Design of a Pick and Place Serial Manipulator

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Abstract- Repetitive tasks and high accuracy have become the two contradictory needs of any industrial process. By introducing autonomous robotic applications, simple repetitive tasks can be accomplished keeping the demands of the accuracy and speed in mind which will result in optimum utilization of the machine and manpower. However, developing these applications for industries specific to countries like Nigeria, where cheap labour is available, becomes a major problem to be tackled in terms of cost. This project deals with the design, fabrication and control of a 3 degrees of freedom serial manipulator used to pick and place ferromagnetic metals from one place to another. The serial manipulator mechanism was designed using a direct drive mechanism. The links of the arm were designed using Blender CAD software and fabricated using 3D printing technology. Two servo motors control the motion of the arm while another one controls the rotation of the base. Robot motion is controlled using three knobs switch and a toggle switch for the electromagnetic end effector. The motor control is achieved using a microcontroller. The electromagnetic end effector can be moved in a workspace which is in a hemisphere of 40cm. The serial manipulator was able to carry a payload of 15 N with relative ease.

Keywords: Serial manipulator, Electromagnetic, Robotic and Automation

1. Introduction

In today’s world, robots are all around us, they come in a variety of different shapes and sizes, designed to do an extraordinary range of tasks. When we think of robots we picture these big humanoid robots from science-fiction films like “Transformers”, “I Robot” or the big robotic arms seen manufacturing cars on automated assembly lines. When we talk about robots, what we are really talking about is machines that will do what human beings would normally be expected to do. These machines mimic the operation of the human being or at least certain parts of it.

RIA (1977) defined a robot as a re-programmable multi-functional manipulator designed to move material, parts, tools, or specialized devices, through variable programmed motions for the performance of a variety of tasks”. The term ‘robot’ got prominence way back in the 1920s when a Czechoslovakian playwright, Karl Capek in his play R.U.R. (Rossum’s Universal Robots) denoted the birth of a superior race that had intelligence similar to that of humans, then later a well-known Russian science fiction writer Isaac Asimov coined the word robotics, (William, 2016).

In general, robotics, which is the science of robots, can be divided into two areas, industrial and service robotics. IFR (1987) defines a service robot as a robot which operates semi- or fully autonomously to perform services useful to the well-being of humans and equipment, excluding manufacturing operations. In general, service and industrial robots are in widespread use, performing jobs more cheaply and with greater accuracy and reliability than humans. They are also employed for jobs that are too dirty, dangerous or boring to be suitable for humans. Robots are widely used in manufacturing, assembly and packing, earth
and space exploration, surgery, weaponry, laboratory research and mass production of consumer and industrial goods. As robotic technology develops and becomes cheaper, domestic robots for cleaning or mowing the lawn are available, along with robotic toys for children of all ages.

Craig (2016) stated that industrial robots is growing at a fast pace, in the last few years the demand for industrial robots is increasing. A major reason for the growth in the use of industrial robots is their declining cost. Through the decade of the 1990s, robot prices dropped while human labor costs increased. Also, robots are not just getting cheaper; they are becoming more effective, faster, more accurate and more flexible. If we factor these quality adjustments into the numbers, the cost of using robots is dropping even faster than their price tag is. As robots become more cost effective at their jobs, and as human labor continue to become more expensive, more and more industrial jobs become candidates for robotic automation. This is the single most important trend propelling growth of the industrial robot market.

The most common robot used in industry today is the ‘serial manipulator’ also known as robot arm. These arms are used to weld, package, paint, position and assemble a host of products that we use daily. Basically, a robot arm is a series of linkages that are connected in such a way that a motor can be used to control each joint.

2. Mechanism

Tsai (1999) defined a serial manipulator as a mechanism consisting of “several links connected in series by various types of joint, typically revolute and prismatic joints”. Another common name for serial manipulator is ‘robotic arm’. Serial manipulators are sometimes referred to as open-loop manipulators simply because one end (or the base) of the manipulator is fixed and the other end (known as gripper or end effector) is free to move in space.

Serial manipulators can be classified into direct drives and non-direct drives. Kazerooni (1989) stated that direct drive robots have two major advantages over the non-direct drive systems. The first advantage being that the direct-drive arms are free from mechanical backlash and friction due to elimination of transmission systems. A small mechanical backlash in the transmission system would cause the gear teeth to wear faster. The high rate of wear in the gear would develop an even larger backlash. About 25 percent of the torque in non-direct drive arms is used to overcome the friction. The second advantage is such that the structural stiffness of the direct-drive arms is greater than the non-direct drive systems. About 80 percent of the total mechanical compliance in most non-direct drive industrial robots is caused by transmission systems. The high structural stiffness allows for wide-bandwidth control, the low structural stiffness of non-direct drive arms due to the existence of many mechanical elements in the transmission system is a limiting factor on the achievement of a relatively wide bandwidth control system.

Since continuous rotation is not required, therefore servo motors will be used as the actuator in this project.

Components of the Serial Manipulator

This serial manipulator was designed using the direct drive method. To accomplish this goal, careful analyses have been made concerning the materials that will be suitable for this project. The components include the mechanical, electronic and computer component.

Below is a list of the materials used for the mechanical part of the serial manipulator.

- Actuators (Servo motor)
- 3mm thick Polylactic acid
- Fastening screws
- Couplers
- KK-P20/15 Electromagnet
- Spur gears
Actuators: A lightweight servo motor is used as the actuator for the arm because they are not heavy and can be easily controlled. The servo motor used in this project is the TowerPro MG995R servo motor. It produces a torque of 9.218 Nm at 4.8V and 10.787 Nm at 6.0V.

Link: The links were designed using the CAD software called Blender before being sliced using another software called Dicer, after which it was then printed using a 3D printer. After the printing of all the links to be used, the links were coupled together using screws and fasteners. Polylactic acid of thickness 3 mm was used as links due to their light weight.

End-Effector: The electro-magnetic end effector used in this project is the KK-P20/15 which is rated 2.5kg at 12V DC, consuming 3W. The electromagnet works at a lower voltage with reduced pulling power.

For the electronics and computer, the materials used are:
- ATMegaMicrocontroller (ATMega328P);
- Programmer board;
- SPDT switches;
- LEDs;
- Diodes;
- Resistors;
- Capacitors;
- Voltage regulators and
- Arduino Integrated Development Environment

Joint Torque Calculation

![Figure 1: Simple Overview of the Manipulator](image)

Where \( W_1, W_2 \) and \( W_3 \) are the weight of the links \( l_1, l_2 \) and \( l_3 \) respectively \( W_s \) and \( W_b \) is the weight of the shoulder joint and base joint respectively, \( W \) is the weight of the object to be carried.

With good engineering decision, we take:
\[
l_1 = 0.05 \text{ m}, \quad l_2 = 0.20 \text{ m} \quad \text{and} \quad l_3 = 0.29 \text{ m}
\]

Also,
\[
W_1 = 3.3034 N, \quad W_2 = 0.9565 N, \quad W_3 = 0.5334 N, \quad W_s = 1.0791 N, \quad W_b = 0.5395 N, \quad W = 14.7150 N
\]

Torque about joint 3,
\[
T_3 = (W \times L_3) + \left( \frac{W_3 \times L_3}{2} \right)
\]
\[
T_3 = (14.7150 \times 0.29) + \left( \frac{0.5334 \times 0.29}{2} \right)
\]
\[ T_3 = 4.345 \text{ Nm} \]

Torque about joint 2,
\[
T_2 = (W \times [L_2 + L_3]) + \left( W_3 \times \left[ L_2 + \frac{L_3}{2} \right] \right) + (W_5 \times L_2) + \left( W_2 \times \frac{L_2}{2} \right)
\]
\[
T_2 = (14.7150 \times [0.2 + 0.29]) + \left( 0.5334 \times \left[ 0.2 + \frac{0.29}{2} \right] \right) + (1.0791 \times 0.2) + \left( 0.9565 \times \frac{0.2}{2} \right)
\]
\[
T_2 = 7.210 \text{ Nm}
\]

Torque about joint 1,
\[
T_1 = (W \times [L_1 + L_2 + L_3]) + \left( W_3 \times \left[ L_1 + L_2 + \frac{L_3}{2} \right] \right) + (W_5 \times [L_1 + L_2]) + \left( W_2 \times \left[ L_1 + \frac{L_2}{2} \right] \right)
\]
\[
+ (W_6 \times L_1) + \left( W_1 \times \frac{L_1}{2} \right)
\]
\[
T_1 = (14.7150 \times [0.05 + 0.2 + 0.29]) + \left( 0.5334 \times \left[ 0.05 + 0.2 + \frac{0.29}{2} \right] \right) + (1.0791 \times [0.05 + 0.2])
\]
\[
+ \left( 0.9565 \times \left[ 0.05 + \frac{0.2}{2} \right] \right) + (0.5395 \times 0.05) + \left( 3.3034 \times \frac{0.05}{2} \right)
\]
\[
T_1 = 8.679 \text{ Nm}
\]

Since \( T_1, T_2 \) and \( T_3 \) are lesser than the 10.787 Nm torque provided by the servomotors at each joint, the suggested length of the links is justified to be used.

3. Results

From the calculations, the torque needed at the elbow, shoulder and base joints are 4.345 Nm, 7.210 Nm and 8.679 Nm respectively for it to move optimally. Since the motors at each joint produces 10.787 Nm torque according to the producer specification, which is more than the needed torque, then the serial manipulator should move optimally.

The serial manipulator was able to carry a payload of 15 N which was made possible by the use of a direct drive mechanism. With a direct drive, the arm is made lighter, and torque is increased.

4. Conclusion

Robotic arm or serial manipulator, as demonstrated in this project, can be made to carry heavier loads without forfeiting the movement speed using direct drive mechanism. It can also be seen that the project is justified as it will help reduce human efforts and improve efficient material handling with precision and accuracy.

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