Design and Development of a Mechanism of Robotic Arm for Lifting Part1

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ABSTRACT

The main focus of this project was to design and develop the mechanism for robotic arm for lifting. The robotic arm was designed with four degrees of freedom and programmed to accomplish accurately simple light material lifting task to assist in the production line in any industry. 3D printing method is used in this project to fabricate the components of the robotic arm. Therefore, it provided more precise dimensions and huge time and cost-saving in fabrication. The robotic arm is equipped with 4 servo motors to link the parts and bring arm movement. Arduino, an open-source computer hardware and software is applied to control the robotic arm by driving servo motors to be capable to modify the position. Wireless control was done by using a smart phone with android operating system through a Bluetooth module. The robotic arm was under testing and validating its performance and the results indicates that it can perform the lifting task properly.

Keywords: *Robotic Arm, Arduino,Lifting Mechanismes, Design, Validation, Four Degree of Freedom, Servo Motors, Robot Control.*

INTRODUCTION

Robotic is defined as the study, design and use of robotic systems for manufacturing[1]. With the rise in manufacturing industrial activities, a robotic arm is invented to help various industries to perform a task or work instead of using manpower. Robots are generally used to perform unsafe, hazardous[2], highly repetitive, and unpleasant tasks. Robot can perform material handling, assembly, arc welding, resistance welding, machine tool load and unload function, painting and spraying, etc[3, 4]. It is very useful because it possesses high precision, intelligence and endless energy levels in doing work compared to human being. For an example, a robotic arm is widely used in the assembling or packing line by lifting the small objects with repetitive motion that human couldn't bear to do in a long period of time[5]. The light material lifting task can be done by the robotic arm efficiently and time-saving because it is not restricted by fatigue or health risks which man might experience.

There are mainly two different types of robots which are service robot and an industrial robotic. Service robot is operated semi or fully autonomously to perform service useful to the well-being of humans and equipments except manufacturing operation[6-8]. On the other hand, industrial robot is officially defined by ISO as an automatically controlled and multipurpose manipulator programmable in three or more axis[1].

An industrial robot is a re-programmable multifunctional manipulator design to move material, parts, tools, or specialized devices through variable programmed motion for performance of a variety of tasks. This is the definition from the Robot Institute of America to reflect main features of modern robot systems. An industrial robot system can includes any devices or sensors together with the industrial robots to perform its tasks as well as sequencing or monitoring communication interfaces[3, 9].

In 1970, Stanford University developed a computer-controlled robot arm with electric drive motors, known as *Stanford Arm*. In 1973, the first industrial robot equipped with a minicomputer-based control system was developed in Cincinnati Milacron Corporation. In 1977, a European company, ASEA, also developed electrical powered industrial robots equipped with the microcomputer-based control systems. In the same year, a robot vision system was developed by Stanford Research Institute (SRI) at Stanford University. In 1978, the Puma (programmable universal machine for assembly) robot was developed based on the Stanford arm in America. This robot uses servomotors equipped with an advanced control system using a few microprocessors and advance software. In 1079, Sankyo and IBM developed the famous SCARA (selective compliant articulated robot arm) at Yamanashi University in Japan[10].
In 2007 the world market grew by 3% with approximately 114,000 new installed industrial robots. At the end of 2007, there were around one million industrial robots in use, comapared with an estimated 50,000 service robots for industrial use[11].

Apart from industrial usage, the robotic arms also designed to imitate human movement with high precision. A design of robotic arm which can dance, weight lifting, Chinese calligraphy writing and color classification is done by a group of Korea students[12]. There is also an eight degree of freedom robotic arm designed by a group of USA engineers. It is able to grasp many objects with a lot of shapes form a pen to a ball and stimulating also the hand of human being[13]. Furthermore, robotic arm with multiple degree of freedom have been used to perform variety of tasks in space application. The system is known as Space Shuttle Remote Manipulator System (SSRMS) or Canadarm. Robotic arm's tasks in the space included inspections of space shuttle using a specially deployed boom with cameras and sensors attached at the end effecter and satellite deployment and retrieval manoeuvres from the cargo bay of the space shuttle[14-16].

This present work is carried out at Universiti Malaysia Pahang, Malaysia, the main focus is to design, develop of a mechanism of robotic arm for lifting purpose with stumpy cost, accurate and superior control. Robotic arm with four degrees of freedom was able to perform simple tasks especially light material handling for industrial application.

DESIGN WORK

I. Robotic Arm

The mechanical design of the robot arm is based on a robot manipulator with similar functions to a human arm[14, 17-19]. Robotic arm system often consists of links, joints, actuators, sensors and controllers. The links are connected by joints to form an open kinematic chain. One end of the chain is attached to the robot base, and another end is equipped with *a tool* (*hand, gripper, or end-effectors*) which is analogous to human hand in order to perform assembly and other tasks and to interact with the environment[10, 20]. There are two types of joint which are prismatic and rotary joints and it connect neighbouring link.

Figure 1 shows two types of joint in robot.

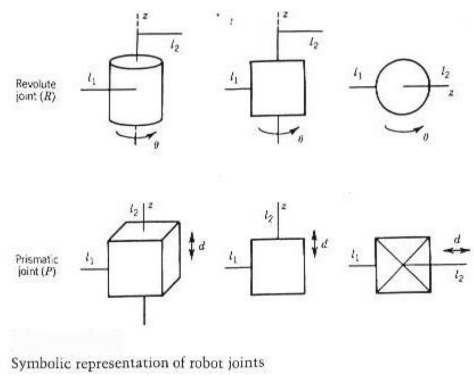

Figure 1. Symbol of revolute (rotary) and prismatic joints.

Source: http://www.tareksobh.org/

The links of the manipulator are connected by joints allowing rotational motion and the links of the manipulator is considered to form a kinematic chain[3]. **Figure 2** shows the Free Body Diagram for mechanical design of the robotic arm. A robotic arm with only four degrees of freedom is designed because it is adequate for most of the necessary movement. At the same time, it is competitive by its complexity and cost-saving as number of actuators in the robotic arm increases with degrees of freedom. In a robotic system, the number of degrees of freedom is determined by the number of independent joint variable[21].

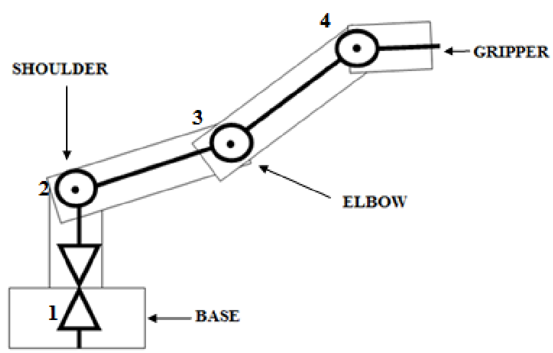

Figure 2. Free body diagram of the robotic arm.

The robotic arm has four servo motors, each motor for one DOF and the motors operate with 6 volts. There are four rotating DOF in the arm and their ranges of rotation are indicated in the **Table 1**.

Table 1.Number of degrees for specific DOF.

Degrees of Freedom(DOF)	Degrees
1	180
2	90
3	90
4	90

The area that the gripper so called as end-effecter can reach is known as robot workspace. It depends on the DOF and translation limitation, the arm link lengths, the angle at which something must be picked up at and robot configuration. Figure 2 shows the typical work region of the robotic arm with four degree of freedom (4 DOF)[3].

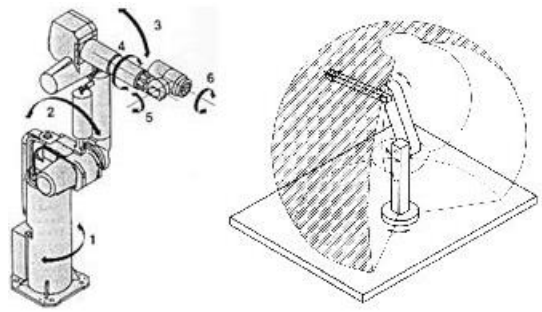

Figure 3. Work Region of the robotic arm[3].

A sketch for robotic arm is done after considering certain angles and degrees of freedom.

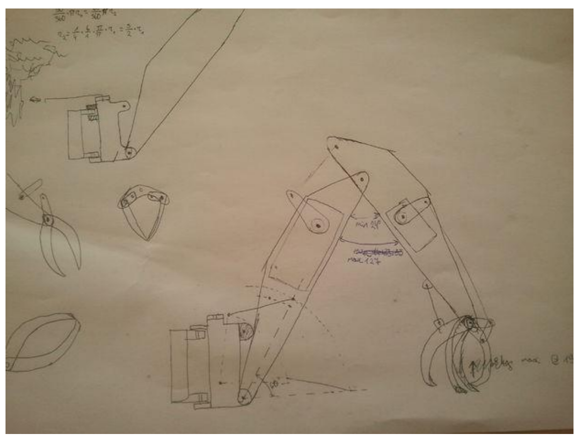

Figure 4.Sketching of robotic arm.

By using Autocad software, the finalized design is as follow.

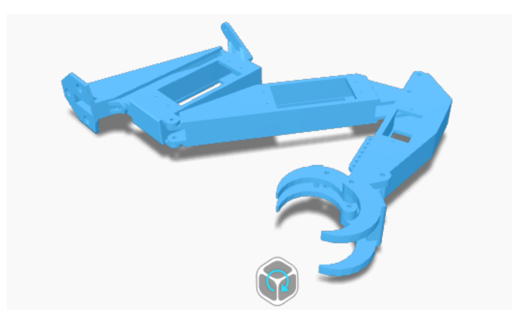

Figure 5.Autocad assembly of parts.

This is a support for the robotic arm and will be fixed at base. The design is slightly wider at the base and slanted at 20 ^{o} degree to the top. The rib design is added to the part to increase stiffness due to load applied to the part design. It changed the geometry of the part and it is practical and economical to increase the structural strength of a part. Moreover, this part has a tetragonal shape to distribute the load evenly as it is required to support large load applied by the object to be lifted, servo motor and link. This limb is designed for rotational purpose and also the motor for up-down motion of the robotic arm. The overhanging part is where the wires will be connected and then actuated by the servo motor at the base. Motor housing is nicely fit into the hollow part of the limb. This is also the linkage to the next part for up-down motion. The following limb shown below is designed with maximum extending shape as well as the area for motor to be fit in. The lower part is connected to the previous limb using a connecting wire. This part consists of the vital part of the robotic arm as it houses the motor for gripper. The gripper will be connected to this limb and controlled by the motor through the connecting wire. The gripper consists of lower and upper claw. It is designed that the lower claw is fixed at a certain angle on the previous limb and the moving upper claw to the motor. The shape of the claw is croissant and it can maximize the gripping performance. According to Kadirgama K and Noor.M.M, during a metal fabrication in end milling process, a roughness is usually undesirable because mechanical component with a rough surface can wear quickly and have higher friction than a smooth surface as the surface's irregularities can form nucleation sites for crack and corrosion [22].

II. Actuators

Actuators are devices that cause rotary joints to rotate about their motion axes, or drive prismatic joints to slide along their motion axes. Generally, there are three types of fundamental actuating systems used in robot systems: hydraulic actuating systems, pneumatic actuating systems, and electrical actuating systems[23]. In our design, we are using electrical actuating systems. DC motors and stepper motors are used to actuate the movement of the robotic arm. This is because this system can be controlled easily and the servo motor is able to give a fast response, high accuracy, included encoders which automatically provide feedback to the motors and adjustability of position accordingly[3, 7].]. This type of actuator is suitable for small robots[24]. However, the disadvantages of the servo motor is that rotation range is less than 180^{o} span, thus the region reached by the arm and possible positions are greatly decrease[7, 25]. As we have 3 joints in the robotic arm, we need to set up 3 controllers to control all joint actuators.

Selecting suitable motor for the application is crucial in the design stage which decision is made based on torque and the speed of the motor. Force calculation of joint ensures that the motor chosen can support the weight of the robotic arm and also the load which need to be carried[20]. Servo motors is recommended when high torque and precise speed desired by the user. For only positioning without requiring a high torque, stepper motors are used in the application[2].

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[26]

Where, F=force acting on the motor

L=length of the shaft

Force, F is given by,

F=m*g N[5]

Where, m=mass to be lifted by the motor

g=gravitational constant=9.8 m/s

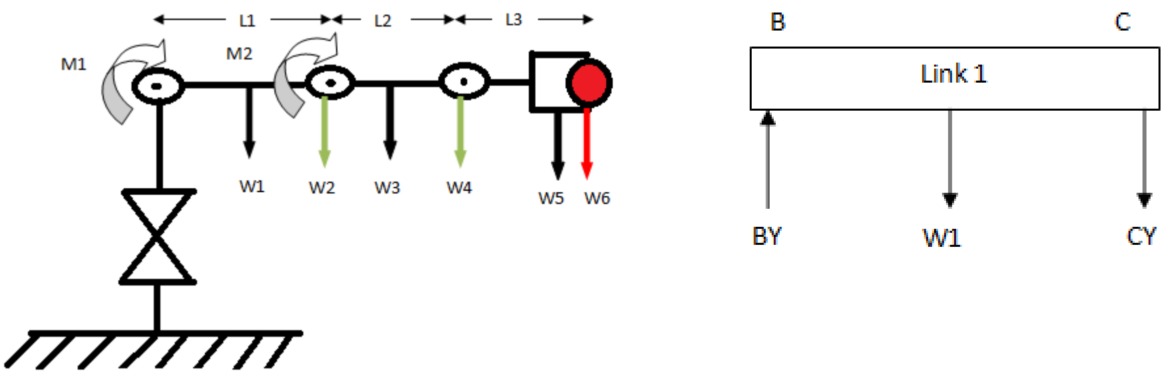

Figure 6. View of loads/moments on joints (right) and force diagram of link 1(left).

The values used for the torque calculations:

W1=0.019 kg (weight of link 1)

W2= W4=0.050 kg (weight of motor)

W3= 0.020 kg (weight of link 2)

W5= 0.027 kg (weight of gripper)

W6= 250g (weight of load)

L1= 0.07m (length of link 1)

L2= 0.12m (length of link 2)

L3= 0.145m (length of link 3)

Taking the sum of forces in the Y-axis,

$\sum Fy = (W6+W5+W4+W3+W2)\,g - CY=0$
(1)

CY= 11.24 N
(2)

$\sum$Fy = (W6+W5+W4+W3+W2+W1) g−BY=0
(3)

BY= 11.43 N
(4)

$\sum Mc = -\left(\frac{W3L2}{2}\right) - W5\left(L2 + \frac{L3}{2}\right) - W6\ (L2+L3) - W4\ (L2) + Mc = 0$
(5)

$\sum Mb = -W6\ (L1+L2+L3) - W5(L1+L2+\frac{L3}{2}) - W4(L1+L2) - W3(L1+\frac{L2}{2}) - W2(L1) - W1(\frac{L1}{2}) + Mb = 0$
(6)

Mc= 0.929 Nm=79.40 oz/in
(7)

Mb=1.792Nm=134.67 oz/in
(8)

Based on the moment calculated, a suitable servo motor was selected, is, which has a torque of 152.8 oz-in to comply with the torque requirement of the robotic arm. They can turn 60 degrees in 15millionsecond and weight of 55.0 grams each. For the gripper, a micro servo with 9 grams and 0.12sec/60 degrees is used because not much torque needed to operate the gripping process due to the light weight of gripper. In the robotic arm, 4 servo motors are used.

Motors served different purposes at each part of the robotic arm:

- Motor 1 for rotational motion.
- Motor 2 for elbow movement.
- Motor 3 for wrist movement.
- Motor 4 for gripping motion.

III. Electrical Circuit

The electrical circuit was design to be neat and efficient based on the output given out by Arduino Uno. The below items are the total of outputs used in Arduino Uno and connected by wrapping wires on the donut board.

1. 2 Ground pin (left and right side of the board)
2. Power supply of 3.33V for powering Bluetooth module
3. Digital output 0 to for Receiving signal from Bluetooth module
4. Digital output 1 to for Transmitting signal to Bluetooth module
5. Digital output 4 to for Gripper servo
6. Digital output 5 to for Elbow servo

7. Digital output 6 to for Shoulder servo
8. Digital output 7 to for Base(rotation) servo
9. Power Supply for Arduino Uno
10. Power Supply for servo

The circuit presented below is the sketching diagram on the breadboard using the software ‘Fritzing’. It allows the user to understand the flow of the circuit and ensue the pins are connected to the correct pin and ground to the same area.

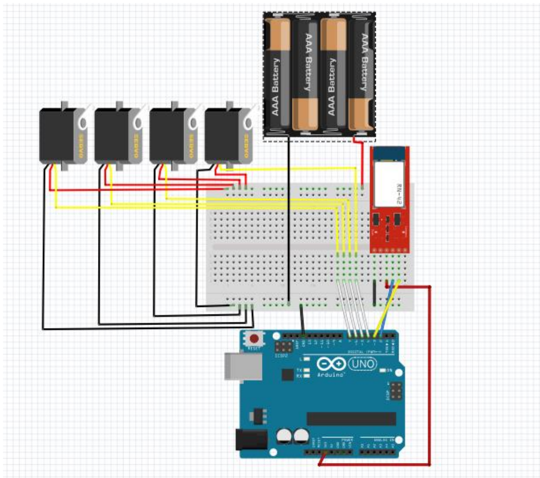

Figure 7. Electrical circuit diagram for a better understanding on the connections of the circuit.

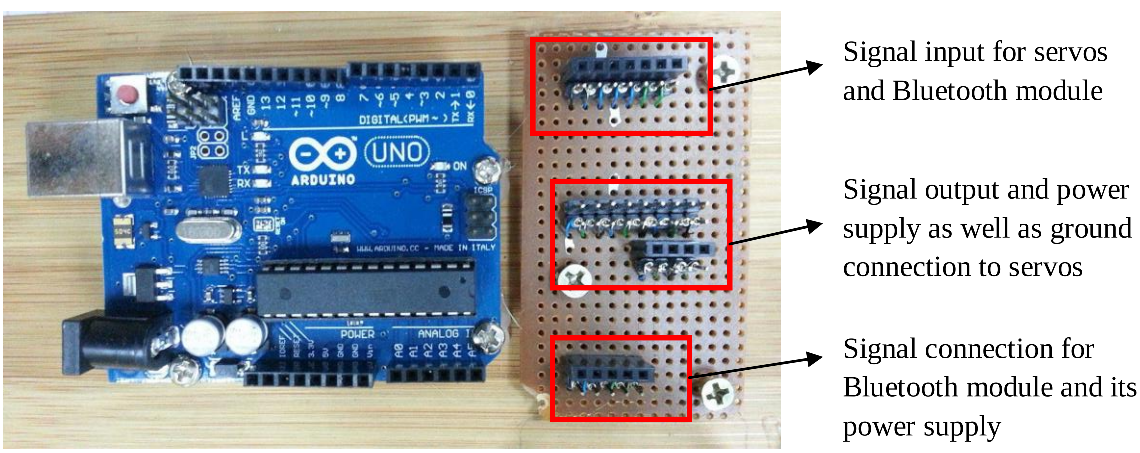

Figure 8. Electrical circuit diagram complete with wrapping of wires Arduino (left) and Donut board (right).

The electrical circuit was design so that the whole wiring system will look neat and more organize. Besides that by wrapping the wire all cross over connection are only not visible anymore as they are located below the donut board circuit. For the power supply, only Bluetooth module was powered by

Arduino as there are available source from it. The only separated power source is the servos which they require at least 1.73A in order to operate the whole system. This was overcome by supplying them with the power source from power banks or direct current which are 5V optimum. Using the circuit above allow the whole electrical system to be smaller, compact, neat and easier to plug in.

Block Diagram

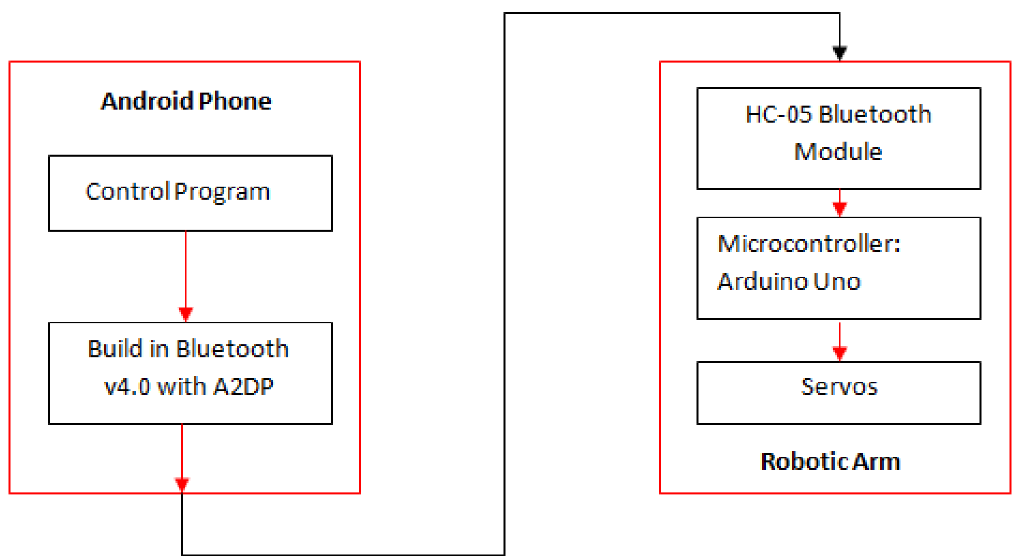

Figure 9. Robot Control System block diagram.

Robotic arm communicated with user via Bluetooth to the Bluetooth module installed on the control system of robotic arm. When a user slides each button on the application, input signal or controlling signal is given from the paired Android smart phone and then sent via Bluetooth to the robotic arm. The data from the smart phone is sent in the form of ASCII format in order to be received by the Bluetooth module and passed on to Arduino for further operation. The Arduino detected the input of signal and converted them into command, the robot then checked the command with its previously defined commands and the servo motors acts accordingly depending on the command received from the microcontroller by moving forward, backward, left, right or to stop. Thus, a smart phone Android operated robot is created to perform lifting tasks.

TEST RIG DEVELOPMENT

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 13 shown tests conducted on the robotic arm have been carried out in laboratory.

By varying the position of the objects which need to be lifted by the robotic arm, the servo motor movement range is tested. Different direct impulses to each servo motor are sent by giving a command through smart phone. This can helps to verify the response of the servo motor whether it can moves to the right position according to the command given by the user. 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 position are marked to rate the accuracy of the actuator.

For overall system performance, maximum load which able to be lifted by the robotic arm is determined using different weights. During the test, the robotic arm picked up the weight and moved it to a particular position.

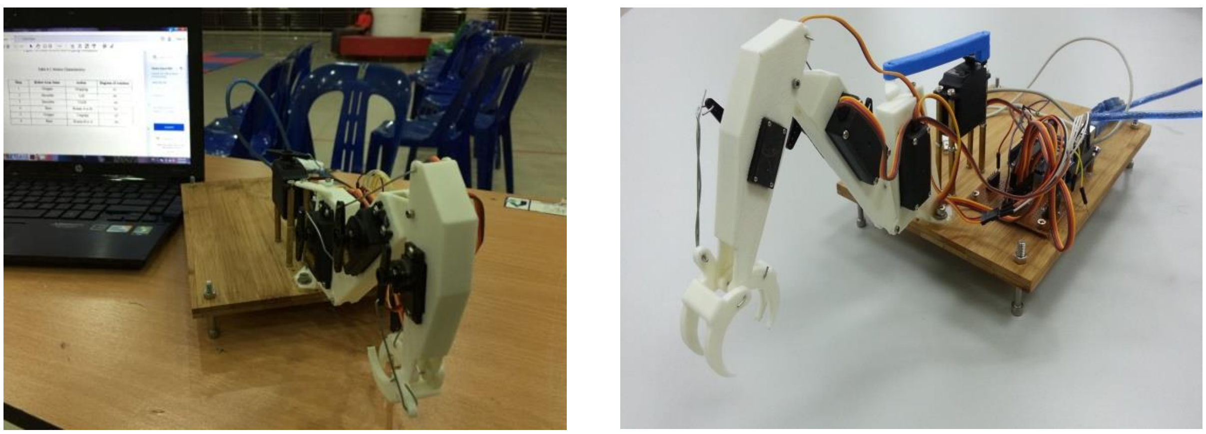

Figure 10. Test configuration and complete design.

RESULTS & DISCUSSION

I. Robotic Arm Movement Coverage

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 21.0cm, and the maximum angle the robotic arm can reach is 92^o, with range from 36^o to 128^o.

II. Final Position

Result of the robotic arm of lifting with different weight is presented in this section. The load to be lifted in this experiment is a sand bag with different weight. The robotic arm is commanded to lift the sand bag and relocate it to a specific position. The experiment is started to examine the accuracy of positioning with a variation in weight of a sand bag which is in the range of 20 grams to 100 grams, the load with 20 grams act as a reference. The precision of the robotic arm to lift different weights is recorded in the table below. From the data obtained, the robotic arm can lift 100 grams as expected result in this project. However, the movement of robotic arm is not smooth when it lifted 100 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 which made up of steel.

Table 2. Precision in x and y axis.

Weight (grams)	Precision (mm)	
	x-axis	y-axis
20	0	0
40	3	7
60	0	10
80	12	17
100	30	32

III. Time Duration

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

Table 3. Duration of lifting process.

Weight (grams)	Duration (second)
20	15.54
40	15.64
60	15.65
80	15.67
100	15.68

The furthest pickup point was only 21.0cm is because the inconsistency length and not rigidity of it. This causes some stretches or expanding on the galvanized wire linkage. As for its rotation angle, it can rotate up to 92^{o}; with range from 36^{o} to 128^{o} this rotation is expected as the rotation linkage is unstable due to the elevation of the servo motor. The elevation is a must to meet up the height of the motor. Total precision of 90^{o} is only possible if the whole linkage is in one piece and not connected using screw, bolts and nuts.

The final position of the robotic arm varies as the weight increases. Again, the reasons for its imprecision are caused by two factors. The first factor was the size of the weight which is not compatible and not suitable for the gripper due to its smooth surface. Secondly, the linkage bends a lot when gripping the 100g weight. This shows the lack of strength of the galvanized wire which causes imprecision for the robotic arm. The lifting of the weight shows a good result nevertheless as is it able to lift a 100g as calculated. This robotic arm will be able to lift a better weight and more precise with a better designed linkage for it.

The robotic arm was able to reach a good precision on its timing is because the usage of servo motor. Servo motors moves according to the input receive. The programming was set to perform the task within the given time For example: delay (500) which indicate the delay for 500 milliseconds. This shows that the robotic arm will perform the task within 500 milliseconds.

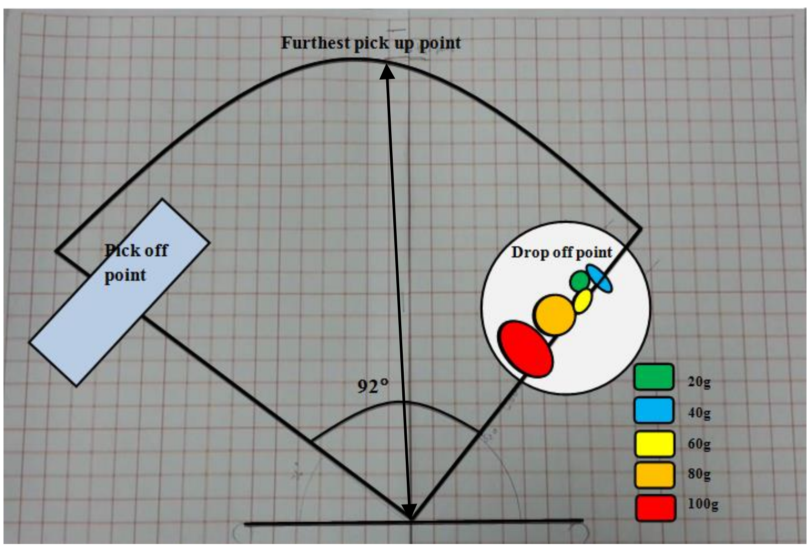

Figure 11. Maximum range of robotic arm movement.

CONCLUSION

This paper presents the design and development of a robotic arm for light material lifting application. The robotic arm is drafted using computer aided design software, Autocad and fabrication with advance technology, 3D-printing to save cost and time. The robotic arm is made up of ABS (Acrylonitrile Butadiene Styrene) and one of the linkages between the body and motor is made up of PLA (Polylactic Acid). During the 3D printing process, we faced a problem in printing an overhanging part which strongly affected the joining part by causing a severe defect. Meshmixer software which can generate support automatically at the overhanging part thus a satisfied product is obtained. The actuator used to perform arm movement is 4 servo motors. The servo motor is controlled via an Arduino Uno through coding. Due to the limitation of the servo motor, the movement range of the robotic arm is restricted within 180 degrees. The robotic arm is designed with four degrees of freedom because it is suitable for most of the application included lifting .Therefore, it can be cost-effective and simple construction by using only 4 actuators. The robotic arm parts are joined together by fastener: screws and nuts. For the robotic arm control, the system mainly consisted of three components which are microcontroller, android application and servo motor. Arduino microcontroller is cheaper and easier to be programmed with C language compared to the other microcontrollers. A user interface in Servoarduino, an android application allows the user to control the movement without any training needed so the robotic arm is user-friendly. 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.

FUTURE SCOPE

In the further development, the robotic arm can be situated on a mobile platform with 4 wheels to allow portability and navigation. Design of a universal gripper is interesting because it can lift different shapes of objects. Robotic arm has sensors to detect the position of the objects and the whole process is automated and it can also communicate with user through networking.

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