ICMIEE20-259

Design and Construction of an Articulated Pick and Place Manipulator

Md. Istiaque Zahur[*]*, Pronob Deb Nath, Md. Helal-An-Nahiyan, Md.Kutub Uddin*
Department of Mechanical Engineering, Khulna University of Engineering & Technology, Khulna-9203, BANGLADESH

ABSTRACT
This paper presents the development of a pick and place articulated robot manipulator prototype. In some cases, human is liable to make error under stress or repetitive work; whereas the robot manipulator can provide precise and efficient performance if there is not much decision-making issue appears. This manipulator is designed and constructed to sort object based on their length. The design of the manipulator is done considering the stress on each link. The control system is embedded with microcontroller and manipulator mechanics. The microcontroller is used to render the activity when the sensor detects any presence of object in the work envelope of the manipulator. MATLAB had been used to simulate the work envelope of the manipulator and the trajectories it follows. The horizontal reach of the manipulator is 84 mm from the base up to which it can pick the object and place it. The manipulator can pick the sensed object through sensor and by following the joint angles, it places the object in the destination. It can place objects up to 15 cm length in one side and larger size in another side. The developed prototype of the manipulator can handle a little amount of weight (15g) but proper scaling to higher dimension may increase its lifting capacity.

Keywords: Manipulator, Kinematics, Microcontroller, MATLAB

1. Introduction

Industrial automation with robotic technology has ushered new scope and sector for human beings. Robot manipulator is a chain that connect several links by joints to produce rotational or translational swerving. The industrial revolution showed us the necessity of increased quality product and reduced the manufacturing cost and time. The inflexibility and relatively high cost compelled the industry to approach towards robotic technology. Robot controllers have been presented by assembling ventures for playing out certain assignments, for example, material taking care of, spot welding, splash painting and gathering [1]. Manual production is comparatively slow, and it is only economical when the volume of production is less. Whereas the production increases rapidly and the production process become more complex. Moreover, the required material handling rate is high, and precision of placement is extremely necessary. Therefore, optimum solution is the use of robotic system that can be developed and controlled easily and set up within the system to do the work without any obsolescence. Mechanical robots are utilized to do repetitive tasks as well as those that require accuracy and speed regulation. This has made it conceivable and improved the effectiveness of their assembling.

The word robot entered in English jargon as right on time in1923, however, the real improvement of robot controller did not happen until after 1940s. The rise of mechanical robots was expected at first to deal with dangerous materials and in space exploitation and later to accomplish industrial automation. Due to rapid development of this robotic arm and manipulator sector, different kinds of study work related to design, control, operations and others sectors have been carried out with the evolution of technology and process. Enaiyat Ghani Ovy et al works with a microcontroller-based controller circuit for the motion of an articulated robot with 3 DOF forming an anthropomorphic structure [2]. Dynamics and control of a planer 3 DOF parallel manipulator with actuation redundancy studied by Jun Wu et al [3]. Kinematics and singularity analysis of a novel type of 3-CRR 3-DOF translational and parallel manipulator studied by Xianwen Kong and Clement M. Gosselin [4]. A decoupled 3 DOF parallel module head orientation and kinematic optimization studied by Fugui Xie et al [5]. Gregorio presented a new architecture of a 3 DOF parallel manipulator with pure translational motions [6]. A new 3 DOF translational parallel manipulator kinematic analysis and design studied by Yangmin Li and Qingsong Xu [7]. Conditioning and stiffness indices for optimum design of a 3 DOF spherical parallel manipulator operational performance studied by Xin-Jun Liu et al [8]. David Corbel et al analyzed about actuation redundancy to improve the acceleration capabilities of 3T and 3T1R pick-and-place parallel manipulators [9]. Position control method for pick and place robot arm for object sorting system studied by Khin Moe Myint et al [10]. Varinder Singh and Sukhdeep S. Dhami analyzed robot position optimization for a pick and place operation with automated dynamic analysis of mechanical system [11]. War War Naing et al design and analyzed position control of 3 DOF articulated robot arm using PID controller [12].

Nowadays, robot manipulator is a matter of great interest. But the fact is that the underdeveloped or developing countries are still far behind the race as the technology here is so limited. There are likewise numerous manipulators but among their designs, a few have unique kinematics attributes. The main purpose is to build up a miniature of pick and place manipulator prototype that can be implemented in recycling plastics plant. As plastic is lightweight the prototype can be really handy in such industries. The technique used in sorting plastics for recycling is basically gathering of all sorts of

* Corresponding author. Tel.: +8801789204053
E-mail addresses: [1]*istiaquezahur1@gmail.com

plastics and then dumping in a vessel containing holes. So the smaller plastics go through the holes and the larger one stays in the vessel. But this process can't ensure quality sorting of plastics. So if manipulator is introduced in the distribution line it can sort out the plastics easily by size.

2. Working principle

There are variety of robot manipulators in action today but the design considerations for each manipulator varies based on their operating conditions. The main objective of this project is to pick and place object and sort the objects according to their size. There are two criteria for sorting objects for the manipulator. The main focus is given on the fact that whether it is greater than 15 mm or not. If both the sensor sense that the distance or length greater than 15 mm then the object considered as large and placed right side of the manipulator. Otherwise it is small object and placed at left of the manipulator.

The movement of the gripper originates from the series transformation of previous joints. The gripper is controlled by a servo connected to pin 7. The jaw of the gripper stay at 75^0 apart at initial as one jaw is directly attached to servo's shaft along with a gear which is in mesh with another gear that moves the other jaw. So whenever one jaw moves the other moves in make the grip and there a rubber lining in the gripper that comforts the holding of object. As shown by Fig.1, the detection of objects and movement are followed by the whole manipulator system. The whole action part follows the figure for completing the command bestowed to the manipulator.

3. Design and Development

Design and development of the robot manipulator is accomplished in several steps as explained in the following part.

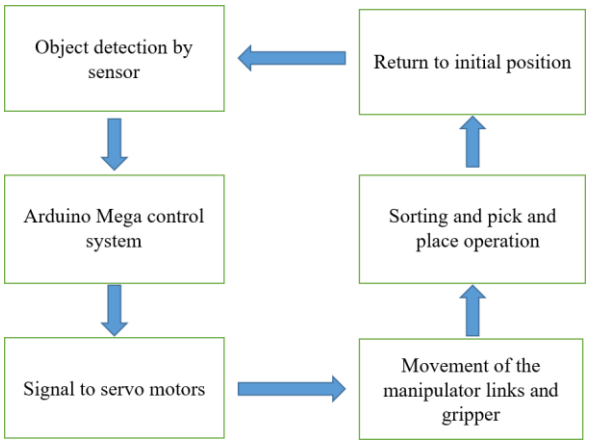

Fig. 1: Control scheme

3.1CAD Model

The articulated manipulator cad model is designed in SOLIDWORKS 2018 software with proper scaling as shown by Fig.2. Each of the parts components design individually with shrinkage factor and save as that can be printed in 3D printer.

. The designed manipulator replicates usual arm movement of human being only with 3 degree of freedom The total weight of the manipulator is 481 gm. The base is about 30mm high from the ground and the shoulder is about 81mm from the base. This developed manipulator gets about 84 mm working space from the base to pick and place object with its elbow. If only three links are attached in serial combination, then the manipulator can become a pure cantilever beam. So I have attached parallel links to carry the same weight. So the payload is actually divided into two segments.

3.2Construction

The manipulator structure is built with the following components: (a) One Base, (b) Two links and (c) A gripper. All the components are 3D printed in Creality mini 3D printer maintaining the kinematics and balance of load. As shown by Fig.3, the base of the manipulator is set up on a frame with a height from the ground to assist the manipulator to move easily. The Arduino mega alongside motor driver and resistor are set up just beneath the base on a different layer.

The sonar sensors notify the microcontroller about the existence of nearby object and then the microcontroller give command to the base servo motor to

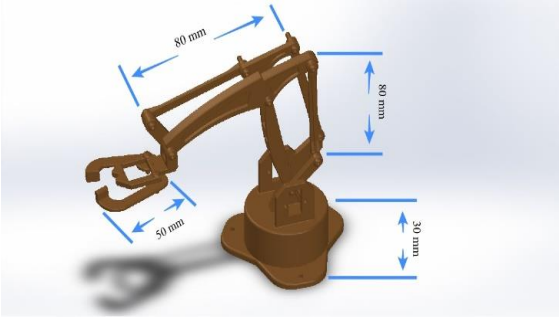

Fig. 2: Isometric view of the manipulator

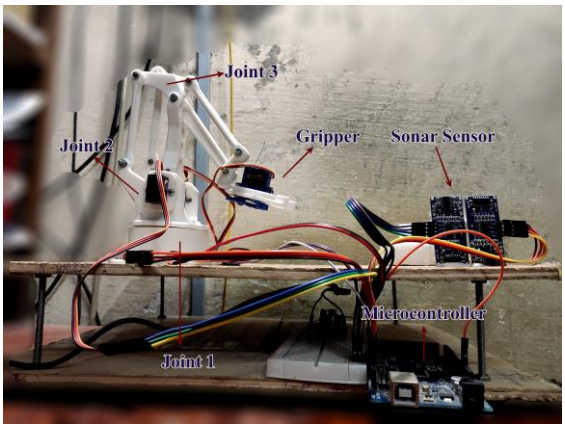

Fig. 3: Robot manipulator prototype

* Corresponding author. Tel.: +8801789204053
E-mail addresses: [1]*istiaquezahur1@gmail.com

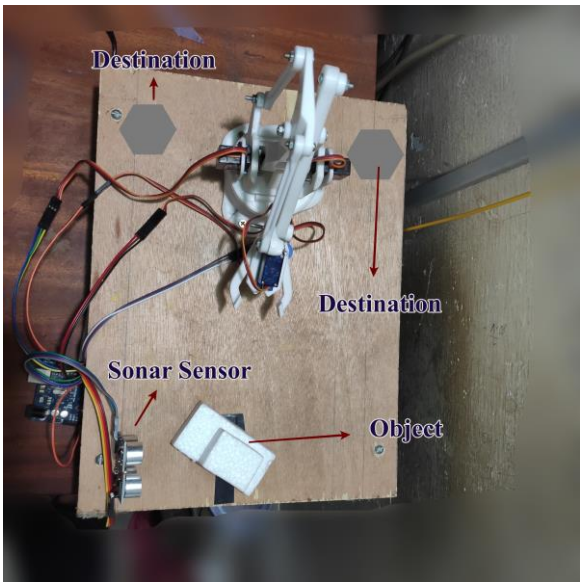

Fig. 4: Orientation of initial and final position

Table 1 Technical Specification of components.

Name	Specification
Manipulator motor	2.20 kg-cm
Gripper motor	1.3 kg-cm
Microcontroller	Arduino Mega 2560
Power System	AC 9volt, 2 Amp adapter
Sensor	HC-SR04

move around as needed. As shown by the Fig.4, the manipulator moves from its initial position to destination. The manipulator moves 90^0 ahead to grip the object and while it catches the object, it will move about 0^0-90^0 or the whole base can move about 180^0 to place the object in the specific destination. Servo motors are associated with the pin number 4, 5, 6, 7 in the Arduino mega board and the sensor 1 is appended to pin 12, 13 while sensor 2 is connected to pin 8, 9. Four servo motors work for joint movement and the movement is specified by objects position.

4. System features

The whole system is divided into two units: mechanical unit and electrical unit. The electrical unit is the main part that produce signals for the mechanical part and the mechanical part moves according to the control signal. The technical specification of different components is presented in Table 1 and Table 2. Electrical unit consists of the following components describe below.

4.1 Arduino mega r3 2560

The Arduino Mega r3 2560 is a microcontroller used for different purpose. This Arduino board is based on the ATmega2560 as shown by Fig. 5. It includes 54 pins digital input or output with 16 pins analog inputs and 14 pins used for PWM output. It also has 4 Universal Asynchronous Receivers Transmitters (UARTs) hardware serial ports, a USB connector, a power jack, a 16 MHz crystal oscillator, an In-Circuit Serial port (ICSP) header and a reset button. In this work, about 8 pins are used for controlling the manipulator with common power and ground pins for all experiments.

Table 2 Servo Motor movement capability.

Joint	Angle Range (degree)	Allowable speed (degree/sec)
Base	0-180	1.80
Shoulder	90-120	1.80
Elbow	90-160	1.80

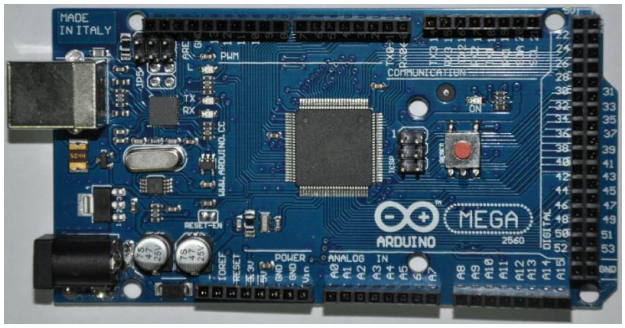

Fig. 5: Arduino mega r3 2560 [13]

Fig. 6: Servo motors [14]

Fig. 7: Sonar sensor [15]

4.2 Servo motor (MG90s and SG90s)

RC servo work by torque multiplication. There is combination of small drive gear and large driven gear so that it can produce high torque. Several numbers of such combination confirms it's proper working. MG90s is used as an actuator in this manipulator base and others joints as it is small and lightweight with high output power. SG90s servo is used for gripper as it is lightweight and don't effect much on overall load.

4.3 Sonar sensor

The sonar sensor 1 is attached to pin 12,13 and sonar sensor 2 is attached to pin 8,9. All of thses are digital pins. There are two action occur during sonar detection.

* Corresponding author. Tel.: +8801789204053
E-mail addresses: [1]*istiaquezahur1@gmail.com

One is when the object is placed before the sensor the sensor triggered by the pulse send by the arduino and the echo system calculate the distance or length & then the servo system actuates to sort objects.

To fasten the connection between links and joints, nuts and bolts are used properly. The system is powered by using the 9V, 2A AC adapter. For connecting with different electronics components, jumper wires are used. For completion of the circuit 220 Ω resistors are also used.

5. Workspace simulation

Characterizing the workspace is obviously significant for more than one explanation; pertaining to but not limited to design, enhancement, wellbeing, and designing of a kinematic structure layout [16]. When the sonar finds anything, then it will confer a signal to the Micro controller. At that point, the yield sign stops the pivoting and turn over working to get the part. If there should be an occurrence of holding an item, the processor furnished with Arduino mega R3 that gives voltage signal from double coded data.

As this is a three-dimensional co-ordinate framework, this can be shown in MATLAB with following graphical portrayal. As shown by Fig.8, the manipulator moves in the downward direction while moving to catch the object from the specific position. The second projection was carried out for joint angle that varied from 30^0-90^0-160^0. Here, the manipulator moves in the horizontal direction while it holds the object in its grasp. The gripper action is very important for this step because holding and lifting the object mostly depend on the gripper capacity.

During this action, the elbow of the manipulator is completely stretched. The manipulator consists of revolute joints. In Fig.9, around the three-dimensional space, the elbow, shoulder, and base movement makes it possible for the manipulator to reach and place in the required position. The simulation results show the links and joints instead of the whole body, so it makes easy to easy to see the joint rotation or movement during specific actions.

This visualization is done based on second joint angle as to observe the change of angles while the manipulator stretched in its work envelope to perform specific task. The last one carried out for the third joint to inspect its angular efficiency and deviation during expansion of the manipulator links. As shown by Fig.10 the manipulator gripper moves to the destination point where it places the object to fulfill the objective. The simulation results show how the manipulator gripper holds the object while the moving to the final position. The tension in the gripper arm makes able it to hold the object while moving.

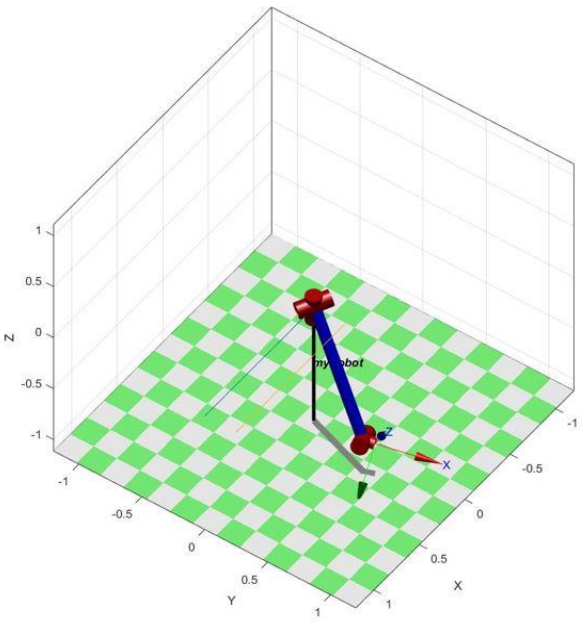

Fig. 9: Workspace simulation for 30^0-90^0-160^0

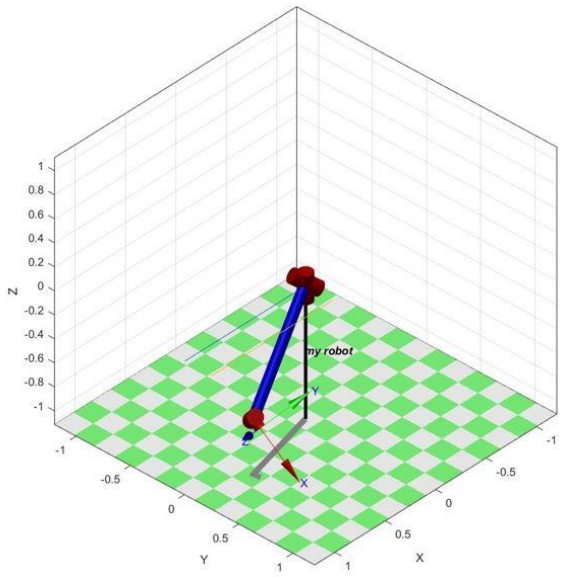

Fig. 8: Workspace simulation for 0^0-90^0-180^0

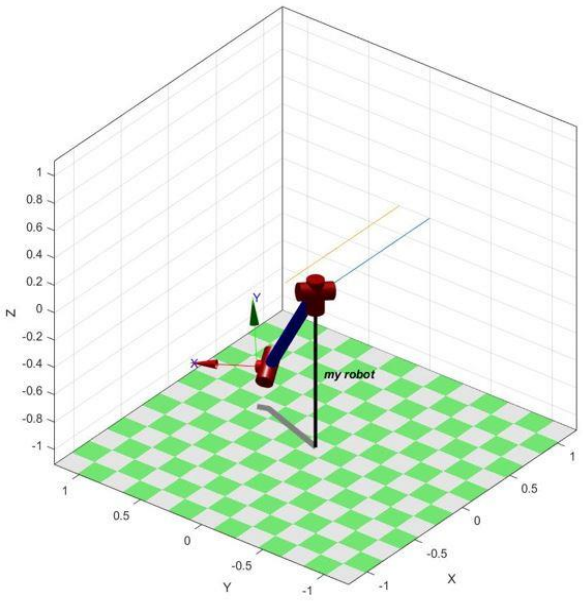

Fig. 10: Workspace simulation for 30^0-90^0-120^0

* Corresponding author. Tel.: +8801789204053
E-mail addresses: [1]*istiaquezahur1@gmail.com

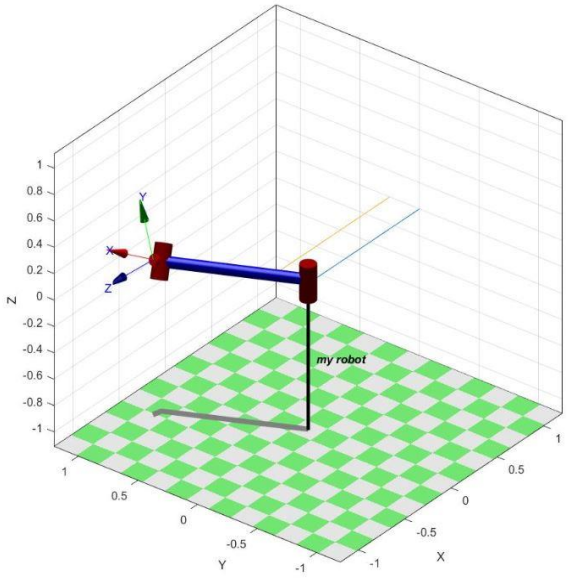

Fig. 11: Workspace simulation for 0^0-90^0-120^0

As shown by Fig.11 that represents the movement from the final to initial position for the next command to carry out. Then the manipulator become ready for the next command to follow.

6. Results

The fabrication process of an articulated manipulator has discussed earlier in this study. During the preparing and design verification process, all the parts developed correctly and mate properly with each other. Dimensions, weight of system components monitor during development process as it cannot exceed maximum allowable dimensions or weight. The electrical and mechanical connection are integrated perfectly. Different operating working conditions with effects results are describe in the following part.

6.1 Repeatability

The effectiveness of this manipulator changes while doing repeatability test by doing the same job for several times. The end effector attempts to do the full task pick and place object to the desired position as close as possible within the time. The time required to determine each test are showed in Table 3.

6.2 Angular accuracy

Due to friction, payload of joints, effect of gravity, and inertia, the manipulator cannot be able to move to the desired position with defined trajectory. With the help of manipulator link length, the most effective accuracy can be obtained. After lots of similar trial, the maximum deviation is found as less than 7%.

6.3 Weightlifting test

As it is a loading and unloading type manipulator it has certain lifting ability. Though, it is developed as a prototype to visualize the actual model, its lifting ability

Table 3 Repeatability tests of manipulator.

Test no.	Object type	Time required
01	Small	10.75
02	Large	11.25
03	Small	10.82
04	Large	11.74
05	Small	10.91
06	Large	12.21

Table 4 Angular accuracy tests of manipulator.

Angle type	Determined angle	Actual angle	Deviation (%)
Θ_1	90	84	6.67
Θ_2	30	24	6.67
Θ_3	70	68	2.86

Table 5: Lifting tests of manipulator

Test no	Weight	Remarks
01	5	Success
02	10	Success
03	15	Success
04	20	Failed

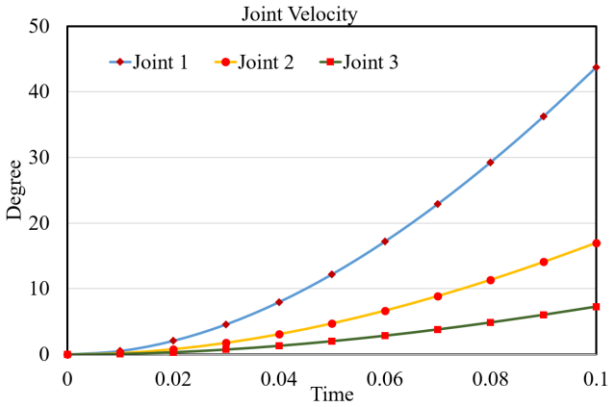

Fig. 12: Joint velocity of the manipulator

is restricted to lower limit.

The repeatability tests show when loading occurs for several times the links and the servo are caught by fatigue. Therefore, their working ability reduces as the time for placing the objects in destination increases. During simulation the torque and velocity are visualized for varying load but the total torque in each joint must be equal or less than the actuator torque. We need different position for every joint angle. Also for further calculation by MATLAB we need to input every joint mass, moment of inertia, joint angle with its first and second derivative, jacobian and others parameters for calculation of velocity and torque.

As shown by Fig.12, the joints of the manipulator carry different load. Therefore, when the manipulator moves the velocity changes and according to the Fig.12 the velocity change forms curve during movement. During the lifting test the prototype showed lifting capacity to a certain limit. It actually simulates the actual model. Besides the

* Corresponding author. Tel.: +8801789204053
E-mail addresses: [1]*istiaquezahur1@gmail.com

workspace simulation shows how far it can reach in it's workenvelope. From joint to joint, there is a clear variety of load and base carry the maximum load as it holds the complete framework. During operation load property varies from link to link and moment changes from joint to joint. As shown by Fig.13 the generated torque changes in each joints. Friction plays vital role here.

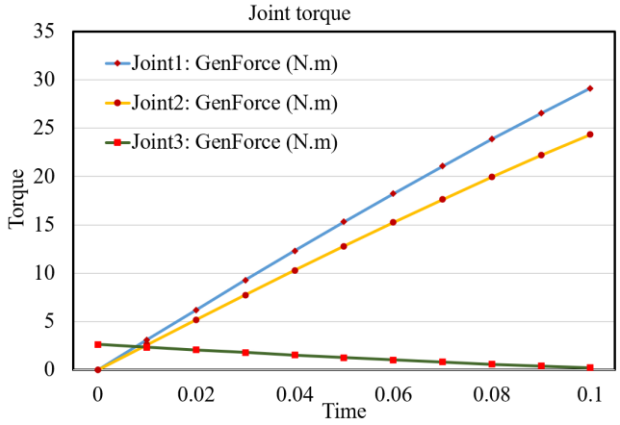

Fig. 13: Joint torque of the manipulator

The occurrence of jerk shows the instant friction between the moving parts. However, the manipulator succeeded in picking and placing the object in the defined destination.

7. Conclusion

A pick and place articulated manipulator had been developed with a view to loading & unloading, sorting objects. The whole frame had been develoed by ABS material which was done in creality 3D mini printer. The servo motor used in the movement made it easy to control but these motor had low range of span like 0^0 to 180^0. So considering future development stepper motor could be used to increase its effectivity. The manipulator had been developed with 3 degree of freedom as such constructions consisted of the basic movement in 3D dimension . The gripper was also designed along with the whole body to ensure sure mesh. The gripper hold and place objects by the interaction of two gears. The whole control scheme had been built in such a way that any individual could easily understand the steps taken by the motors. Hence its made it more conveniet to implement in the industrial automation process. In future, Image processing could be implemented to make the prototye more unique in sorting objects.

8. Referrances

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* Corresponding author. Tel.: +8801789204053
E-mail addresses: [1]*istiaquezahur1@gmail.com