

# Design, Analysis and Implementation of Robot Arm

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**Abstract:** *Today, technology is developing in the same direction in line with rapidly increasing human needs. The work done to meet these needs makes life easier every day. Robot arms work with an outside user or by performing predetermined commands. Nowadays, the most developed field of robot arms in every field is the industry and medicine sector. The main focus of this project is to design and develop the mechanism for robotic arm for pick and place. The robotic arm is designed with 5 degrees of freedom and programmed to accomplish accurately simple light material pick and place task to assist in the production line in any industry. 3D printing method is used to fabricate the project's components of the robotic arm. Therefore, it provided more precise dimensions and huge time and cost-saving in this method. The robotic arm is equipped with 6 servo motors to link the parts and bring arm movement. Arduino, an open-source computer hardware and software is applied for control the robotic arm by driving servo motors to be capable to modify the position. Wireless control is done by using a smart phone with android operating system through a Bluetooth module. The robotic arm is under testing and validating its performance and the results indicates that it can perform the pick and place task properly. To establish a good simulation environment we use Fusion 360 Software.*

**Keywords:** Robotic arm, axis, degree of freedom, working envelope and work volume, space, kinematics, payload, Pick & Place Robot, Robotic arm, Robo-Arduino.

## I. INTRODUCTION

To understand how and why the robots work, We should have to understand the scientific principles of the robotics. Robotics is an interdisciplinary subject which drawing ideas and tools from mathematics and physics. We take brief at some of the ingredients of robotics, such as kinematics, dynamics, sensing and intelligence(1). Kinematics deals with the motion of rigid bodies (links of robots) in space with 5 degrees of freedom. In kinematics, we study the functional relationship between the motion at the joint and end-effector. The robots are generally, computer-controlled manipulator consisting of several rigid links and connected in series with help of revolute or prismatic joints. One end of the link or chain is attached to a supporting base, while the other end is free and equipped with a tool to manipulate objects or perform assembly tasks. The robot's wrist subassembly is designed to reach a work piece located within its work volume. The work volume is the sphere of influence of a robot whose arm can deliver the wrist assembly unit to any point within the sphere. The arm subassembly can move with three degrees of freedom. Here  $l$  indicates the number of links (including the ground link),  $m$  shows the number of total joints,  $j$  is number of degrees of freedom of the  $j^{\text{th}}$  joint and has value depending upon type of mechanisms

### A. Classification and uses of Robots

- Industrial robots - robots employed in an industrialized manufacturing atmosphere. Typically, they are robotic arms particularly created for applications like material handling, painting and welding other works
- Medical robots - robots employed in medicine and medicinal institutes. A typical example is the Vinci Surgical System - a robotic surgical system.
- Service robots - robots which operate semi- or fully autonomously to perform services useful to the well-being of humans and equipment, and excluding manufacturing operations. Examples include lawn mowing robots, vacuum cleaning robots and sewer robots.

- Military robots - robots brought into play in military and armed forces. They consist of bomb discarding robots, shipping robots and exploration drones.
- Entertainment robots - robots employed for entertainment. They include model robots such as robosapien as well as articulated robotic arms employed as movement simulators.
- Space robots – robots employed in space exploration and other space activities A Common example is the mars exploration rover (4).

The main components of the Robot Arm.

- Servo Motors
- Arduino Microcontroller
- HC-06 Bluetooth Module
- Circuit Diagram

## **II. DESIGN and WORKING**

### **A. Work Volume and Work Envelope**

Work volume is the space within which the robot can manipulate its wrist end. The work volume is determined by the physical characteristics of the robot such as, the size of body, arm and wrist configuration and the limits of the robot joints movement. The area of space within which the robot will operate includes the entire range of points.(4) The space that defines the boundaries and robot manipulator can reach that boundaries is known as work envelope. Different working robot configuration generate characteristic of working envelope shape. Useful work envelope is called standard work envelope

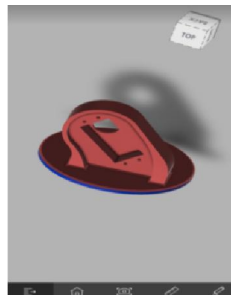
### **B. Mechanical Parts**

Design The mechanical design is limited to 5 DOF mainly hence that such design allows most of the necessary moments and Accordingly, rotational motion of the joints is restricted where rotation is done around two axis in the shoulder and around only one in the elbow and the wrist. The robot arm joints are typically actuated by electrical motors. The servo motors were chosen, which are automatically and adjust the position accordingly (5).( The basic points to be noted and followed for the design are.

- Functionality
- Reliability
- Motion Range and Speed
- Payload



**Figure 2.1: Base**



**Figure 2.2: Waist**



**Figure 2.3: Arm01**



**Figure 2.4:** Arm02



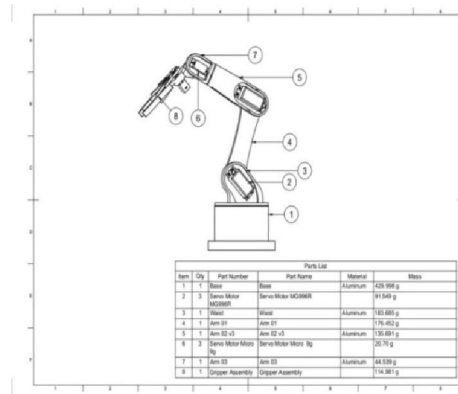
**Figure 2.5:** Arm 3



**Figure 2.6:** Gripper Assembly



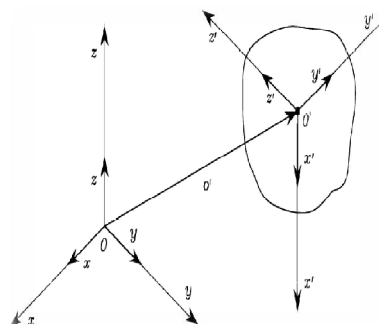
**Figure 2.7:** Robot Arm by using Fusion 360



**Figure 2.8:** 2-D Diagram of Robot Arm

### III .KINEMATICS

By using the kinematic model of the arm . A kinematic model is a way to schematically represent a manipulator from a mechanical viewpoint. The manipulator is modeled as a chain of rigid bodies connected by joints. The joints can be either revolute (rotational) or prismatic (telescopic). The rigid bodies can be completely described in space by their positions and orientations with respect to a reference frame. The reference frame is the combination of the orientation of the Cartesian coordinate system and the position of its origin before the joint. (6) The new frame consists of the new Cartesian coordinate system and the position of its origin after the joint. This is shown in Figure 3.1



**Figure 3.1:** Position and orientation of a rigid body

Every individual joint has been described as either revolute or prismatic and a reference frame has been defined at the base of each joint. In accordance with the convention used in the z-axis of the reference frame is parallel to the revolution axis in the case of revolute joints and parallel to the extension in the case of prismatic joints. The chain of rigid bodies with the axes for the individual joints of the arm designed.

$$\begin{aligned} X' &= X'xX + X'yY + X'zZ \\ Y' &= Y'xX + Y'yY + Y'zZ \\ Z' &= Z'xX + Z'yY + Z'zZ \end{aligned}$$

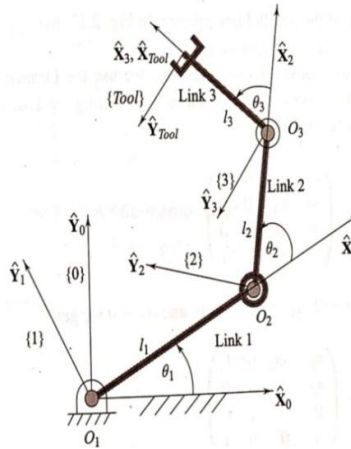
In equation 3  $X'x$  symbolizes the rotation of the x-axis of the new frame with respect to the x-axis of the reference frame. In the same way the term  $X'y$  denotes rotation of the y-axis of the new frame with respect to the x-axis of the reference frame, et cetera. By multiplying these rotation factors with the original frame the new frame is found. The rotation matrix R then equals the (3x3) matrix:

$$R = \begin{bmatrix} X'x & Y'x & Z'x \\ X'y & Y'y & Z'y \\ X'z & Y'z & Z'z \end{bmatrix}$$

The translation vector consists of the vector connecting the origin of the reference frame to the origin of the new frame. It can be represented as the (3x1) vector  $O'$

$$O' = \begin{bmatrix} O'x \\ O'y \\ O'z \end{bmatrix}$$

The terms  $O'x$ ,  $O'y$  and  $O'z$  represent the translation in the x-direction, the y-direction and the z-direction of the reference frame respectively.



**Figure 3.2:** The chain of rigid bodies with the axes for the individual joints of the arm

Forward transformation of a 2-degree of freedom arm.

We can determine the position of the end of the arm in space by defining a vector for link 1 and link 2.

$$R1 = [L1 \cos \theta, L2 \sin \theta] \tag{1}$$

$$R2 = [L1 \cos(\theta1 + \theta2), L2 \sin(\theta1 + \theta2)] \tag{2}$$

Vector addition of 1 & 2 yields the co-ordinates X & Y of the arm (Pw) in word space

$$X = L1 \cos \theta1 + L2 \cos(\theta1 + \theta2) \tag{3}$$

$$Y = L1 \sin \theta1 + L2 \sin(\theta1 + \theta2) \tag{4}$$

Reveres transformation of a 2-degree of freedom arm

$$\cos(A + B) = \cos A \cos B - \sin A \sin B$$

$$\sin(A + B) = \sin A \cos B + \sin B \cos A$$

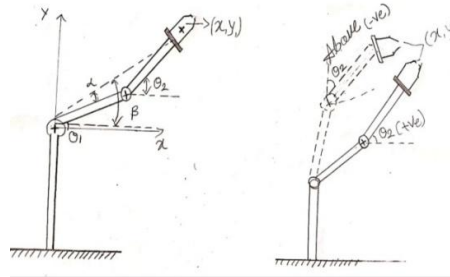
Now equation 3 and 4 can rewrite as per above eqns

$$X = L1 \cos \theta1 + L2 \cos \theta1 \cos \theta2 - L2 \sin \theta1 \sin \theta2$$

$$Y = L1 \sin \theta1 + L2 \sin \theta1 \cos \theta2 + L2 \cos \theta1 \sin \theta2$$

Squaring both sides and adding the two questions

$$\cos \theta 2 = \frac{x^2+y^2-L1-L2}{2L1L2} \tag{5}$$



**Figure 3.3:** Arm's initial and new positions with angles

Defining the angle  $\alpha$  and  $\beta$  as in fig.

$$\tan \alpha = \frac{L2 \sin \theta 2}{L2 \cos \theta 2 + L1}$$

$$\tan \beta = \frac{Y}{X}$$

Using trigonometry identity

$$\tan(A + B) = \frac{\tan A - \tan B}{1 + \tan A \tan B}$$

We got

$$\tan \theta 1 = \frac{Y(L1+L2 \cos \theta 2) - X(L2 \sin \theta 2)}{X(L1+L2 \cos \theta 2) + Y(L2 \sin \theta 2)} \tag{6}$$

Knowing the link length then by using this questions find the required angles in the space L1. and L2 represent the lengths of the arm pieces. r, the distance between the origin and the point in space denoted by (x y z), is found using equation 7. By rewriting equation 8, which is the rule of cosines, into equation 9  $\theta 2$  is found.

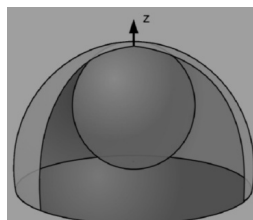
$$r = \sqrt{X^2 + Y^2} \tag{7}$$

$$r^2 = L1^2 + L2^2 - L1 L2 \cos(\theta 2) \tag{8}$$

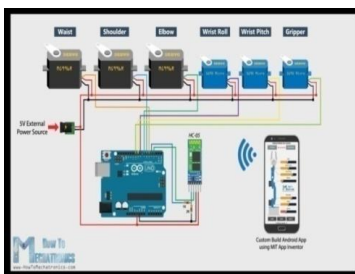
$$\theta 2 = Lr \cos \left( \frac{L1^2+L2^2 - r^2}{2L1L2} \right) \tag{9}$$

#### IV. WORK SPACE ANALYSIS

It is essential to have knowledge about the Arm workspace in order to determine at what positions and orientations Bricks may be picked. Furthermore, analysis of the workspace will allow comparing different Arm mounting alternatives. Finally, it will give a qualitative understanding of situations where Cartesian space trajectory generation is doomed to failure. Naively, the assumption might be made that the reachable workspace has the geometry of a half sphere, since there is obviously control of the Arm radius with the Elbow as well as latitude and longitude control by Shoulder and waist, respectively. Unfortunately, however, with increasing Elbow bending the latitude control becomes limited. This leads to an unreachable sphere-like region on top of the Waist. Figure 4.1 illustrates the reachable workspace qualitatively (7,8).



**Figure 4.1:** Qualitative insight into the reachable workspace.



**Figure 4.2:** Block Diagram of the working System

**V. RESULT AND DISCUSSION**

**A. Need for Stress Analysis**

A good design is always judged by its load bearing capacity. Stress analysis is an engineering discipline that uses many methods to determine the stresses and strains in different materials and structures subjected to forces. In engineering, stress analysis is often a tool rather than a goal; the ultimate goal being the design of structures and artifacts that can withstand a specified load, using the minimum amount of material or that satisfies some other optimality criterion (5). The stress on the part can be related with the load carrying capacity. Typically, the starting point for stress analysis is the geometrical description of the structure, the properties of the materials used for its parts, how the parts are joined, and the maximum forces that are expected to be applied to the structure. The result of the study (analysis) is a description of how the applied forces spread throughout the structure, resulting in stresses, strains and the deflections of the entire structure and each component of that structure (9). By default, meshing provided by inventor is made and the part is simulated, after the detail study of this stress distribution obtained. We found some areas where stresses are more when compared to remaining areas. The initial sizes of mesh are 10mm minimum element size and the average element size is 15mm.

Mesh Size	No. Nodes	No. Elements
10mm	27119	15113
15mm	13649	7057

**Table 5.1:** Mesh size and results

The speeds of the joints are tabulated below table for the calculation of moment. The angular moment L can be calculated using the formula  $L = I \times \omega$  Where I is the moment of Inertia of the body and  $\omega$  is the angular speed.

Overview of the arm:

- Degrees of freedom (DOF): 5
- Payload capacity: 150gm
- Joint speed (approximate): 40 - 50 rpm
- Hardware interface: pin connector
- Base spin: 360 degrees
- Shoulder base spin: 160 degrees
- Elbow spin: 120 degrees
- Wrist spin 180 degrees
- Gripper Opening (Max) = 6 - 7cm

**PC/ABS Plastic**

Density	3.573E-07 kg / mm <sup>3</sup>
Young's Modulus	2780 MPa
Poisson's Ratio	0.4
Yield Strength	54.4 MPa
Ultimate Tensile Strength	54.1 MPa
Thermal Conductivity	2.4E-04 W / (mm C)
Thermal Expansion Coefficient	6.7E-05 / C
Specific Heat	2133 J / (kg C)

**Table 5.2:** Material properties are

☐ Safety Factor (Per Body)  
0 8



☐ Stress

☐ Von Mises  
[MPa] 0 24.95



☐ 1st Principal  
[MPa] -8.99 25.12



☐ 3rd Principal  
[MPa] -31.75 9.98



☐ Displacement

☐ Total  
[mm] 0 2.065



☐ Safety Factor (Per Body)  
0 8

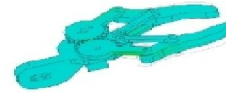


☐ Stress

☐ Von Mises  
[MPa] 0 33.26



☐ 1st Principal  
[MPa] -11.98 33.49



☐ 3rd Principal  
[MPa] -42.33 13.8



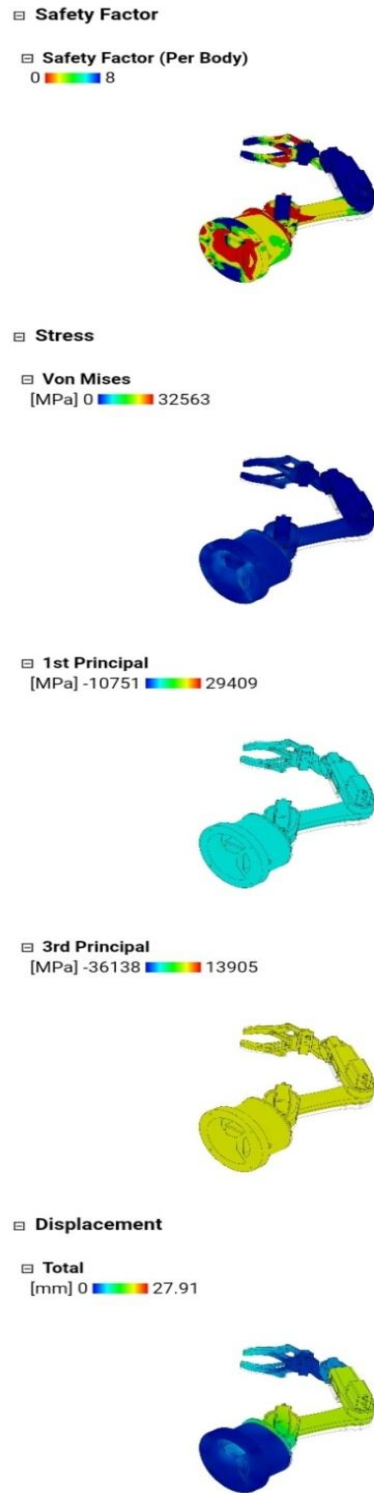
☐ Displacement

☐ Total  
[mm] 0 2.754



Figure 5.1: Mesh size 10mm and 10N Load applied.

Figure 5.2: Mesh size 15mm and 20N Load applied.



**Figure 5.3:** Full Assembly result of 10N load applied

## **VI. CONCLUSION**

This paper presents the design and development of a robotic arm for light material lifting (pick and place) application. The robotic arm is designed, drafted and Analysis will done by using FUSION 360 Fabrication with advance technology, 3D-printing to save cost and time. The robotic arm model is made up of ABS (Acrylonitrile Butadiene Styrene) material and one of the linkages between the body and motor is made up of PLA (Polylactic Acid). The robotic arm is designed with five degrees of freedom because it is suitable for most of the application included lifting. Experiment is set up to test the performance of the robotic arm by varying the load to be lifted; the lifting mechanism of a robotic arm is validated supported by the results obtained in the experiment.

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