International Journal of Applied Science and Research

Robotic Arm Application for Pick and Drop Operations

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DOI: https://doi.org/10.56293/IJASR.2022.5535

IJASR 2023
VOLUME 6
ISSUE 4 JULY – AUGUST **ISSN: 2581-7876**

Abstract: There is always the need to pick and place objects or parts repeatedly in manufacturing especially in mass production. This research work was focused on the design and manufacture of a prototype robotic arm for pick and drop operations. The robotic arm was designed with four degrees of freedom and programmed to lift and drop parts on production line. 3D printing technology was used in the production of the components for the robotic arm. Arduino, an open source computer hardware and software was used to control the robotic arm by means of servo motors. The maximum experimental load carried was 25g at 13.70 seconds.

Keywords: Aduino, robotic arm, pick and drop, programming, servomotors, operations.

1.0 Introduction

Robotics is divided into two areas: industrial and service robotics. These robots are used in many fields of engineering. It is best suited for repetitive operations and where it will be dangerous for humans to operate and, all in saving cost and improving productivity and efficiency. Therefore, robots are used from manufacturing to automotive to husbandry/agriculture, industrial robotic arms are one among the foremost common sorts of robots in use today.

Robotic may be programmed to try a horizonless number of tasks during a sort of environments. They are utilized in many areas in engineering [1].

At the early stage of robotic development teaching was required for the robot to perform defined tasks, like picking one sort of parts from one location with a chosen configuration. Robots were not able to pin point one objects among many, determine the part location with some degree tolerance or adjust the hold based on object orientation [2]. Presently, Intel Real Sense high-resolution depth cameras, high performance CPUs and GPUs, and Artificial intelligence technologies like the Intel Distribution of Open VINO toolkit, robotic designs are supplemented with the detection and capability to do new tasks. [2].

Robotic arms are machines that are programmed to execute a selected task or job quickly, efficiently, and very accurately. Generally, motor-driven, they are usually applied where rapid, heavy, high performance and repetitive operations are required in industrial sectors. 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. Robotic development was slow with emphasis on space exploration. Its application started in 1980's with automobile and use in production lines [2]. 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, can rotate as well as moving like a hinge [3]. The end of the robotic arm is the effector [4], and can be used to perform many tasks.[5] can be mobile so that 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 task independently of human control.[6] The reason of using robots is to reduce human errors and reduce fatique for repetitive operations [7]. There are some mechanical engineering operations that require pick and drop operations, sorting of objects on objects on conveyor belt. These processes are repetitive and if done by human will cause fatigue and error. The robotic arm is normally actuated by electrically by using DC servo motors for archiving three rotational motions and one for linear vertical motion [8]. These motors are controlled by C-programming language in Arduino. Industrial robots are gaining widespread application for the past few years. The application demonstrated is a robotic arm for lifting of work pieces. These robots of different levels of complexity are required at various places in assembly lines and machine shops of manufacturing industries.

The major objective of this research is to design and produce prototype robot for pick and drop operations.

Robotic has gone from just picking and dropping to feeling and translating intelligence. In fact, current research is on-going on the possibility of a robotic arm to possess the ability to touch, twist, grasp, and feel. In medical science, researchers are setting up a system to test whether a person could learn to control a robotic arm simply by thinking about it.[9] Research on computer –brain interface is on-going to restoring motion to people with paralysis and for developing new prosthetic limbs to turning thoughts to text.

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.[10] All these are giving lead ways to new perspective and research 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.

Some of the researches in manipulation at the Robotics Institute Pennsylvania are listed herewith

Prof. Erdmann's team found a graph-theoretic technique for modeling planning problems, so that the global capabilities are revealed by the homotropy type of a "strategy complex". A key result is a controllability theorem [11**].** 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 research high impact is best shown by the numerous imitations that have appeared since Ballbot's debut [12]. Prof. Likhachev's group focuses on developing fundamental new graph-search techniques addressing the many unique challenges of mobile manipulation. Prof. Likhache 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:

i. Locomotion techniques suitable for a high-centered mobile robot or an inverted turtle
ii. Folding of origam
iii. Manipulation preparatory to grasping
iv. New approaches to autonomous manipulation with simple hands
v. Assembly of consumer electronics
vi. Design of hands with scale-invariant or pose-invariant contact geometry

vii. Caging
viii. Imitation learning of manipulation strategies
ix. Data-driven approaches to grasp recognition and localization
x. RISE climbing robot
xi. DSAC and DTAR dynamic planar climbing robots

The manipulator or robotic arm has many similarities to the human body [13]. The arrangement of base, arm, wrist, and end-effector is shown in Figure 1.

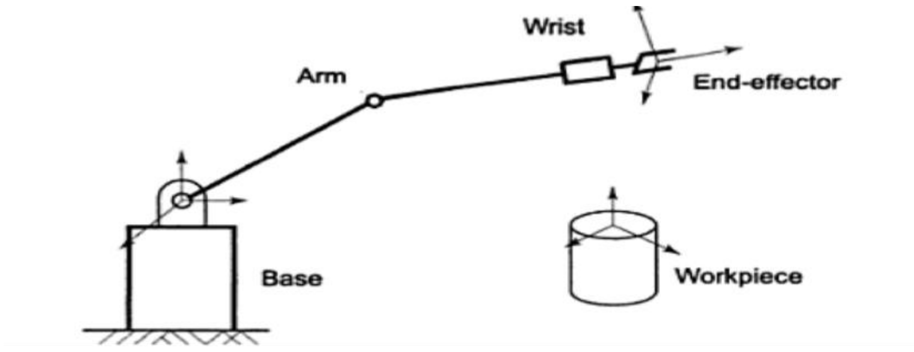

Figure 1: Mechanical structure of a manipulator [14]

A link that can connect at most two other links are called binary link. This is shown in Figure 2.

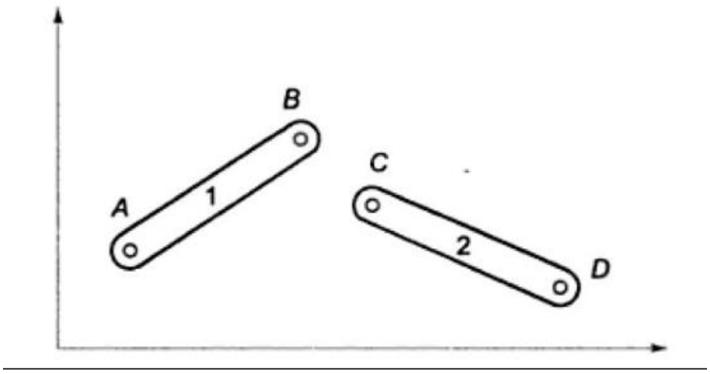

Figure 2: Two rigid binary links in free space [15]

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.

[15] six independent movements pictured in Figure 3 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

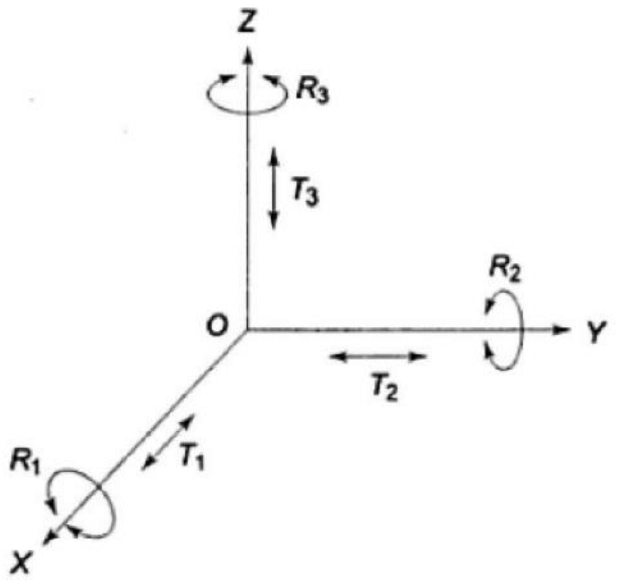

Figure 3: Representation of six degrees of freedom with respect to a coordinate frame [16]

The mechanics of the arm with 3-DOF depends on the type of three joints employed and their arrangement. The purpose of the arm [3] is to position the wrist in the 3-D space and the arm base 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 Work piece but also has to carry the wrist and the end-effector.

By joint movements and arrangement of links, four well-distinguished basic structural configurations are possible for the arm [3].

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 position the end-effector to do the task properly [17]. Fewer than 3-D0F 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 Figure 4.

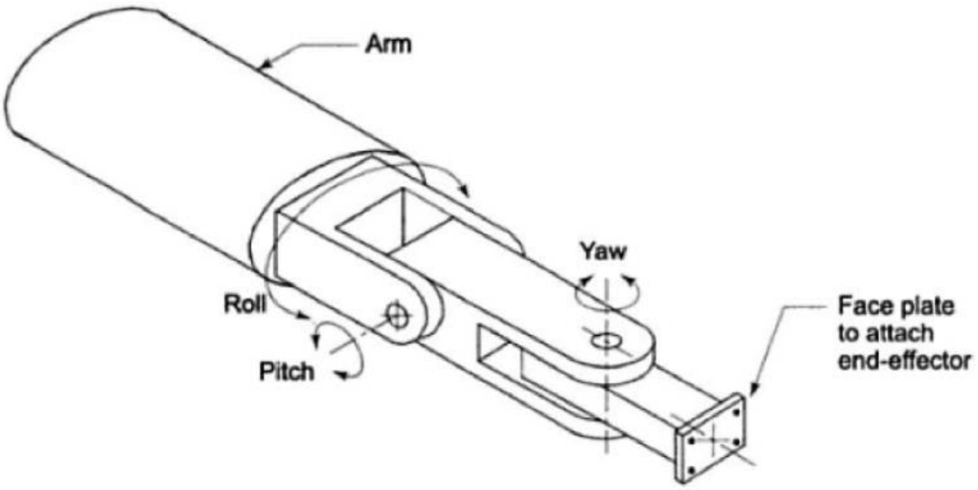

Figure 4: A DOF RPY wrist with three revolute joints [17]

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 manipulability. 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: grippers and tools.

Grippers are end-effectors to grasp or hold the work piece 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 [18].

Some typical mechanical grippers are shown in Figure 5.

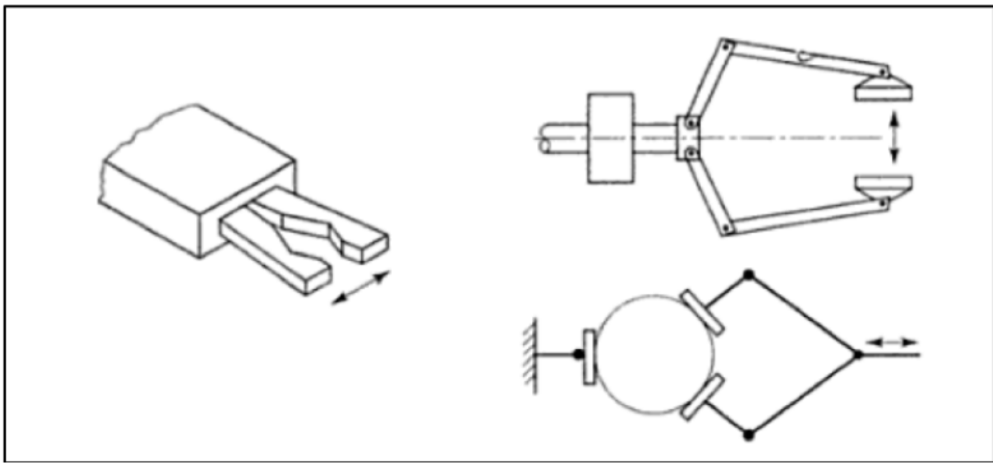

Figure 5: Some fingered grippers for holding different types of jobs [19]

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 work piece. Tool changer devices can also be attached to the wrist end for multi-tool operations in a work cycle [20].

The robotic arm is the most commonly used manufacturing robot. Robotic arm is programmed to perform many tasks and can do almost anything [21]. An articulated robot is a robot [22], 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 [23] 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

2.0 Materials and Methods

The robot in this research has four degrees of freedom (4 DOF) and revolute joints (often denoted as RRRR). This work uses a DC for a bi-phase encoder for the first joint at the bottom of the arm and digital servo motors for the remaining three joints and another additional servo motor for the end-effector [24]. The project will provide beginners with interest in robotics with a prototype low-cost hardware and software platform that allows easy experimentation with forward and inverse kinematics algorithms [24]. PID control and controller/computer interfacing.

Figure 6 is a block diagram showing the main components of the robotic arm.

The embedded controller determines the pose of the robotic arm by commanding each of the four joint motors to the desired angles. It implements a serial command interface with a very simple ASCII string protocol for receiving target angles from the companion computer. It also implements a PID control loop for controlling the rotation angle of the DC motor at joint 1. To do so, it reads the current motor position from the bi-phase encoder attached to the DC motor, and computes the required PID output signal to drive the motor to the target angle. The servo motors are handled much more easily by using only an open-loop control scheme. As noted earlier, forward and inverse kinematics algorithms are written in MATLAB and run in the companion computer. Both algorithms return of angles for each of the four joints, which are then sent to the embedded controller via the serial communications interface.

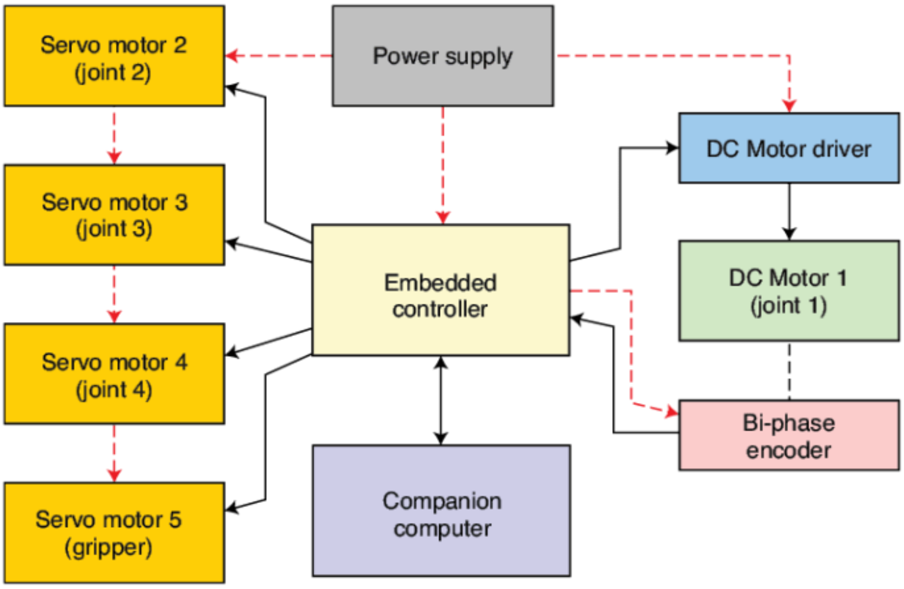

Figure 6: A block diagram showing the main components of the robotic arm [25]

The design criterion was to meet aesthetics, including the end-user. The cost of production, economy of repair and maintenance/improvements, availability of energy source, ease of operation, durability and operation safety and Efficiency and response

The following components and units were utilized in the robotic design for pick and drop and operations. After design analysis: Adruino UNO board, Power Supply, Metallic Servo motor, Micro Controller and Bluetooth module.

In this device, the Arduino UNO serves as the microcontroller which is the brain of the device responsible for receiving data from required units and sending out information through another unit. All other units were connected to the Arduino UNO board by interfacing which will be discussed below. These components were connected to

the Arduino UNO board by soldering and the aid of jumper cables and glues where necessary. This process of interfacing different components is shown in Figure 7.

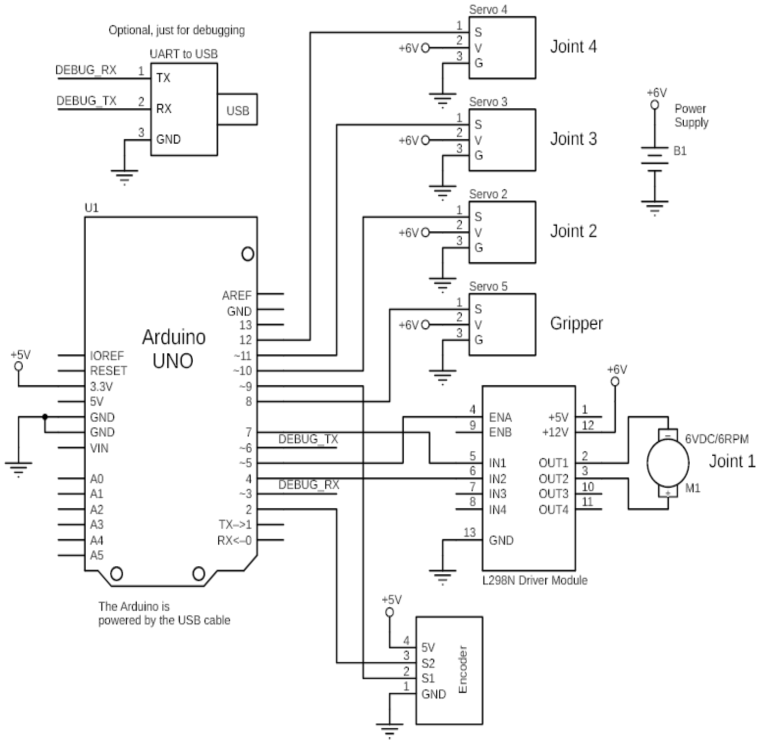

Figure 7: Circuit schematic diagram [25]

[26] Arduino Uno is a microprocessor board based on the AT mega 328(data sheet), [27] has 14 digital input/output pins (of which 6 can be used as PWM output), 6 analogue inputs and 16 MHz ceramic resonator (CSTCE16MOV53-RO), a USB connection, a power jack and ICSP header and a rest button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with an AC-to-DC adapter or battery to get started. An Arduino UNO board is shown in Figure 8.

Figure 8: Adriuno UNO board [28]

The power supply source for this device is a power bank which supplies 4.2 Volts when fully charged. This powers the Arduino UNO board.

MG9OS is a high torque standard servo. These servos have metal geared arrangement in them. Its operating voltage is between 5V to 8 V. It has a stall torque of 9.4 kg/cm at 4.8V and maximum stall torque 11kg/cm is achieved at 6V. Rotation of servo is between 0-180 deg can also be extended to 360 deg. Its total weight of servo is 55g. Figure 9 shows the metallic servo motor.

The packaging was produced using a plastic material called PLA (Polylactic acid) which is a great material to use for 3D printing because it is easy to print and very inexpensive. [29] several factors led to the type of packaging adopted, which includes mechanical damage protection, moisture protection, portability, cost, convenience, etc. The compartment was produced using 3D printing following the steps below:

Figure 9: Metallic servo motor [28]

i. Creating the design (blueprint of the compartment) using inventor professional: Figure 10 shows the various parts of the arm.
ii. Sending the 3D design of the compartment to the printer
iii. collection of the 3D printed compartment.

Figure 10 shows the parts of the robotic arm and Figure 11 the 3D of the robotic arm

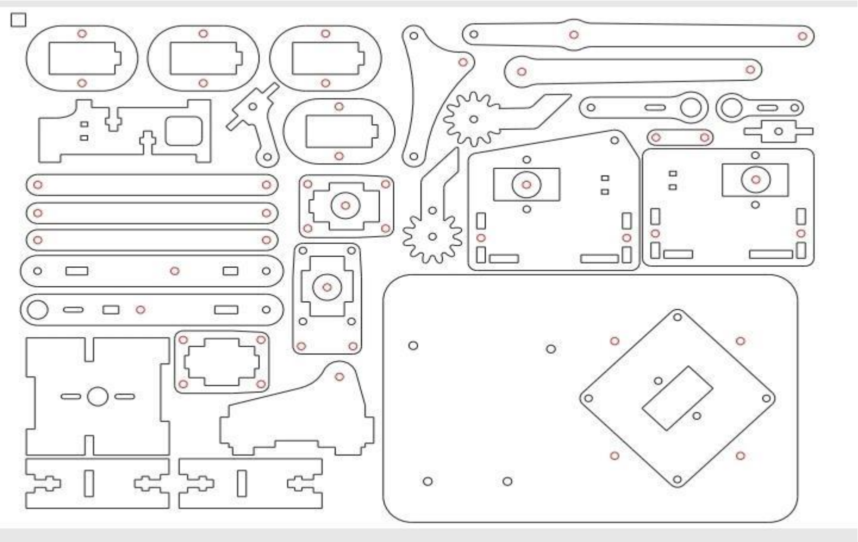

Figure 10: Parts of the robotic arm [28]

Figure 12 shows 3D of the computer model of the robotic arm.

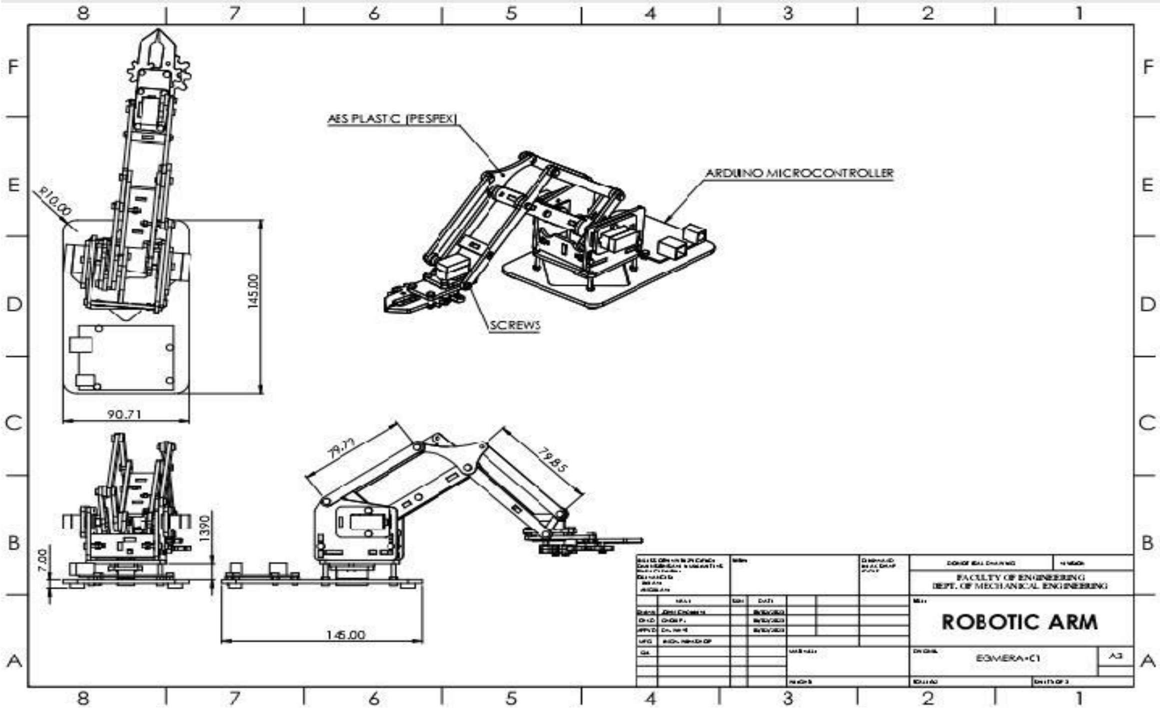

Figure 11: 3D of the robotic arm [28]

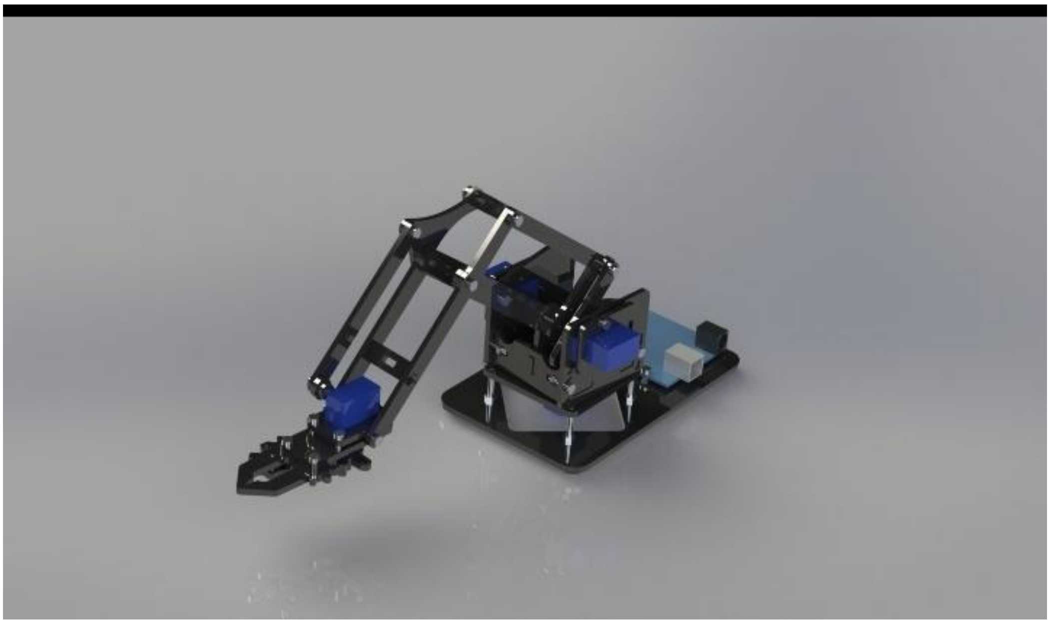

Figure 12: 3D Computer Model of Robotic Arm [28]

2.1 Static Torque Calculation

Static torque calculation is an essential process for selecting the required servo motors. From this we get the required torque and for an individual elbow and column. This calculation was carried out in order to find out the torque required at the elbows and shoulder for a given payload of 150g.The values which we get from this method will help us to choose suitable servo motor for the work. In order to find out the torque the arm must be kept at home position (i.e., Elbow and shoulder angle should be zero with respect to the base link). From basic moment and equilibrium concept we get the following [30] Equations 1, 2 and 3. [4] torque is the tendency of force to rotate an object about an axis. Mathematically, torque is defined as the cross product of the lever-arm distance and force, which tends to produce rotation i.e.

T=F*L Nm

$$T_{shoulder} = F_{load} * (L_1 + L_2 + L_3) + (W_3 * ((L_3/2) + L_1 + L_2)) + (W_{m3} * (L_1 + L_2)) + W_2 * ((L_2/2) + L_1) + (W_{m2} * L_1) + (W_{m1} * (L_1/2))$$

Equation 1

where, F is the force acting on the motor
L is the length of the shaft
Force, F is given by,

$$F = mxg\{N\}$$

Equation 2

where, m is the mass to be lifted by the motor
g is the gravitational constant=9.8 m/s

$$T_{shoulder} = F_{load} * (L_1 + L_2 + L_3) + (W_3 * ((L_3/2) + L_1 + L_2)) + (W_{m3} * (L_1 + L_2)) + W_2 * ((L_2/2) + L_1) + (W_{m2} * L_1) + (W_{m1} * (L_1/2))$$

(10m/s)
Torque at Elbow 01

Equation 3

Torque at Elbow 02

Equation 4

Torque at Shoulder

Equation 5

Solving the Equations in MATLAB the following result were obtained: For elbow one and elbow two the minimum torques required are 0.1779 Nm, 0.4695 Nm and for the shoulder is 0.8502 Nm.

2.2 Static Structural Analysis

Static structural analysis is necessary task to perform in order to find out the sustainability of the designed structure. Calculations have been performed by keeping the robotic arm at home position and load at individual part has been calculated. Software Used: Solid Works Mesh Type

Base Analysis:
Total mass of robot: 509 g
Mass of base: 130 g
[31] Total mass acting on the base in home position: 509 -130 = 379 g
For safety, rounding of the mass to 500g. So, 500g = 0.5 kg
Force = mass (m) x acceleration due to gravity (g) [32] = 0.5 x 10= 5 N
We will apply 5N force on the base to perform static structural analysis.

From the above structural analysis, we can conclude that our design has been sustained for the applied load. The results are shown in Table 1 and Figure 13.

$$T_{elbow1} = F_{load} * L_3 + W_3 * (L_3/2)$$

Table 1: Base Result

S No	Parameters	Values
1	Max von mises Stress (Mpa)	4.28387
2	Factor of Safety	1.6
3	Resultant Displacement (mm)	0.0327760

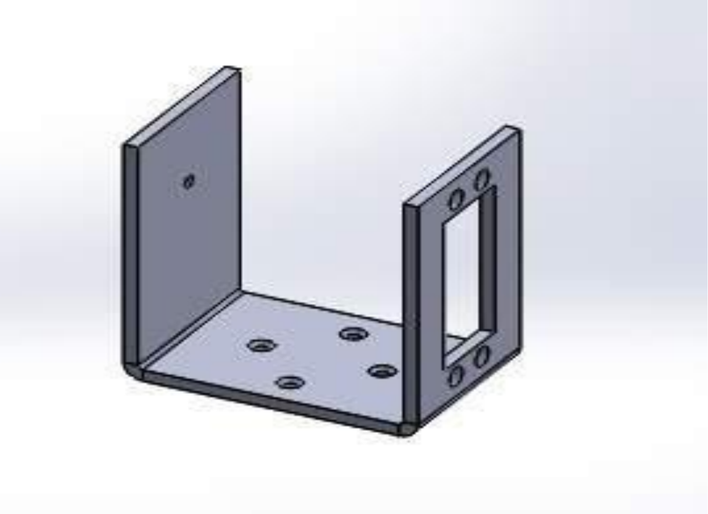

Figure 13: Base of the robot [28]

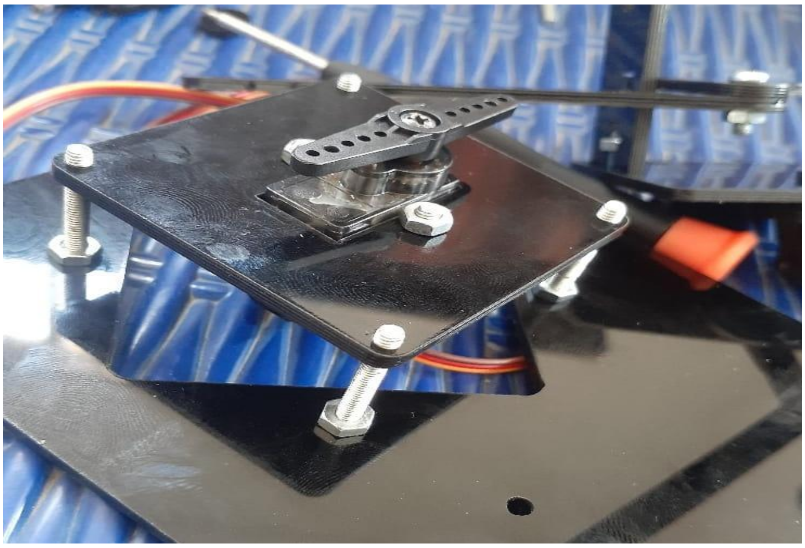

Figure 14: U-Joint Analysis [28]

Total mass of robot: 509 g
Mass of U-Joint: 17 g
Total mass acting on the base in home position: 509 –(130+17) = 362 g
For easy calculation rounding off the mass to 400g.So, 400g = 0.4 kg Force = mass (m) x acceleration due to gravity (g) [32] = 0.4 x 10 = 4 N
4 N was applied on the base to perform static structural analysis. The results are shown in Figure Table 2.

Table 2: U Joint Result

S No	Parameters	Value
1	Max von mises Stress (Mpa)	2.66
2	Factor of Safety	2.6
3	Resultant Displacement (mm)	2.56

Elbow 01 Analysis was carried out:
Total mass of robot: 509 g

Total mass acting on the base in home position: = 199 g ~ 200g Since, Acrylic sheet is a brittle material it would be beneficial to take higher value of force than required in order to find out whether it will sustain or not [31]. That is why we are considering a mass of 500g in place of 200g. So, 500g = 0.5 kg
Force = mass (m) x acceleration due to gravity (g) [32] = 0.5 x 10 = 5 N
5N force was applied on the base to perform static structural analysis.

Gripper analysis was performed:
Gear Used: Spur Gear
Gear Ratio: 1:1
Maximum angle: 160 deg
Total mass of gripper: 49 g
Required maximum working mass for pick and place: 50 g
So, 150g = 0.15 kg

Force = mass (m) x acceleration due to gravity (g) = 0.15 x 10 = 1.5 N Since, the gripper in some cases may have to lift weight more than 50g so in order to check its sustainability. A safety factor of 2 was used i.e. 300 g = 0.3 kgx10 =3N .3 N force was applied on the base to perform static structural analysis.
PID (Proportional–integral–derivative controller) control and filtering was done:

[24] proportional–integral–derivative controller is a control-loop mechanism used in many control systems, such as robotics. It calculates the error and uses it to calculate the output signal made of the tree terms and applies the signal to the actuator as a correction signal to obtain the required output.

Results and Discussion

3.1 Results

In order to validate the robot arm and its component, few tests were carried out which included testing both components and the overall robotic arm system. Figure 15 shows the tests conducted on the robotic arm. By varying the position of the objects which was needed to be lifted by the robotic arm, the servo motor movement range was tested. Different direct impulses to each servo motor were sent by giving a command through smart phone. [33] this process occurred when servo motors interpreted the signal from microcontroller through encoder which resulted in the rotation to the desired position. The initial and final positions were marked to determine the accuracy of the actuator. For overall system performance, maximum load which was able to be lifted by the robotic arm was determined using different weights [34].

The maximum range for the robotic arm is recorded during the experiment and shown in the figure below. The further pick up point of the robotic arm is 20cm, and the maximum angle the robotic arm can reach is 92 degrees, with range from 36 degree to 120 degree

The load to be lifted in this experiment was a sand bag with different weights. The robotic arm was commanded to lift objects and relocate it to a specific position. The experiment was started to examine the accuracy of positioning with a variation in weight of objects which was in the range of 5 grams to 25 grams, the load with 5grams acted as a reference. [35] the precision of the robotic arm to lift different weights was recorded in Table 4. From the data obtained, the robotic arm can lift 25 grams as expected. However, the movement of robotic arm was not smooth when it lifted 25 grams due to lack of strength in the linkage that made up of galvanized wire with 1mm diameter. This problem can be solved by using a high strength linkage of steel.

Figure 15: Testing configuration of complete design [28]

Table 3: Precision in x and y axis.

Weight (grams)	Precision (mm)	
	x-axis	Y-axis
5	0	0
10	3	7
15	0	10
20	12	17
25	30	32

A complete lifting cycle can be done at 15.55 seconds and there is an insignificant difference of time taken for various weights.

Table 4; Duration of lifting process

Weight (grams)	Duration (seconds)
5	13.45
10	13.50
15	13.60
20	13.65
25	13.70

3.0

The furthest pickup point was only 20cm because the inconsistency length and none rigidity of it. This caused some stretches or expansion on the galvanized wire linkage. As for its rotation angle, it can rotate up to 92 degrees; with range from 360 degree to 120 degree this rotation is expected as the rotation linkage is unstable due to the elevation of the servo motor.

4.0 Conclusion

This research successfully presented a prototype robotic arm for application in pick and place operations for light material. The robotic arm was able to operate with four degrees of freedom .3D-printing technology deployed in production saved cost and production time. The servo motor movement range of the robotic arm was restricted within 180 degrees. The maximum experimental load carried was 25 grammes at 13.70 seconds and with 5 grammes a time of 13.45 seconds was obtained.

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