinematics of 7- DOF arm of the humanoid robot, ARMAR using Inverse Kinematics. The paper explains the approach used to generate human-like motions.

3. Kinematics of Robotic Arm

Kinematics is a branch which classifies the mechanism that describes the motion without any interference of the cause of motion. In general, this is named as 'geometry of the motion'. Kinematics plays a vital role in Robotics. By using kinematics, the position and orientation of the given robot parts can be found. The Robot kinematics can be classified into two types namely, Forward Kinematics and Inverse Kinematics.
Forward Kinematics: A homogenous equation of the robot arm is found to specify the position of the end effector from the known joint parameters. Denavit Hartenberg method which uses four parameters is the most commonly used method to find the position of end effector with the given parameters.
Inverse Kinematics: A homogenous equation of the robot arm is found to specify the position of the join parameters from the known position of end effector. In inverse kinematics, joint angles can be found by using the position end effector. The methods used to solve the inverse kinematics are Analytical Method and Jacobian Method. In analytical method inverse kinematics was solved and was shown in Figure 6. Inverse kinematics formulae, link lengths, distances were shown in Figure. 7, 8.

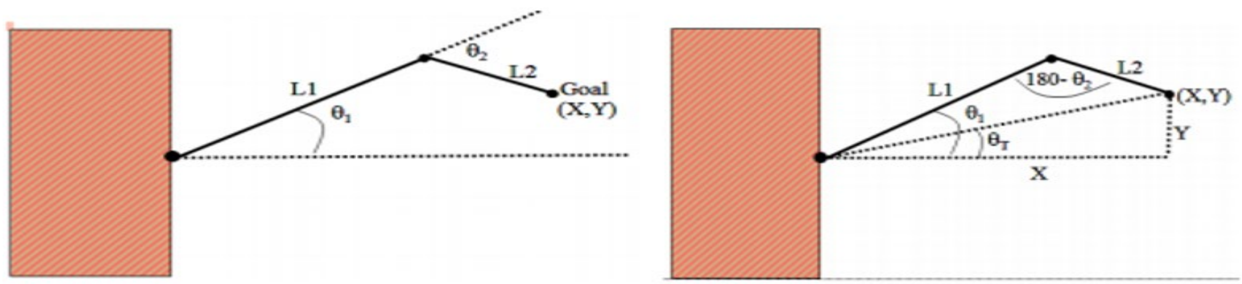


Figure. 6. Inverse kinematics solved in Analytical method

$$\cos(\theta_1-\theta)=\frac{L_1^2+X^2+Y^2-L_2^2}{2L_1(\sqrt{X^2}+\sqrt{Y^2})}, \quad \theta_1=\cos^{-1}\left(\frac{L_1^2+X^2+Y^2-L_2^2}{2L_1(\sqrt{X^2}+\sqrt{Y^2})}\right)+\theta$$

$$\cos(180^\circ-\theta_2)=\frac{L_1^2+L_2^2-(X^2+Y^2)}{2L_1L_2}, \quad \theta_2=180^\circ-\cos^{-1}\left(\frac{L_1^2+L_2^2-(X^2+Y^2)}{2L_1L_2}\right)$$

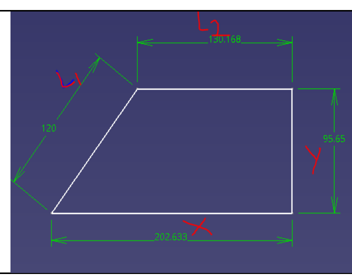


Figure.7 Inverse Kinematics Formulae

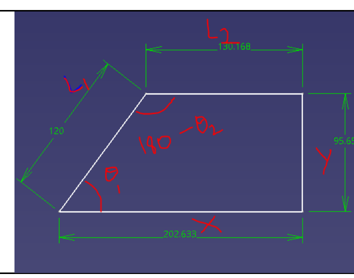


Figure. 8 Link lengths, distances, angles measured w. r. t. origin taken from Sketch

From the Figure. We have, L_1=120.2mm, X= 202.6332, Y=95.652, L_2 = 130.1682, $\theta = 45°$
First angle:

$$\cos(\theta_1-\theta)=\frac{L_1^2+X^2+Y^2-L_2^2}{2L_1\,(\sqrt{X^2+Y^2})}=\theta_1=\cos^{-1}\left(\frac{L_1^2+X^2+Y^2-L_2^2}{2L_1\,(\sqrt{X^2+Y^2})}\right)+\theta$$

$$=\cos^{-1}\left(\frac{120.2^2+202.6332^2+95.6522^2-130.1682^2}{2*120.2\,(\sqrt{202.6332^2+95.652^2})}\right)+45$$

θ_1=$\cos^{-1}(0.665)+45$= 93.31°

Second angle:

$$\cos(180-\theta_2)=\frac{L_1^2+L_2^2-(X^2+Y^2)}{2L_1\,L_2}$$

$$\theta_2 = 180 - \cos^{-1}\left(\frac{L_1^2 + L_2^2 - (X^2 + Y^2)}{2L_1\, L_2}\right)$$

$$= 180 - \cos^{-1}\left(\frac{120.2^2 + 130.1682^2 - (202.6332^2 + 95.652^2)}{2 * 120.2 * 13.1682}\right.$$

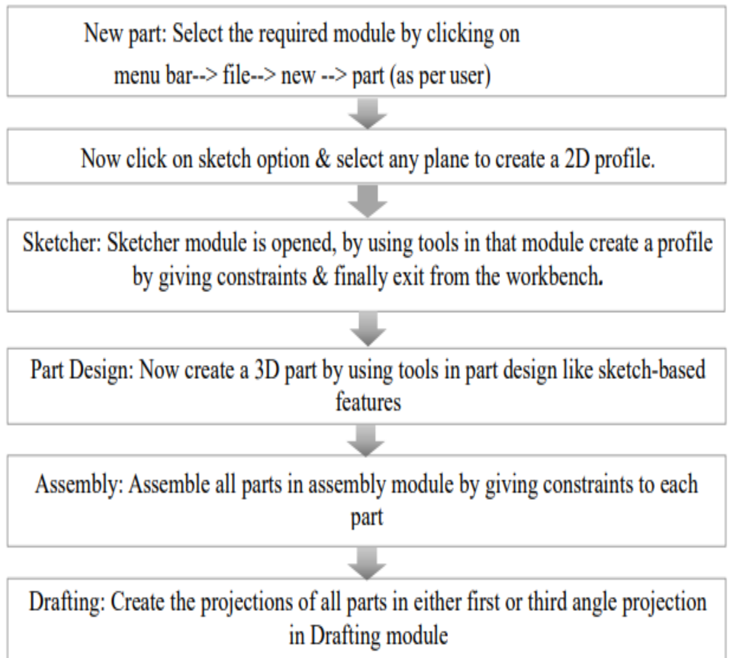
θ_2 =180-$\cos^{-1}(-0.603)$ =52.91°

Therefore, $\theta_1 = 93.31°$, θ_2 =52.91.

4. Design Of Robotic Arm

CATIA: CATIA stands for "Computer Aided Three-Dimensional Interactive Application". It was initially released by DASSULT SYSTEMS in the year 1977. The CATIA software is a mechanical design application software that permits the users to sketch their ideas with features and dimensions, and produce models with detailed drawings. It is now a software suite, which incorporates the following capabilities like CAD, CAE & CAM. The flow chart for creating a component in CATIA were shown in Flow chart 1.

Flow chart 1. Creating a component in CATIA:



4.1. 3D Figures of Robotic Arm designed in CATIA:

As CATIA software is used for designing the components and it was shown in Figure 9, 10, 11, 12, 13, 14 and 15. The assembled Figure were displayed in Figure 16.

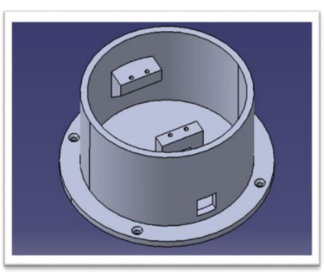
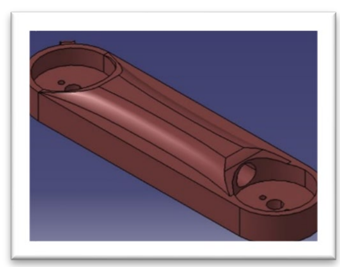
		

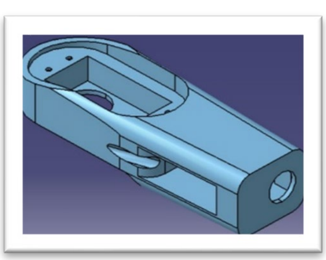
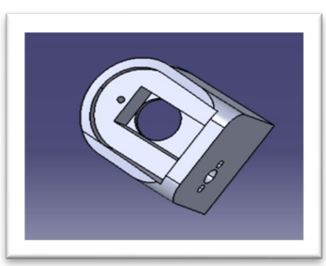
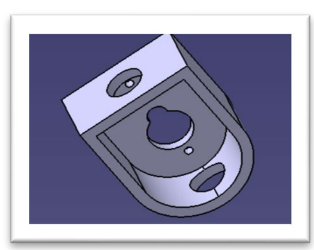
Figure. 9. 3D design of Base	Figure. 10. 3D design of Waist	Figure.11 3D design of Link 1
		

Figure. 12. 3D design of Link 2	Figure. 13. 3D design of Wrist	Figure. 14. 3D design of Gripper holder

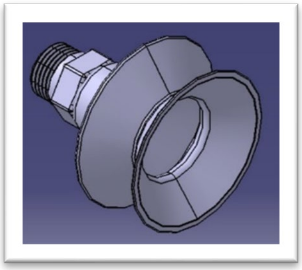


Figure. 15. 3D design of Gripper

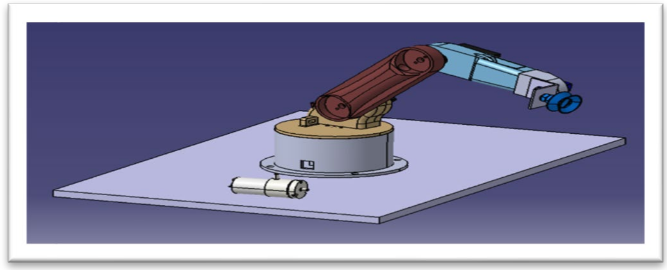


Figure. 16. Side views of Assembly design

5. Fabrication and Material Used

5.1 3D Printing: It is also known as Additive Manufacturing, is the fabrication of 3-Dimensional object from a Digital 3D model. It is a technology where the material is printed in the form of successive layers to create a three-dimensional object. Among the different 3D printings machines are available, selection is made based on the requirement and type of material to be used.

3D Printer: We have used "**FLASHFORGE DREAMER**" 3D printing machine to fabricate the designed parts. It was shown in Figure 17. It mainly consists of bed, material spool right and left extruders and the control unit. This 3D printer mainly works on "Fused Deposition Modelling (FDM)". This 3D printer is easy to handle and the software used is also simple. The 3D filament used in this is ABS Plastic.

Figure. 17. Flashforge Dreamer 3D printing machine

Fused Deposition Modelling (FDM): In this method a plastic filament was used as a input material to an extrusion nozzle. In this the material will be heated to melt the material and it will be deposited on the bed in both Horizontal and vertical directions. The material will be immediately cooled after deposition from the nozzle.

5.2 Material used: The material used to fabricate the robotic arm is Acrylonitrile Butadiene Styrene (ABS) in the colour 'Natural white'. It is an amorphous and opaque thermoplastic polymer. Thermoplastics become liquid at certain temperatures. ABS melts into liquid at 200°C. It will be heated upto its melting point followed by cooling, and then re-heated again with no significant degradation. As an alternative of burning, ABS tends to liquefy. ABS has good strength, strong resistance to corrosive chemicals and physical impacts. It is light in weight and flexible. It is easily machinable and simple to be used in 3D printing machine due to the fact that it has a low melting point.

Spool specifications:
- Weight – 1 kg
- Length – 330m
- Diameter – 1.75mm

Input parameters for 3D printing using ABS plastic:

- Temperature for right extruder (Print temperature) - 245°C (Range for ABS is 200°C to 260°C)
- Platform temperature - 100°C (80-110°C) for ABS (as per manual)
- Density – 35%

5.3 3D Printed Assembled part:

The parts of robotic arm which are printed in Flashforge Dreamer 3D printing machine were assembled and shown below in Figure 18.

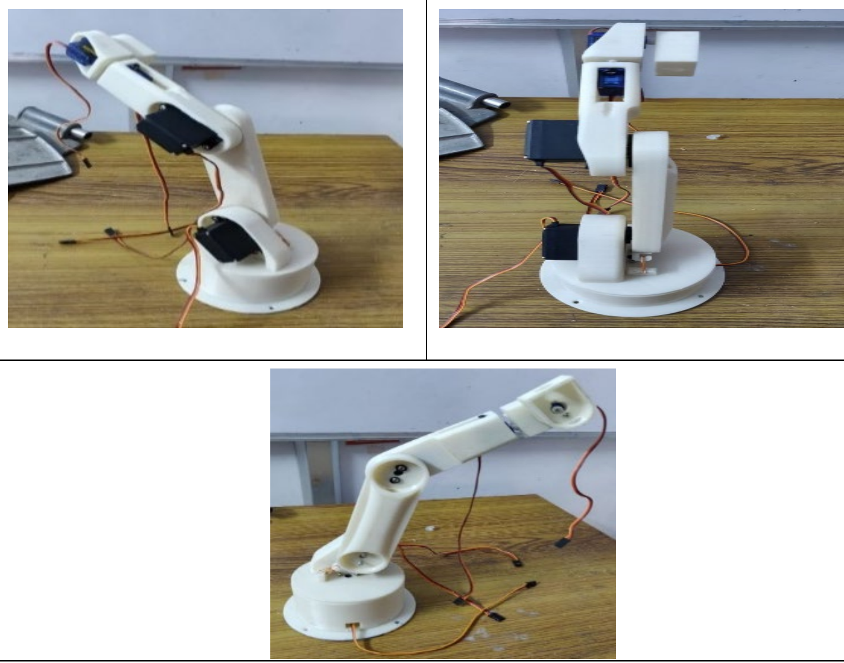


Figure. 18. Different views of the 3D printed assembled parts

6. Methodology

6.1 Components of the robotic arm:

- **Accelerometer:** It is a device which translates movements/motions into an electrical signal, is shown in Figure 19. It can measure static (postures) and dynamic (gestures) accelerations in tri-axial directions. Accelerometers are ideal for communicating with microcontrollers. It helps in detecting vibrations, speed variations and tilts. In this, human hand motion and direction are detected and converted into electrical signals. Tri-axial sensing: In tri-axial accelerometer the movements in X, Y and Z directions are sensed. To maintain a constant sensitivity throughout 360 of tilt, the Z axis can be combined with either X or Y axes.

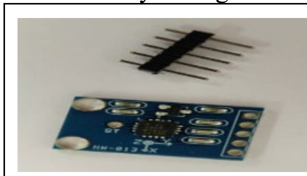


Figure. 19. Accelerometer Sensor

Figure. 20. Arduino UNO

Figure. 21. Zigbee Module

- **Microcontroller (Arduino based**): A microcontroller is generally referred as the brain of the robot, is shown in Figure 20. It collects information from input devices (accelerometer), executes a program and controls the output devices such as servo motors in accordance with the program.
- **Zigbee Module**: It is a wireless communication module that is evolved as an open global stranded for transmission of unique data with the help of microcontroller, is shown in Figure 21.
- **Servo motor**: Servo motors work on the principle of servo mechanism and are used in numerous applications where position control is important. In a hand motion controlled robotic arm, servo motors are used to actuate the

joints. These give angular movement to joints according to the instructions given by the microcontroller. In this robotic arm, servo motors are placed at shoulder joint, elbow joint and wrist. The potentiometer which is embedded within the servomotor receives the electrical signal (analog or digital) from the Arduino based microcontroller place over the robotic arm, senses it and gives motion to the servomotor. Servo motor MG996R and servomotor SG90 were used in the project and are shown in Figure 22, 23.

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Figure. 22. Servo motor MG996R	Figure. 23. Servomotor SG90	Figure. 24. 12V DC Motor	Figure. 25. Flexible Suction Cup

- **Vacuum pump**: It is a device which sucks the air form stipulated volume in order to leave vacuum. Used 12V DC motor for the project and shown in Figure 24.
- **Suction Cup**: It is the end effector of the robotic arm which is in touch the object. It holds the object by means of suction mechanism. A suction cup is made of rubber, silicon, or soft plastic, shown in Figure 25.

6.2 Suction mechanism:

This mechanism consists of a suction cup, a pipe and a propellor attached to a high-speed DC motor. Schematic Representation of Suction mechanism was shown in Figure 26. The entire process works on the vacuum principle where the suction cup acts as the gripper/holder. When the DC motor starts rotating, the propellor attached to it also starts rotating, creating movement in the vacuum chamber. As the movement is generated, the vacuum chamber tries to suck in the air through the pipe. The air enters the pipe through a suction cup. A butterfly valve is placed in the middle of the pipe so that the air does not enter the vacuum chamber in non-working conditions.

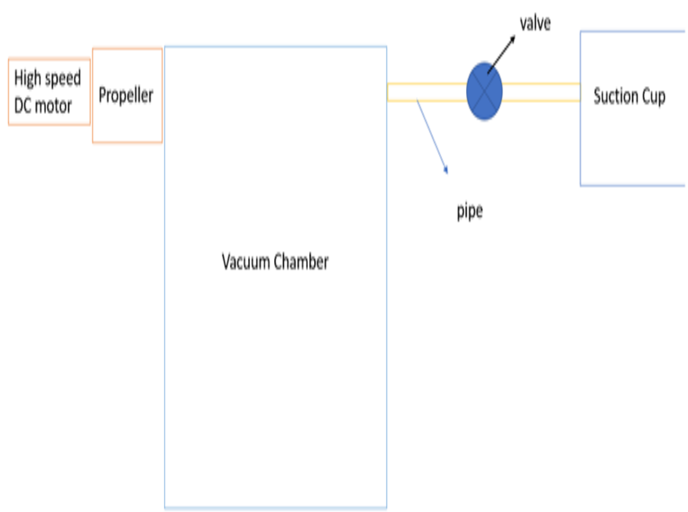


Figure. 26. Schematic representation of Suction Mechanism

7. Working Principle

Accelerometers are attached to the human hand (left or right) which senses the motion, pressure and forces of the hand and converts these physical quantities to electrical signals (analog/digital). These electrical signals are then transmitted to the microcontroller-1 senses the input received from the accelerometer and transmits this electrical input to another microcontroller-2 placed over the robotic arm through a Wi-Fi module. After receiving the electrical input from microcontroller-1, the microcontroller-2 senses it and transmits it to the respective servo motors. The potentiometer embedded within the servo motor receives the signal and gives movement to the servo motor (holding, movement). Figure 27 represents the working of robotic arm.

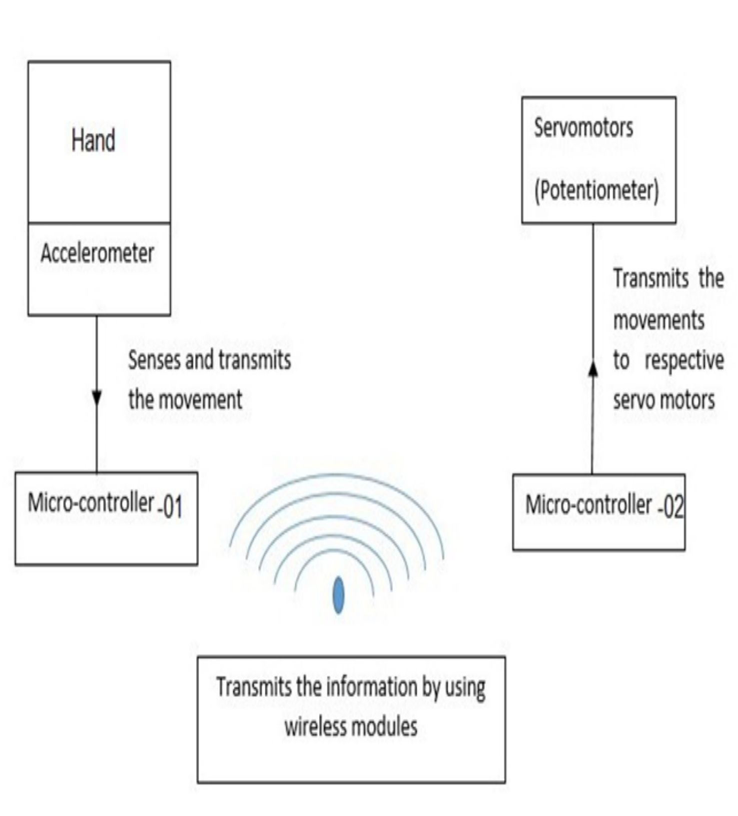


Figure. 27. Schematic representation of working of the robotic arm

8. Workspace

The workspace drawn based on the dimensions of the links of robotic arm and is depicted in the Figure 28.

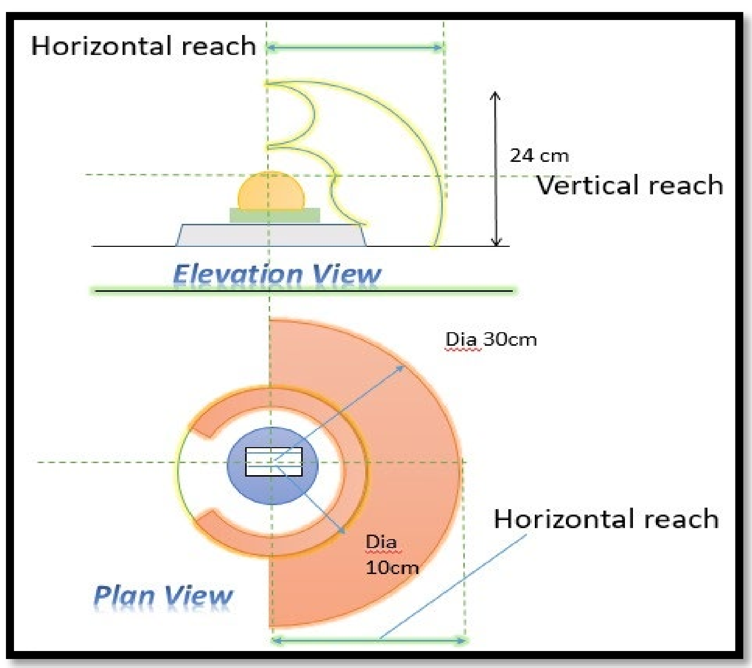
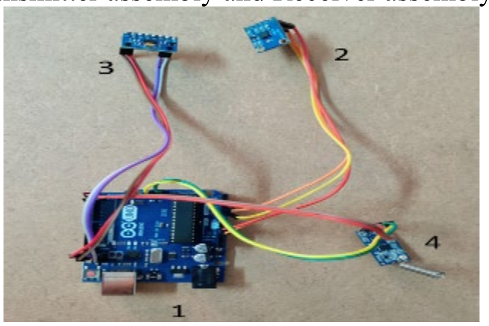


Figure. 28. Workspace of the robotic arm

9. Connections, Hand Gestures & Coding

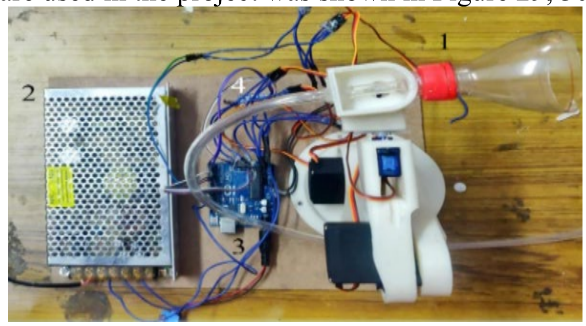
9.1 Transmitter assembly, Receiver assembly and connections:

Transmitter assembly and Receiver assembly which are used in the project was shown in Figure 29, 30.



1. Arduino UNO
2. Accelerometer ADC
3. **3.** Accelerometer I2C
4. **4.** Zigbee module HC12

Figure. 29. Transmitter assembly and connections



1. Robotic arm assembly with servomotors and vacuum gripper
2. AC to DC converter
3. Arduino UNO
4. Zigbee module HC12

Figure. 30. Receiver assembly and connections

9.2 Hand Gestures / motions:

The motions of the robotic arm are defined by giving hand gestures / motions. The Transmitter assembly is attached to gloves and this glove is worn by a person. Various movements of hands are defined for different motions of the robotic arm. The Figure. 31 shows the neutral position of hand gesture with Arduino UNO, battery, MEMS I2C, MEMS ADC and ZigBee module. Representation of positions of servo motors was shown in Figure 32.

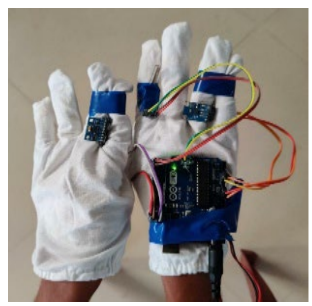


Figure. 31. Neutral position of hand gesture

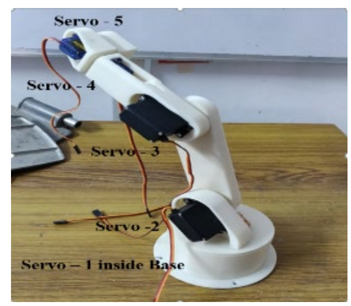


Figure. 32. Representation of position of servo motors

A MEMS (Micro-Electromechanical Systems) I2C sensor (Capable of detecting 10 different motions) is placed on the left hand which detects 6 different movements of the left hand and transfers this signal to the Servo motors 3, 4 & 5. A MEMS ADC sensor (capable of detecting 4 different motions) is placed on the right hand which detects 4 different movements of the right hand and transfers this signal to the Servo motors 1 & 2. The movements of the servo motors centered on the hand gestures are given in below Table 1.

Table 1. Commands

Left Hand Commands	**Right Hand Commands**
90° right – Servo 3 down	Right – Servo1 right (roll)
90° degree left – Servo 3 top	Left – Servo 1 left
45° right - Servo 4 CCW	Front – Servo 2 Top
45° left - Servo 4 CW	Back - Servo 2 down
Front – Servo 5 top	
Back – Servo 5 down	

9.3 Hand gestures / motions: Gestures are used for left and right hands and those are shown in Figure 33 for left hand gestures, Figure 34 for Right hand gestures.

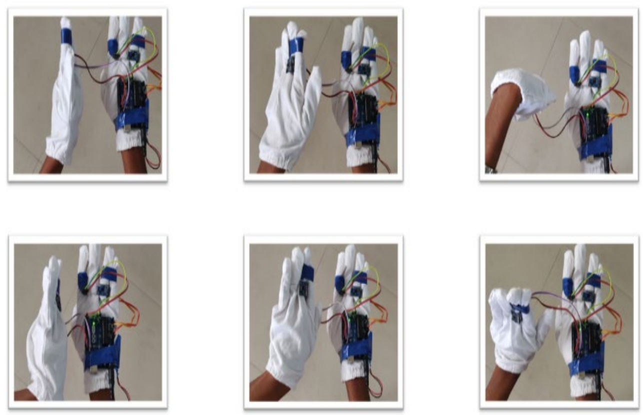


Figure. 33. Left Hand Gestures

Figure. 34. Right Hand Gestures

9.4 Coding

Arduino Integrated Development Environment (IDE) is used for coding. In this IDE, embedded C programming is used to write the codes. The code is given to the brain of the robotic arm i.e., the microcontroller. The codes are given accordingly to the accelerometers for the recognition of the movements. Later, this analog information is now receiver by the Zigbee module. This acts as a transmitter and coded accordingly. Now, the other Zigbee module receives the command from the microcontroller connected to it and this sends the command to the respective Servomotors. This entire setup acts as the receiver unit.

10. Applications & Future Scope

Applications:

- Pick and place of objects.
- Handling sensitive and delicate parts like eggs, papers, etc.
- Industrial usage and for medical purposes like handling tools during surgeries.

Future scope:

- The end-effector used here is Vacuum gripper and for future scope, other end-effectors such as tools can be used based on the application. Zigbee module is near range communication. It can be replaced with Wi-Fi module for far range communication. Image processing can be incorporated for advanced applications. The material used here is ABS plastics. But it can be replaced by metals like Aluminium, etc to increase the pay load.

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