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Research Article

DESIGN AND ANALYSIS FOR CUSTOMIZED INDUSTRIAL ROBOT PROTOTYPE USING ADDITIVE MANUFACTURING

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A B S T R A C T

Additive Manufacturing (AM) is the latest available manufacturing technology for fabrication of prototypes with precise in short duration of time with minimal cost. AM provides maximum flexibility for designer. Currently AM technology is using in almost all the industries. The primary objective of the current work is to design and fabricate functional prototype of custom design Industrial Robot with light weight and low cost. Developed Robot consists of functionalities like picking of a tool or an object and placing it at desired place. Design of robotic arm has been developed using Creo parametric 2.0 software. The Analysis has been carried out on 3D Computer Addied Design (CAD) model using ANSYS software. The prototype Robot was fabricated using AM with Poly Lactic Acid (PLA) material. Robo Analyzer software is used to solve inverse kinematics of the robotic arm for the joint angles of the desired positions. In electronics microcontroller, servo motors are used to obtain Four Degrees of Freedom (4-DoF). An open source computer hardware and software-Arduino, used for programming and to control the robotic arm by driving servomotors. The developed Robot tested for its performance, design structure and the results found are satisfactory.

INTRODUCTION

Nowadays, robots are especially used to perform the repetitive task to replace humans which are increasingly being integrated into different working tasks. Robots are currently used in various areas of applications including office, military tasks, hospital operations and agriculture. Moreover, the robots are used to do specific tasks like picking up explosive objects, defusing bombs etc., in an environment where it is difficult and dangerous for human [1]. Robots have the ability to imitate human motions and those behaviors are imitated to achieve required task perfectly. They do not get bored or tired to do any monotonous tasks. They can be programmed to obey and perform specific tasks.

In general, robotics can be divided into two areas, industrial and service robotics. Service robot can be either semi-autonomous or fully autonomous. For manufacturing operation in industries, industrial robots are used. Industrial robot is officially defined by ISO as an automatically controlled and multipurpose mechanical manipulator which is programmable in three or more axis. An industrial robot is a re-programmable multifunctional mechanical manipulator design to move material, parts, tools etc., from one location to another or, it is a specialized device design to perform variety of tasks through variable programmed motion. A robotic arm is a mechanical manipulator, which is programmable-controlled and has the ability to simulate a real human arm. The various links of a robot arm are connected by joints which allow motion either rotational or translational, in form an open kinematic chain. In which one end is fixed at a position or it can be moveable and the other free end is equipped with end-effector or tools. Depending on application, the free end can be equipped with different tool to perform task such as painting, welding, gripping, spinning etc. The robotic arms can be fully automatic or it can be controlled manually.

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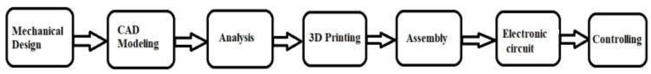
METHODOLOGY

The methodology followed for the development of robotic arm is explained in the below.



- Mechanical design of the robot arm.
- Designed the parts of the robotic arm using CAD software (creo parametric 2.0).
- Finite element analysis to calculate the stress and deformation in the various parts using ANSYS software.

- Inverse kinematics analysis using RoboAnalyzer software to find out joint angles.
- Fabrication of all parts in FDM machine (3D printer).
- Assembling of all printed parts with electronic components.
- Controlling of the Robot using Arduino microcontroller.
- Testing and result.

Mechanical Design of Robot arm

The mechanical design of the robotic arm is designed as a manipulator which can imitate actions similar to a human arm. A Robotic arm system consist of various links, joints, actuators, sensors, controller etc., [2]. The various links of the manipulator are connected by joints which allow either rotational motion or translational motion, but an articulated robot allows only rotational motion. The connected links forms an open kinematic chain of which one end is fixed to the robot base and another free end is equipped with a gripper as shown in Figure 1 below. Designed robot arm has 5 links and 4 joints, it has ability to move in four directions i.e. 4-DoF. The robotic arm with only 4-degrees of freedom is designed because it is adequate for most of the necessary movement [3]. The robotic arm consist four servo motor for each DoF. The area that can reach by end-effecter (gripper) is known as robot workspace.

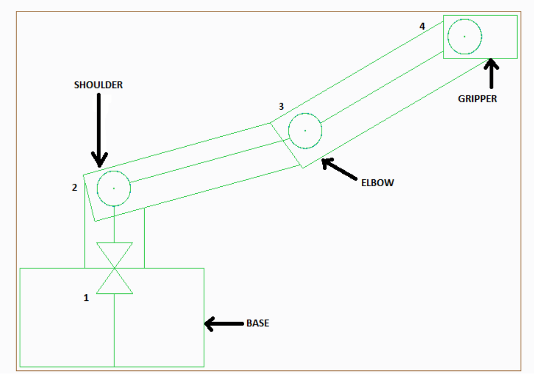


Figure 1 Free body diagram of the robotic arm

Actuators

Actuators are the basis for movement of the robot arm. These are devices that allow the rotary joints to rotate about their motion axes in an articulated robot. There are generally three types of fundamental actuating systems used in robots; they are Hydraulic, Pneumatic, and Electrical actuating systems. In the current work electrical actuating systems have been considered. DC servo motors and stepper motors are used to actuate the movement of the robotic arm. Since these systems can be controlled easily with fast response, high accuracy along with feedback system. However, the disadvantage of the servo motor is movement range, which is less than 180 degree span. Since there are 4 joints in the developed robotic arm, 4 controllers are utilized to control all joint actuators. Selection of suitable motor for the application is made based on torque and the speed of the motor. Force calculation of joint ensures that the motor to be chosen can support the weight of the robotic arm and also the load that need to be carried [4]. Force and Torque acting on the joints are calculated as shown in the below Figure 2.

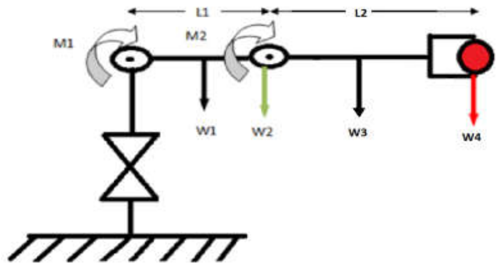


Figure 2 (a) Force diagram of robot arm.

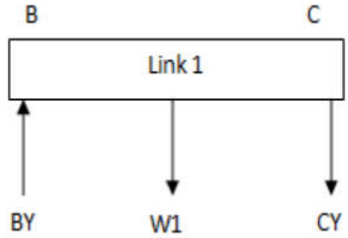


Figure 2 (b) Force diagram of link 1

W1=weight of link 1=57.2gm
W2= weight of motor=55gm
W3= weight of link 2=98.6gm
W4= weight of load=100gm
L1= length of link 1=160mm
L2= length of link 2=265mm
Taking the sum of forces in the Y-axis,

$\sum F_y = (W4+W3+W2)g - CY = 0$

⇨ Cy=2.48N

$\sum F_y = (W4+W3+W2+W1)g - BY = 0$

⇨ By=3.045N

Moment at elbow,

$\sum M_c = - W3\,(L2/2) - W4\,(L2) + M_c = 0$

⇨ Mc=3.95kg-cm

Moment at shoulder,

$\sum M_b = - W4\,(L1+L2) - W3(L1+ L2/2) - W2(L1) - W1\,(L1/2) + M_b = 0$

⇨ Mb= 8.47kg-cm

Based on the moment calculated, suitable servo motor was selected. The servo motors have a torque of 9.4kg-cm for 4.8v and 11kg-cm for 6.0v. They can turn 60 degree in 15millisecond for 6.0v and 20millisecond for 4.8v and has a weight of 55gm each. Maximum torque calculated is at shoulder and is 8.47 kg-cm and the actual torque of shoulder servo is 11 kg-cm. So the motor can perform desired task easily. For the gripper, a micro servo with 1.8 kg-cm torque and can turn 60 degree in 12millisecond for 4.8v and has a weight of 9gm is used. Hence totally 4 servo motors and each Motors has to serve specific purpose at each part of the robotic arm:

- Motor 1 for rotational motion of base.
- Motor 2 for shoulder arm movement.
- Motor 3 for elbow arm movement.
- Motor 4 for gripping motion.

CAD modeling

In the current work 3D CAD model of the robot parts is designed using Creo parametric 2.0 software. Various parts of robotic arm include base, shoulder, shoulder arm, elbow arm and gripper etc [5]. The CAD software provides detail view and walk through overviews for demonstrating design. These

CAD models are utilized to fabricate physical models using AM. The plane view, isometric view, dimensions of parts and 3D views of each parts of robotic arm are shown in Figures 3-7.

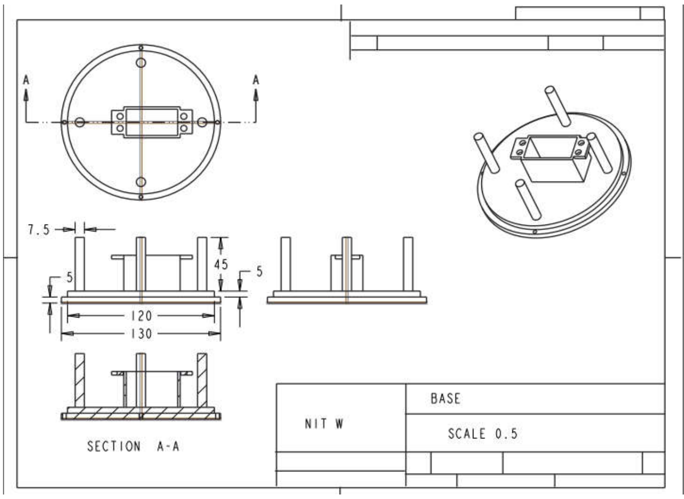


Figure 3(a) Plane of view, isometric view and dimension of base

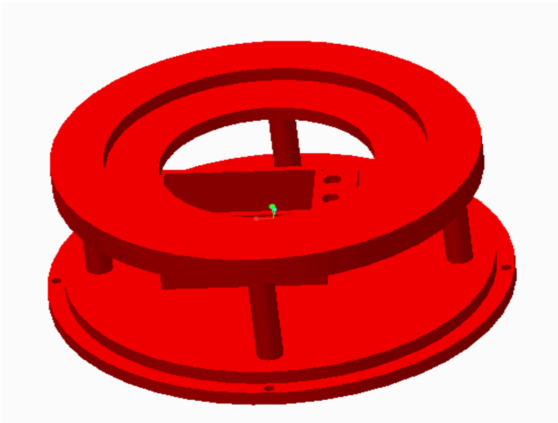


Figure 3(b) 3D view of the base

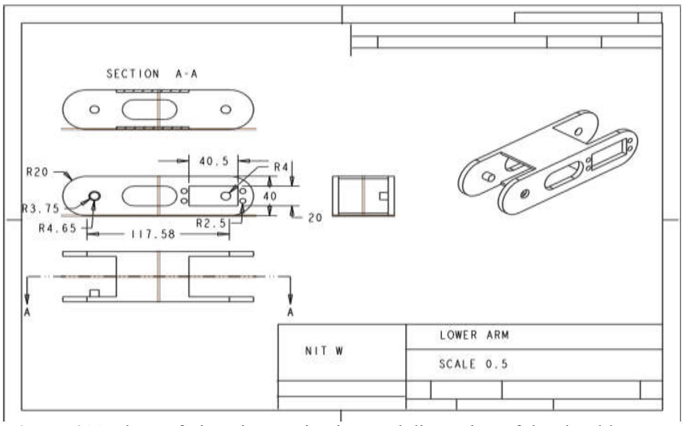


Figure 4(a) Plane of view, isometric view and dimension of the shoulder arm

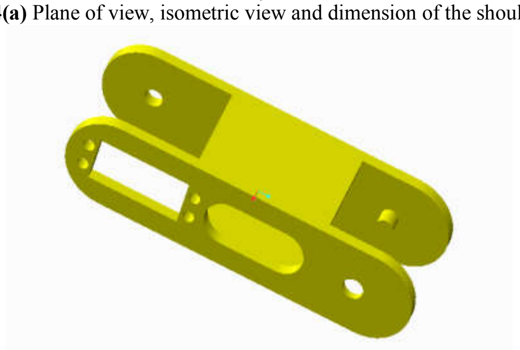


Figure 4 (b) 3D view of shoulder Arm

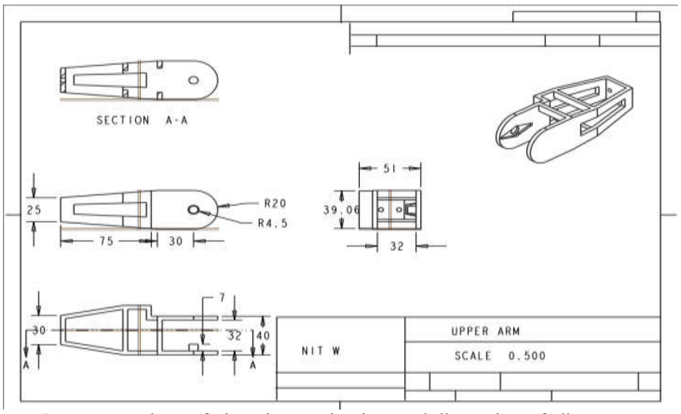


Figure 5(a) Plane of view, isometric view and dimension of elbow arm

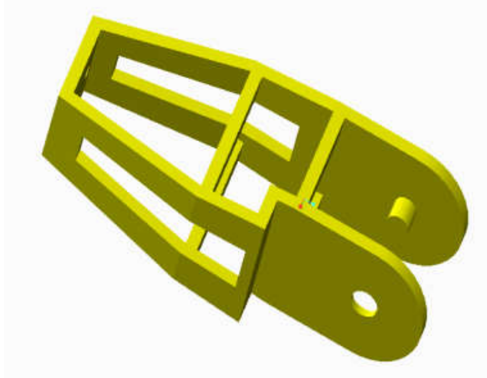


Figure 5(b) 3D view of elbow Arm

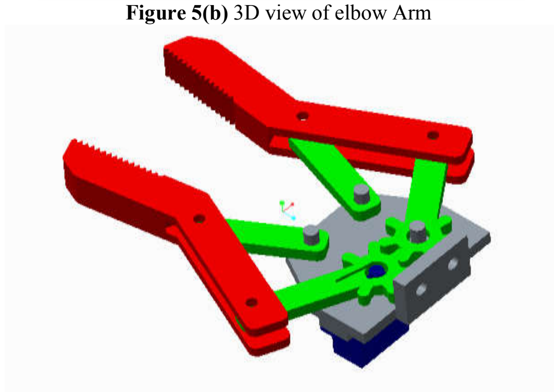


Figure 6 3D view of gripper assembly

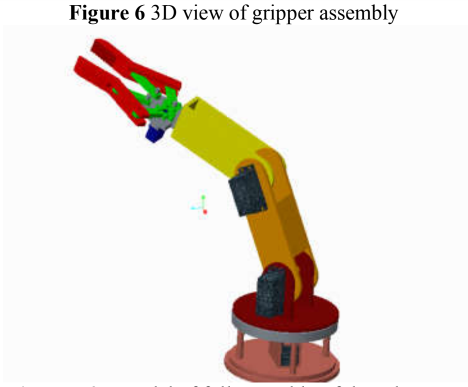


Figure 7 3D model of full assembly of the robot arm

Finite Element Analysis

Finite element analysis is done in ANSYS software in order to know the deformation and stresses induced in the each part of robotic arm. New material (PLA) is added in ANSYS engineering data by providing its properties and this material is used in each part for analysis. The analysis is done for 5kgf force, which is shown in Figures 8-11.

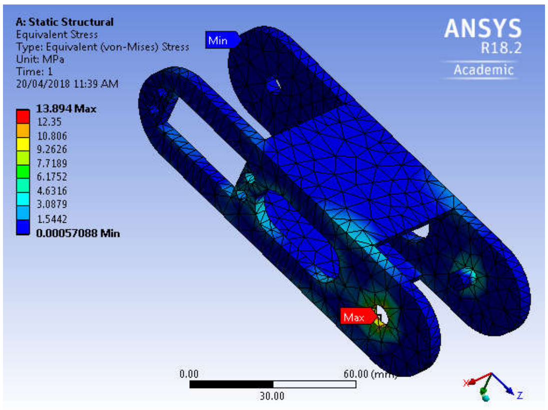


Figure 8 Stress on shoulder

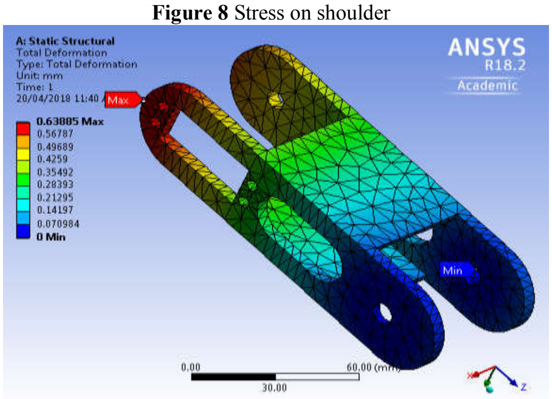


Figure 9 Total deformation of shoulder

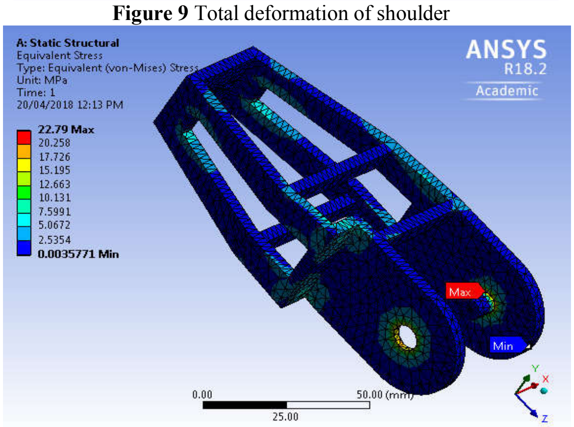


Figure 10 stress on elbow arm

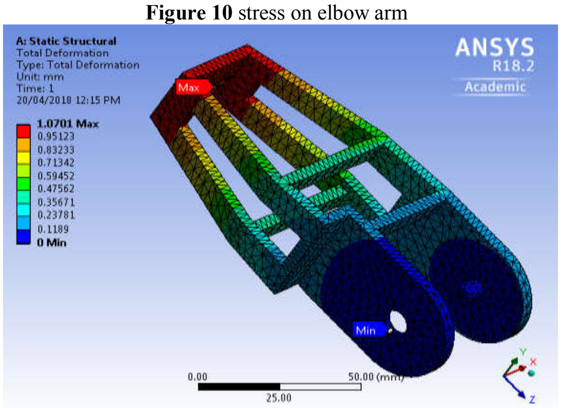


Figure 11 Total deformation of elbow arm

From the analysis carried out in Ansys software the maximum and minimum stress and the total deformation developed in the elbow part are shown in figure 10 and 11. The stress developed in this part is the maximum i.e. 22.79 Mpa and maximum deformation is 1mm for 5kgf force. The ultimate tensile strength of PLA material is 35 Mpa, so the robot arm is strong enough to withstand the load it will carry.

Inverse Kinematics Analysis

To control a robotic arm, both inverse kinematics and forward kinematics analysis is important. For a pick and place robot, position and orientation of the end-effector should be known, so inverse kinematic analysis is important. RoboAnalyzer 3D model based robotics learning software is used in the current work to solved inverse kinematics problem and to find out the joint angles of the robot arm for a given position and orientation of the end-effector [1]. Denavit and Hartenberg (DH) parameters include joint offset, joint angle, link length and twist angle. DH parameters for the current robotic arm are listed in Table 1.

Table 1 DH parameters for the robotic arm

Joint No	Joint Type	Joint Offset (b) m	Joint Angle (theta) deg	Link Length (a) m	Twist Angle (alpha) deg
1	Revolute	0.07	Variable	0.01	90
2	Revolute	0.01	Variable	0.16	0
3	Revolute	0.01	Variable	0.27	0

Above DH parameters are used in RoboAnalyzer software to identify the joint angle(Θ) for different positions of robotic arm and results are obtained are shown in Table 2.

Table 2 Joint angles for different positions of robotic arm.

Sl. no.	Positions	Orientation(α)	Θ in Solution1	Θ in Solution2	Θ in Solution3	Θ in Solution4
1	X=0.1 Y=0.2 Z=0.1	0	Θ1= 68.56 Θ2= 98.98 Θ3= -127.29	Θ1= -121.69 Θ2= -103.27 Θ3= -120.18	Θ1= -121.69 Θ2= 88.58 Θ3= 120.18	Θ1= 68.56 Θ2= -82.93 Θ3= 127.29
2	X=0.15 Y=0.15 Z=0.1	60	Θ1= 50.40 Θ2= 103.70 Θ3= -131.38	Θ1= -140.40 Θ2= -99.74 Θ3= -124.29	Θ1= -140.40 Θ2= 84.30 Θ3= 124.29	Θ1= 50.40 Θ2= -86.74 Θ3= 131.38

Solution1, Solution2, Solution3 and solution4 gives four different trajectory of the robotic arm. For position (0.1, 0.12, and 0.1) of the end-effector, the four trajectories calculated using software. Initial and final position of end-effector for solution1 is shown in Figure 12.

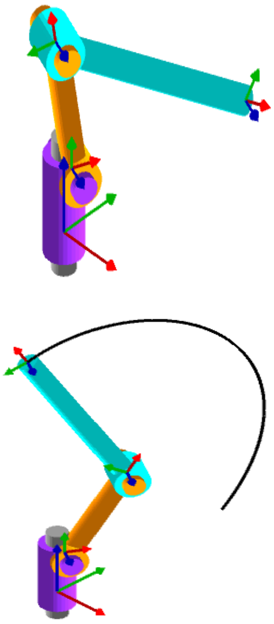


Figure 12 Initial and final position of end-effector for solution1

Fabrication of AM Parts

All the designed robot parts for the current work are fabricated using Fused Deposition Modeling AM machine, which are shown in the Figure 13(a)–(f).

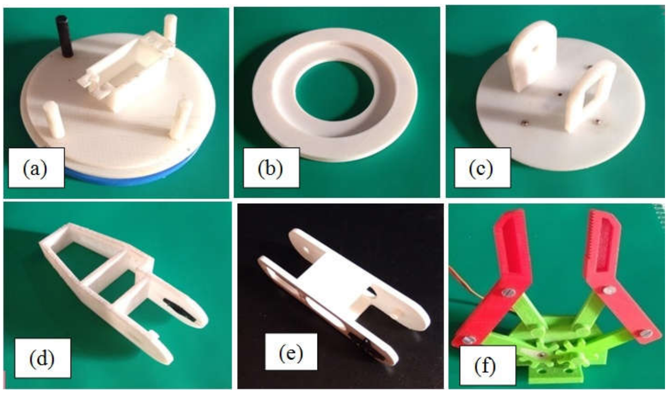


Figure 13 AM fabricated parts (a) base part, (b) base plate, (c) shoulder part, (d) elbow arm, (e) shoulder arm, (f) gripper assembly.

Assembly

All AM fabricated parts are assembled with various electronic components such as Servo motors, Arduino microcontroller, Breadboard and wires etc., as shown in Figure 14-17. For the gripper, all small parts were printed separately and then assembled as shown in Figure 16. The final assembled robotic arm is shown in Figure 17.

Figure 14 Base Assembly

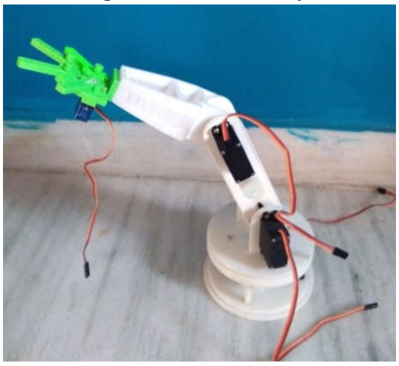


Figure 15 Assembly of connecting links

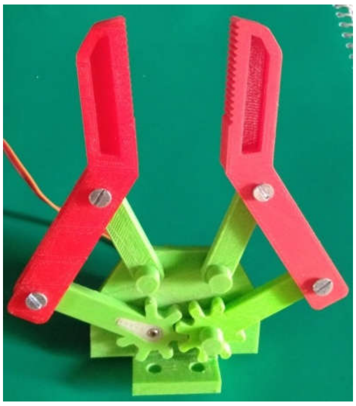


Figure 16 Gripper Assembly

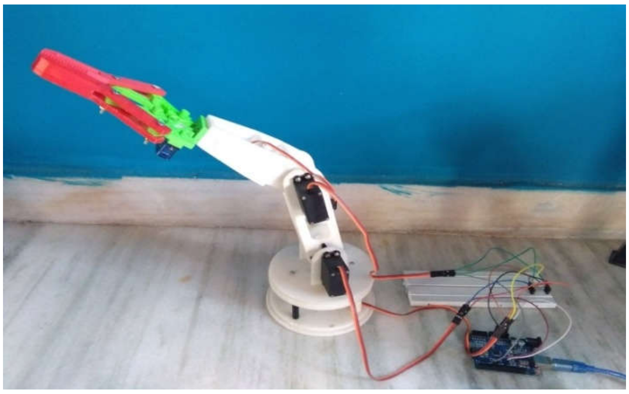
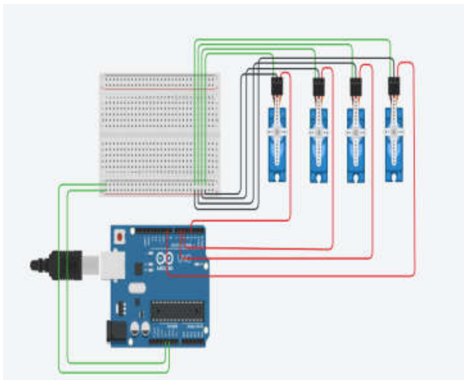


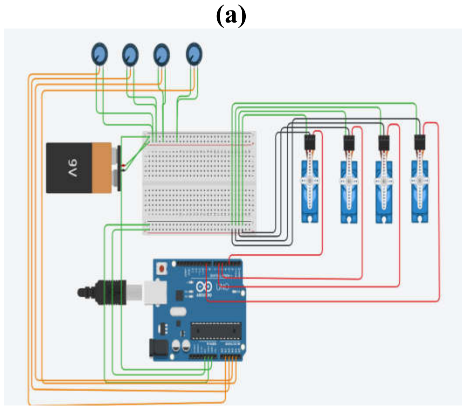
Figure 17 Full assembly of robotic arm

Electronic circuit

The electronic circuit board for controlling the robotic arm is designed, simulated and tested on Autodesk's tinkercad circuit design software. This software is a web-based 3D circuit design application. This software has been used in the current work to design the control circuit of robot, circuit assembly, programming and simulation of the designed circuit. The control board circuit for controlling of robot arm design is shown in the figure 18(a) & (b) and the simulation is carried out. The result of the simulation shows that the circuit design is perfect and validated. Hence, the actual circuit is designed and implemented on breadboard as shown in figure 19(a) and (b). Each servo motors connected to Arduino board is controlled by the necessary PWM (Pulse Width Modulation) signal generated by the Arduino microcontroller. After generating the necessary PWM signal, the microcontroller sends to the corresponding servomotor for necessary movement of the motor shaft.



(a)



(b)

Figure 18 Schematic diagram of robot arm control board circuit –(a) using serial monitoring and (b) with potentiometer

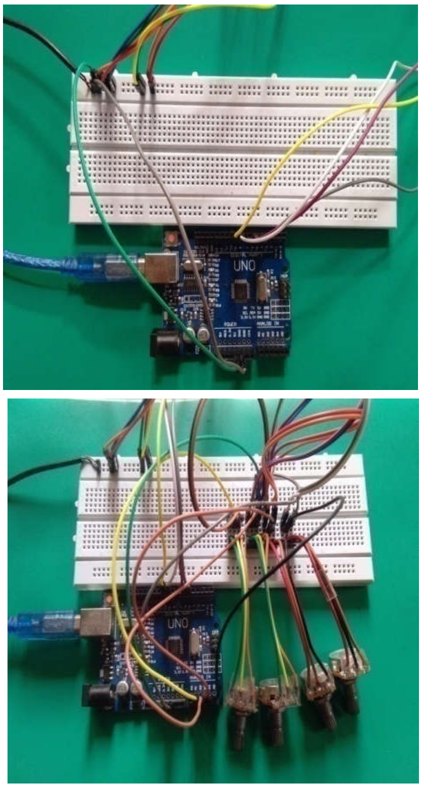


Figure 19 Implementation of control board circuit of the robotic arm on breadboard (a) Without potentiometer, (b) With potentiometer

Robot arm control

The robot arm can be controlled automatically or it can be controlled manually. In manual control, an operator controls the robot arm manually to do a task. In automatic control, the robot can programmed in such a way that it can do a task automatically and repetitively. No need of any operator or human interface for automatic control. To pick an object from one position and placed it in another position, joint angle or the angle of rotation of the servo shaft of the robot should be known. For a given position and orientation of end-effectors, the joint angle can be obtained from the inverse kinematics analysis. Once the joint angle is known from Inverse kinematics analysis, a program can be written in Arduino IDE (Integrated Development Environment) software using those joint angles as shown in Figure 20. After coding the program, it can be upload directly to the Arduino board from the PC via USB cable. Then Arduino microcontroller will control the servo motor according to the written program. The most important aspect of this programming was to set the position of the servo's, which determines the movement of the robot.

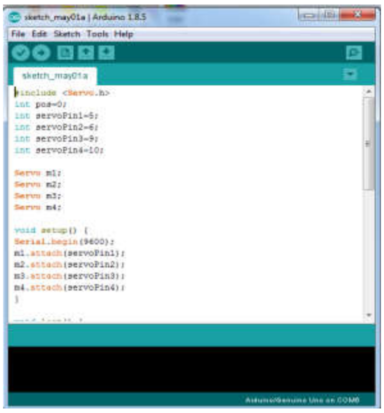


Figure 20 Screenshot of a Arduino program

RESULT AND DISCUSSION

As per the specification of servo motor, it has a span of 180 degree. But the actual range of servo motors obtained in the range from 15 to 170 degree. To check the servo motors range one program was written and a simple connection was done as shown below in Figure 21. The range of servo motors can be identified by putting various angles in serial monitor in Arduino IDE.

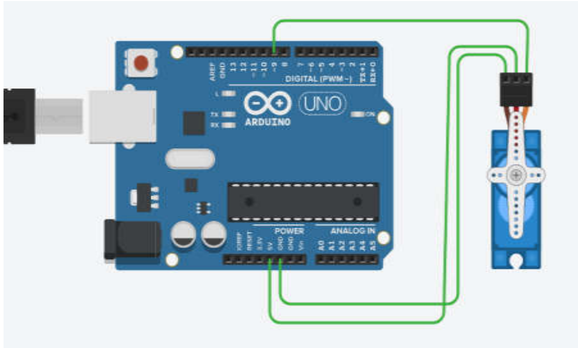


Figure 21 Simple servo motor connection with arduino

The maximum range of the robotic arm are recorded and its further pick up point is found 35cm and maximum angle the robot arm can reach is 155 degree, with the range from 15 degree to 170 degree. The robot arm is tested with different weight to be lifted and found that it can lift up to 80gm. The gripper is designed in such a way that it can lift different shape of object easily (gripper design depends on the shape of the objects to be lifted), but the gripping force is found to be less. More than 80gm weight objects get slides down from the gripper. So, maximum load to be lifted is limited to 80gm only for this robotic arm. The fully assembled robot has easily performed an industrial task such as pick and place an object. The user interface is easy to use and learn. The user interface allows the user to control four servo motors via Arduino microcontroller.

CONCLUSION

The objective of the current work is to develop Industrial Robot with 4 DoF using AM technology. The development of 3D CAD design of the robot has performed using Creo 2.0 design software. In this process the optimal amount of material for adequate strength has been analyzed using ANSYS software. The prototype of Industrial robot is developed with minimal cost. In this regard the AM FDM technology is utilized for the physical parts of robot. From the current work it can be concluded that the developed design of the robot is best suitable for Industrial robot or Special Purpose robot. In future the real time customized Robot can be fabricated for specific requirement using AM technology.

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