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DESIGN AND CONSTRUCTION OF A PERSONAL COMPUTER-CONTROLLED PICK AND PLACE ROBOT WITH MATLAB SIMULATION

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ABSTRACT

As the industrial sector faces great pressure due to the high demand for goods and services, most industries have switched their operations from manned operations to full-scale Automation and Control Engineering, and the heart of this automation is the Robot. The Robot's arm will be controlled by a human operator using a GUI designed with Matlab and running on a PC. The operator will have the ability to input the exact coordinates of the object to be handled by the arm or to use sliding bars on the GUI to control the extent of movement of the arm. The robotic arm was simulated using a GUI designed with Matlab. The simulation was such that the arm could be rotated to any direction within its allowable range of operation by sliding the bars provided for each servomotor at each joint. This study explains how to design and construct a robotic arm to simulate simple movements like pick and place operations. Research can be made on other available faster Microcontrollers that can be used straight away without the need for conversion or step down of signal. A breakthrough in this area would greatly increase the speed of movement of the robot.

KEYWORDS: *Robotic Arm, Matlab GUI, Microcontrollers, Sliding Bars, Movement Co-Ordinates.*

INTRODUCTION

Over the years, robots have been applied in different areas of life, ranging from defence and security to industrial applications. This surge in the need for robots has widened the range of research in the field of robotics. Today, many robots serve various practical purposes and perform jobs that are hazardous to people such as defusing bombs, and mines and exploring shipwrecks.

Robots are now more than machines, as they have become the solution to the future rise in industrial labour. As the industrial sector faces great pressure due to the high demand for goods and services, most industries have switched their operations from manned operations to full-scale Automation and Control Engineering, and the heart of this automation is the industrial robot. Even though the cost of acquiring most robotic systems is high, the increase in the standard of the quality of operation and products set by the International Standard Organisation (ISO) has made industrial processes less human and more robotic.

In industries today, most of the operations are run by automated robots, to deal with the daily production activities, especially in the automobile and chemical firms. Although there are many robotic products available in the market, none of them is cheap in terms of price and are mostly expensive to run especially when considering the cost of fuelling their power sources. The existing robotic arms are bulky and are designed for specific purposes and functions. This means that the input and output are fixed and cannot be reprogrammed for any other purpose or application. This is to prevent any alterations to their design. Also, the robotic arm movements of these existing manipulators are not well synchronized and the coordinates of the object to be handled are not precisely calculated and these result in operations that are not precise. So for this project, the above problems of cost, fixed design, uncoordinated movement, and inaccurate operations will be neutralized. We will design and implement a robotic arm that will be cheap, suitable for a wide range of applications- educational, and research and can serve as a model for future industrial robotic manipulators. Finally, this design will be capable of precise operations.

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A special kind of industrial robot which is very common and used by most industries for a wide range of operations is the robotic manipulator or robotic arm. This robotic arm is used by the automobile industry for precise operations like spraying, drilling, part assembly, and welding. Its range of operation is limited only by the range of flexibility in its design and control.

This study is titled "Design and Construction of a Personal Computer Controlled Pick and Place Robot with Matlab Simulation", which is meant to be designed and implemented on a software and hardware bases. The project is to design a robotic arm that is capable of picking an object, through the coordinates sent to it and placing the object in the coordinated place. The system will be built in three different phases: the software running on a personal computer (PC), a microcontroller, and a robotic arm. To create a systematic, efficient, and faster operation, software is used. The user interface of the software makes the system more user-friendly, thereby enabling easier operations. Also, due to the image processing ability of the software, more precision in terms of material handling will be offered by the whole system. The robotic arm has four Degrees of Freedom (DOF) thereby making it more manoeuvrable.

2.0 LITERATURE REVIEW

Robotics is the branch of mechanical engineering, electrical engineering, and computer science that deals with the design, construction, operation, and application of robots, as well as computer systems for their control, sensory feedback, and information processing. Many of today's robots are inspired by nature, contributing to the field of bio-inspired robotics [1].

A Robot is a virtually intelligent agent capable of carrying out tasks robotically with the help of some supervision. Practically, a robot is an electro-mechanical machine that is guided using a computer and electronic programming. Robots can be classified as autonomous, semiautonomous, and remotely controlled. Robots are widely used for a variety of tasks such as service stations, cleaning drains, and tasks that are considered too dangerous to be performed by humans [1]. The concept of creating machines that can operate autonomously dates to classical times, but research into the functionality and potential uses of robots did not grow substantially until the 20th century. The word ROBOTICS comes from the word 'robots' which was introduced to the public by the Czech writer Karel Cepak, in his play R.U.R (Rossum's Universal Robots), which was published in 1920. The word robot comes from the Slavic word 'robot', which means labour [1].

In 1948, Norbert Wiener formulated the principles of Cybernetics, which are the basis of practical robotics. Fully autonomous robotic arms only appeared in the second half of the 20th century. The first digitally operated and installed robotic arm was installed in 1961, to lift hot pieces of metal from a die-casting machine and stock them [1].

This section of the study is concerned with the fundamentals and concepts of robotic manipulator design, including kinematics, motion planning, computer interfacing, and control. It introduces the most important concepts in these subjects as applied to industrial robotic manipulators. The majority of applications of robot deal with industrial robotic arms (manipulators), operating in structured factory environments. Therefore, any study of robotics must include a rigorous treatment of the different configurations and methods of control of the robotic arm.

2.1 COMMON CONTROL CONFIGURATIONS OF THE ROBOTIC ARM

Robotic manipulators have been designed in several ways, but one remarkable difference in their design is the technique used in the control of these intelligent systems. Some of the most popular of these techniques include RF control from a remote location and the Use of Software Running on a Personal Computer [2].

2.1.1 RF CONTROL FROM A REMOTE LOCATION

Radiofrequency refers to alternating current having characteristics such that if the current is sent to an antenna, an electromagnetic field is generated suitable for wireless broadcasting and communication. These frequencies range from 9 KHz to thousands of gigahertz (GHz). When a radio frequency is applied to an antenna it gives rise to an electromagnetic field that propagates through space called RF [2].

The Radio Frequency control of robotic arms is due to the need to use robots at a safe distance, far from the human operator. It makes use of a transmitter at the operator's end and a receiver at the arm to send and receive signals. This signal is then sent into the microcontroller part of the robotic arm for subsequent processing. H-bridge is normally used as a driving motor. The remote controller uses an encoder that converts the serial data (text, numbers) on the remote controller into parallel data (an 8-bit binary address). This data is now sent using the ASK transmitter to the receiver. The ASK receiver receives the signal, and the decoder decodes the signal.

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This decoded signal is now sent into the microcontroller which enables the manipulator to respond accordingly [2]. This design is limited in distance to a few miles as the radio frequency used is very low and cannot exceed a short distance. Also, the maneuverability of the arm is low [2, 3].

2.1.4 USE OF SOFTWARE RUNNING ON A PERSONAL COMPUTER (PC)

This technique was adapted for this study. It is very versatile in application and has a very easy-to-use graphic user interface (GUI). It involves three major parts: a robotic arm, a dedicated servo-microcontroller, d a well-written software running on a Windows operating system personal computer (PC).

The coordinates of the object to be picked will be inputted into the PC through the graphic user interface of the software. This location is sent into the microcontroller, which now adjusts the position and movement of the robotic arm to locate the objects through its sensors, pick the object and place it exactly at a location also inputted through the user interface of the software.

To enhance ease of operation, this control technique makes use of a camera that is attached to the arm. This camera captures the image of the object to be picked and its surroundings which is sent back to the PC. The software uses its image processing ability to process the image sent. This processed image is shown in the GUI, such that all an operator needs to do is to click the object and the arm automatically adjusts to the location, picks it, and places it at any location within its surrounding chosen by just clicking at a location in the user interface [4, 5].

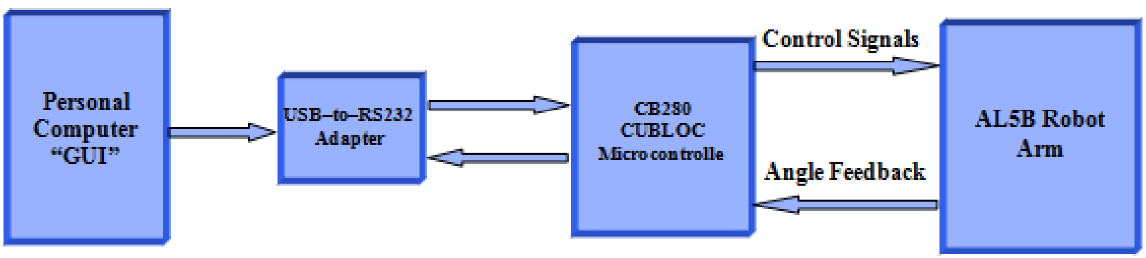

Fig 2.1: System block diagram [5].

2.2 OVERVIEW OF THE ROBOTIC ARM/MANIPULATOR

The manipulator consists of segments that may be joined and move about, allowing the robot to do work. The manipulator is the arm of the robot that must move materials, parts, tools, or special devices through various motions to provide useful work. The manipulator is made up of a series of segments and joints much like those found in the human arm. Joints connect two segments and allow them to move relative to one another. The joints provide either linear (straight line) or rotary (circular) movement. The muscles of the human body supply the driving force that moves the various body joints. Similarly, a robot uses actuators to move its arm along programmed paths and then to hold its joints rigid once the correct position is reached [6].

There are two basic types of motion provided by actuators: linear and rotary, Linear actuators provide motion along a straight line; they extend or retract their attached loads. Rotary actuators provide rotation, moving their loads in an arc or circle. Rotary motion can be converted into linear motion using a lead screw or other mechanical means of conversion. These types of actuators are also used outside the robot to move workpieces and provide other kinds of motion within the work envelope [6].

A robotic arm is usually programmable, with similar functions to a human arm. It has about the same degree of freedom as in the human arm [7]. Humans pick things up without thinking about the steps involved. For a robot or a robotic arm to pick up or move something, someone has to tell it to perform several actions in a particular order from moving the arm to rotating the "wrist" to opening and closing the "hand" or "fingers'' [8]. Some tasks of robot arms may relate to simple mechanisms of picking an object and placing it somewhere. An automated pick-and-place robot arm, which can reach an object in a given domain or range of space, grip it precisely, change its orientation, and place it in a given position will ease the functions mentioned earlier. Thus, it could be named as a Robot Arm with a Three-Dimensional Reach. Robotic arms are mechanically controlled devices designed to replicate the movements of a human arm [9]. These devices are used for lifting heavy objects and carrying out tasks that require extreme concentration and expert accuracy. Robotic arms are often used for industrial and nonindustrial purposes. Robotic arms by definition have multiple degrees of freedom that must be all directed in a kind of electromechanical ballet. The feedback required to motivate sensitive robotic manipulators to become responsive enough to the environment, to be of practical use is something of a new possibility [9]. Therefore, it's been many years since the first practical manipulators went into production for real industrial applications. Modern industrial farms have increased their capability and performance through the use of microcontrollers and computer interfaces. The robotic arm can handle materials through the use of an end device called the End-Effector/Gripper [10].

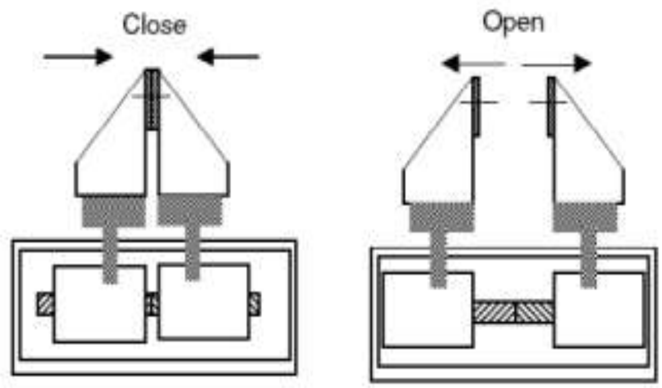

Fig 2.2: A Parallel Jaw Gripper [3].

2.3 THE SERVO-MICROCONTROLLER

A microcontroller is an entire computer manufactured on a single chip. Microcontrollers are usually dedicated devices embedded within an application e.g., as engine controllers in automobiles and as exposure and focus controllers on cameras. To serve these applications, they have a high concentration of on-chip facilities such as *serial* ports, parallel input/output ports, timers, *counters,* interrupt *control*, analog-to-digital converters, random *access* memory, *read-only* memory, *etc.* The *I/O*, memory, and on-chip peripherals of a microcontroller are selected depending on the specifics of the target application. Since microcontrollers are powerful digital processors, the degree of control and programmability they provide significantly enhances the effectiveness of the application [18]. Embedded control applications also distinguish the microcontroller from its relative, the general-purpose microprocessor. Embedded systems often require real-time operation and multitasking capabilities. Real-time operation refers to the fact that the embedded controller must be able to receive and process the signals from its environment as they are received. Multitasking is the capability to perform many functions in a simultaneous or quasi-simultaneous manner [19].

Many types of servo motor microcontrollers could be found in the market such as ASC-16 serial servo controllers, POLULU serial servo controllers, SV203 RC Servo Motor Controller, and PARALLAX serial servo controllers. All of these types of controllers use serial communication technology that lets the user control the servo motor via the serial communication port of the PC. ASC-16 is one of the serial servo-motor controllers that have been developed by Medonis Engineering. This controller can be used to control the actuator of the robot arm. The new controller has a few more fancy features such as a move buffer, position feedback, and speed/ acceleration control in hardware. This will free up some resources on the PC because the software motion controller used with the GUI will no longer be needed. Also, the ASC-16 has an onboard DC-DC connection- which means that the board only needs a single DC power supply [18].

However, the microcontroller adapted for the project is a PIC-based servo controller. This allowed for flexibility of the design made it easy to interface with software written in MATLAB, and generally reduced the cost of the project.

A PIC-based servo controller is a small circuit that has been designed to allow easy control. The Servo Controller uses a PIC89F51 microcontroller to drive servo motors and digital outputs. It receives commands from a host computer via a standard RS232 serial interface. The PIC program can be downloaded which contains a HEX file that most PIC programmers can read; and a PIC Assembler code (ASM) file.

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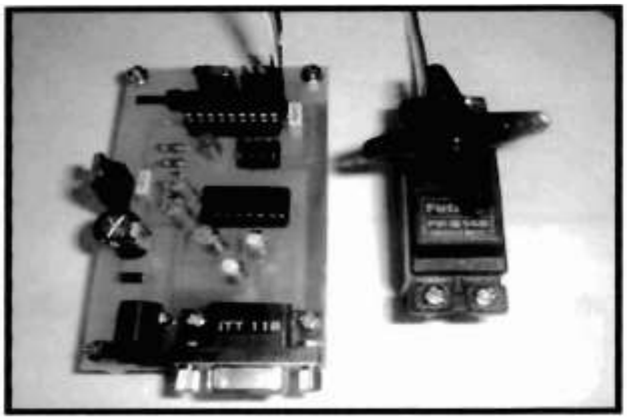

Fig2.7: AT89S51-based servo-microcontroller Board [18].

This circuit can be used to control the angle of rotation of the servo motor in serial communications using Matlab software.

2.4 THE MATLAB SOFTWARE

There are various types of software control or interface control software for the robotic arm and their difference from each other depends on the manufacturer of the software. The software adapted for the graphic user interface is Matlab based. Matlab gives the user the ability to interface the Graphic User Interface into one's code and applications. The programming code has been integrated into Matlab and the Matlab application installed on the host PC, will then execute the code and allow the robot arm to move in any specified direction [20].

The three main things which can be accomplished through the use of Matlab are:
1. Execute and perform the tasks correctly.
2. Create a user-friendly GUI that allows any person with little technical knowledge to successfully use the application.
3. Write an application that runs more efficiently and faster than the previous designs.

Matlab is one of the basic and most popular simulation tools in Engineering. Its user graphic interface is very user-friendly. Programming in Matlab is less complex when compared to other programming and simulation tools. Most of the functions have already been coded, all the programmer needs to do is to call up the function. For simulations, Matlab offers a very high degree of flexibility unmatched by any other simulator. Its Simulink tool carries all the components and resources needed for the simulation on board. With a click on the object in its object window and the proper arrangement of these objects, any kind of simulation can be carried out [21]. Due to the level of versatility offered by Matlab, we decided to choose Simulink as our simulation tool for the project. Furthermore, its image processing capability enabled us to carry out image processing operations, which is very critical for the project.

3.0 DESIGN AND METHODOLOGY

For the design methodology, the system design objectives, considerations, and specifications will be given in detail, to serve as a guide towards actualization of the project design. The primary aim of this study is to design and implement a PC-controlled Pick and Place Robotic Arm. The Arm will be controlled by a human operator using a GUI designed with Matlab and running a PC. The operator will have the ability to input the exact coordinates of the object to be handled by the arm or to use sliding bars on the GUI to control the movement of the arm. A servo-driver circuit will be implemented, to enable communication between the Arm and the Software running on the PC. The arm will be designed to be of the revolute type with 4 degrees of freedom (DOF).

3.1 DESIGN SPECIFICATIONS

The following specifications were put into consideration during the design of the Robotic arm:

1. ARM
   a) Material = Acrylic Material (it is very hard, but very light)
   Thickness = 5mm
   b) Height of the Arm = 73CM
   c) Gripping Force = 75N
   d) Lifting Force (dependent on the base servomotor) = 250N
   e) Acceleration = 2cm/s^2

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f) Mass of Object to be the handled, M
F = Ma
M = F/a = 250/2 = 125g

2. SERVOMOTOR
   a) Voltage = 4.8v
   b) Speed = 0.18sec/60deg
   c) Torque = 2.80kg/cm
   d) Weight = 41g
   e) Size = L*W*H = 39.5*20.0*35.6mm
   f) Current consumption = 2amp/hr
3. BATTERY (POWER SOURCE)
   a) Current = 7amps
   b) Voltage = 6volts
   c) Capacity of battery = 2hrs.

3.2 COMPLETE SYSTEM DESIGN

The design of the project consists of the hardware design phase and software design phase. The hardware design consists of the electrical and mechanical sections. Below is a flow-chart detailing the design process of the project:

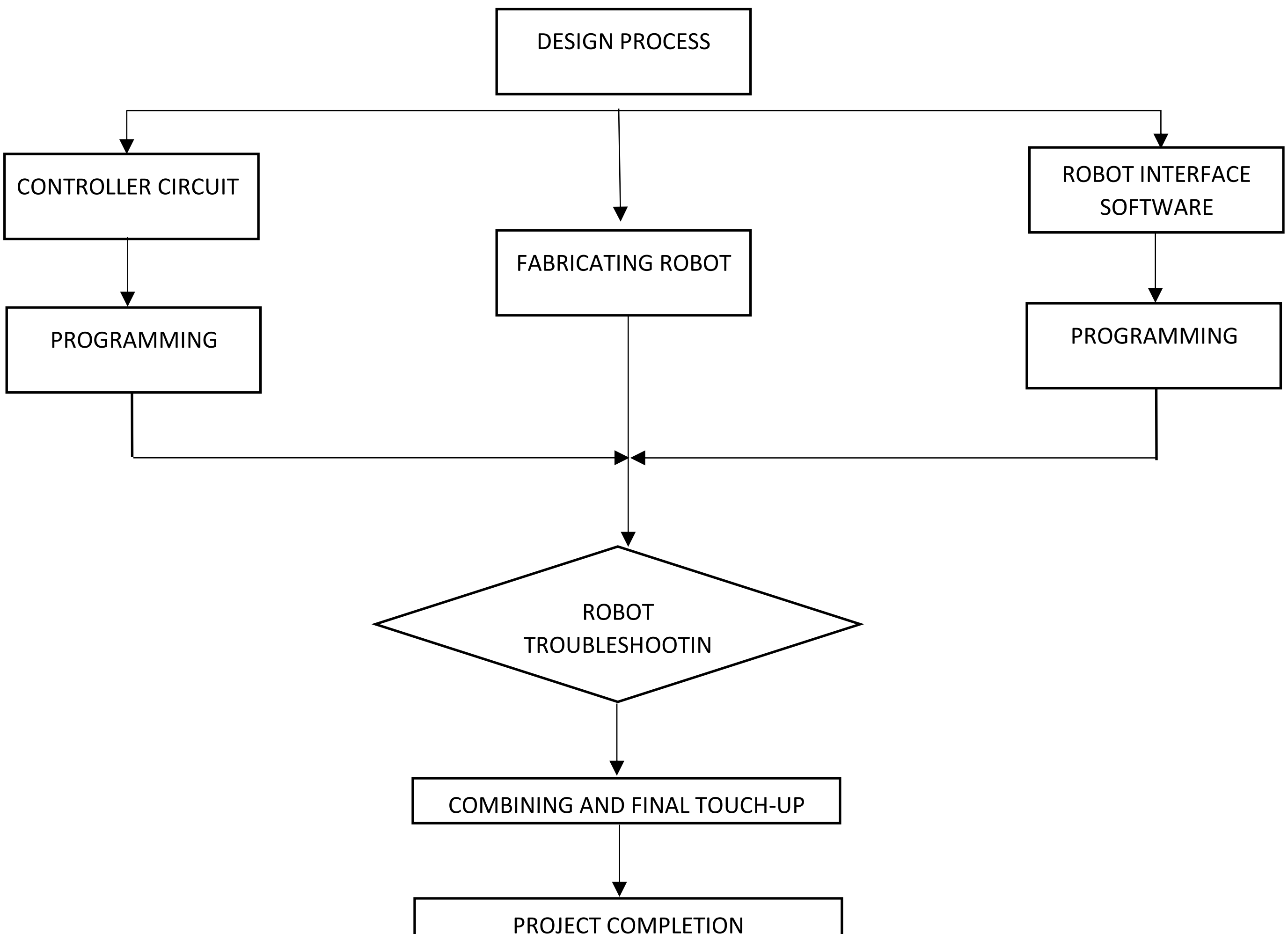

Fig 3.2.1 Flow chart of the design process for the PC Controlled Pick and Place Robotic Arm

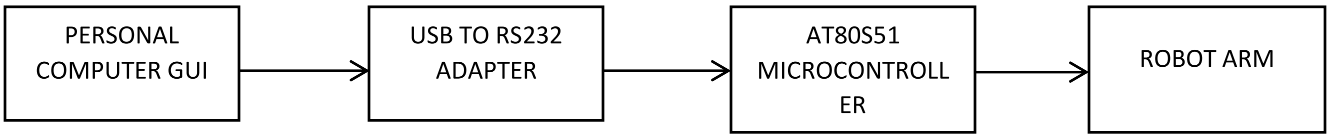

Fig 3.2.2: System Block Diagram of a PC-Controlled Pick and Place Robot.

3.3 HARDWARE DESIGN

The hardware design of the system is made up of two parts: the servo-driver circuit and the mechanical part (the arm).

3.3.1 THE SERVO-DRIVER CIRCUIT DESIGN

The servo-driver circuit provides the means through which the PC communicates with the servomotors placed on the arm. The servo-driver receives the data sent by the software through the USB port of the PC. It then processes the data (angles of rotation of the servos), into digital pulses of varying duration (depending on the value of the angle set for the servos). These digital pulses are sent to the servos causing them to respond and rotate accordingly.

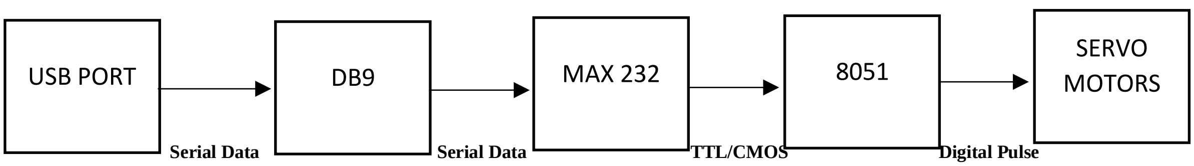

Fig 3.3 Block diagram of the servo-driver circuit

From the block diagram of the servo-driver, the PC communicates to the DB9 ports of the servo-driver through the USB port of the PC. The function of the DB9 is to convert the serial data from the PC from its Universal Serial Bus protocol to the RS232 protocol. This is because the PC is much faster than the servo-driver, hence the need to convert the PC's much faster USB protocol to the slower RS232 protocol, which is compatible with the speed of the microcontroller. From the DB9 Port, the serial data now in the much slower RS232 protocol is passed to the MAX232 converter. The MAX232 now converts the data into the TTL (Transistor-Transistor Logic) standard which is the power standard the microcontroller works with. The microcontroller now processes the data into digital pulses which are then sent to the servomotors.

3.3.1.1 MODULES OF THE SERVO-DRIVER CIRCUIT

Various modules make up the servo-driver circuit of the project. These modules include the following:

- Microcontroller (AT80S51)
- MAX 232 Converter
- The USB Connector
- RS 232 DB9 Connector
- The Servomotors.

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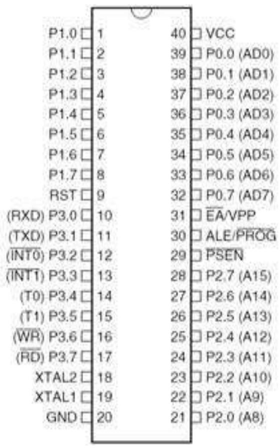

Fig 3.3.1.1 AT89S51

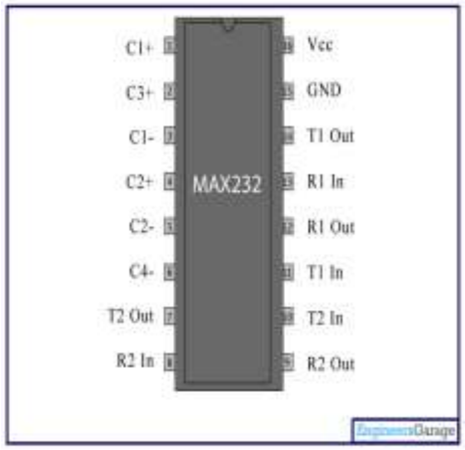

Fig 3.3.1.2 A MAX 232 Schematic

Fig 3.3.1.3 Servomotor

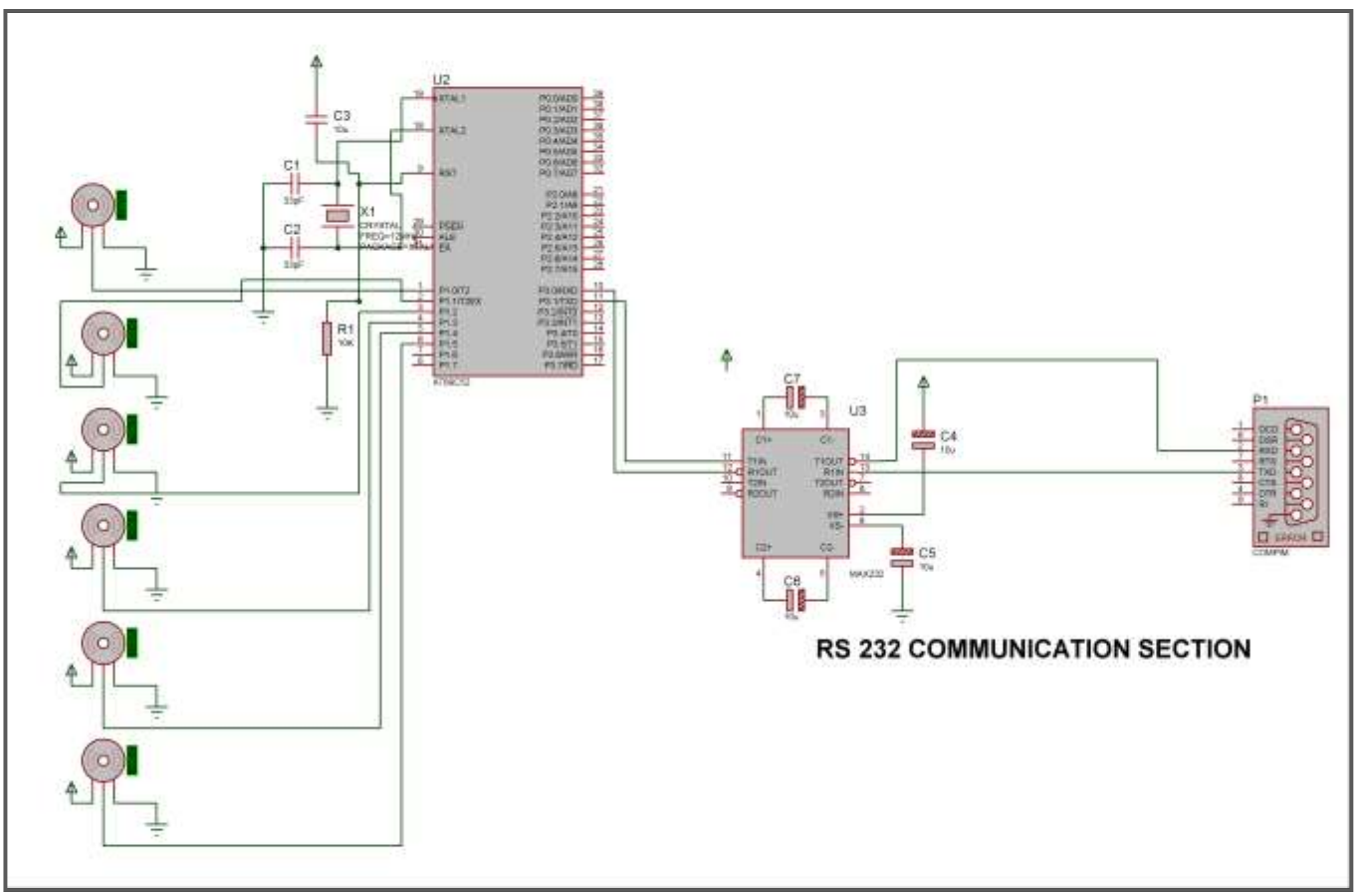

Fig 3.3.1.4 Completed Servomotor Driver Circuit.

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3.3.2 THE MECHANICAL DESIGN

The mechanical design of the project consists of the design and construction of the arm. The arm consists of frame linkages which are connected using revolute joints, controlled with servomotors.

Fig 3.3.2 The Robotic Arm

An Acrylic Composite material was chosen for the frame/body of the arm because of the following reasons:

- Lightweight: The acrylic component is very light in weight. It has a thickness of 5mm which is too small to sufficiently reduce the force required to lift the object.
- Ease of Coupling: The material chosen for the body is very easy to couple together. With a few screws and nuts, the various linkages making up the body frame can easily be coupled together according to the specifications.
- The Acrylic material is resistant to corrosion. Since the acrylic material is non-metallic, it neither rusts nor corrodes.
- Finally, the acrylic material produces smooth rotation of the Arm joints. Equally, it is easy to bend to shapes and cut to sizes.

3.4 SOFTWARE DESIGN (GUI RUNNING ON MATLAB)

To effectively control the movement of the robotic arm, a Graphic User Interface (GUI) was developed. The program codes were written using MATLAB.

The choice of Matlab was made because of the following reasons:

- It is easier and less time-consuming to write.
- It is easier to modify and update.
- Matlab offers overwhelming flexibility as it is compatible with any operating system.
- Matlab provides an easy way of developing GUI by using the drop-down approach, making it possible for someone to develop a GUI of choice without being an expert programmer.

This GUI gives the operator the ability to test the physical system (the robotic arm) without ever having to set up the physical environment and also operator can practice without having to be on site. Another benefit of using a GUI is that we can create any representation needed for the operator. To control the robot in the real world, as well as the virtual world, we use MATLAB/Simulink to numerically analyze the inverse dynamics of the system. This allows us to specify the robot's position that we want and then the software automatically calculates the joint angles that will move the robot to that desired position. The robot will be used to manipulate several objects with known positions within the system, real-world or virtual. We will use trajectory planning techniques to move the robot within the environment; this gives the robot a level of semi-autonomy and allows the user to only have to initiate a single command instead of having to control the robot the entire time it is in use.

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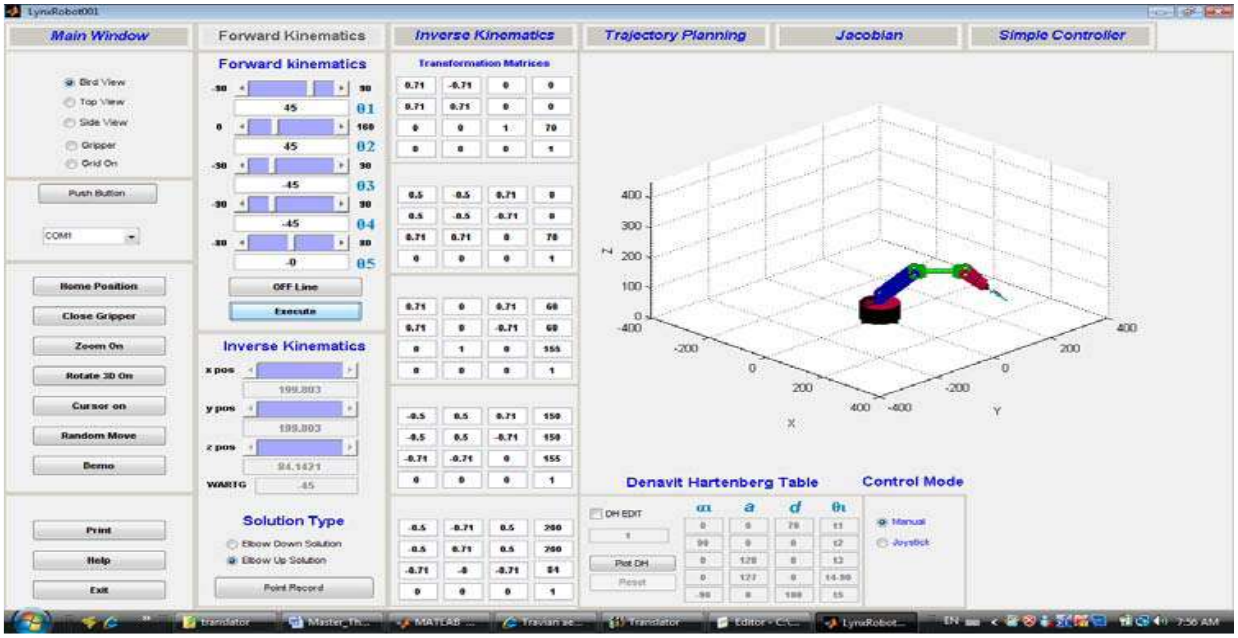

Fig 3.4: Screenshot of the Software GUI Developed Using MATLAB.

3.4.1 CONTROLS ON THE SOFTWARE GUI

- DEMO: The demo button when initiated, makes the Robotic Arm move randomly. It is mainly to be used to test the operational readiness of the arm.
- CLEAR TRAIL: The Clear trail button removes completely the trail which shows the trajectory path taken by the arm during its demo movement.
- HOME: The Home button when clicked, initializes the arm to move to its rest position.
- CHECK BOX: The Check Box when clicked produces a drop-down window with options for Real-time and non-real-time motion.
- SEND: The Send button when clicked sends the coordinates of the arm or the data from the sliding window to the software process control codes, which makes the arm respond accordingly.

  There are two ways the Arm can be controlled using the software, these are:

  I. SLIDING WINDOW: Through the sliding window, all the operator needs to do is slide the bars corresponding to each servomotor accordingly, and then press the SEND button. The arm responds according to the angles each servomotor is slid.

  II. TEXTBOXES: Each coordinate of the robotic arm is represented by a textbox on the GUI. The operator can choose to enter the exact coordinates of the object to be picked on the textboxes (X, Y, Z), and by clicking the send button, the software converts the coordinates to appropriate signals and these cause the arm to respond.

Also, the software GUI has a simulation window, which enables to operator to have a first-hand view of the arm movement before the arm moves. The simulation window can be made to work simultaneously with the arm movement, by selecting the REAL-TIME option. Finally, in developing proper software for arms control, a Flow Chart was developed.

3.4.2 DESIGN OF FLOW CHART

The flowchart shows the sequence of events, which the software carries out before sending the appropriate signals to the servo driver. It is as shown below:

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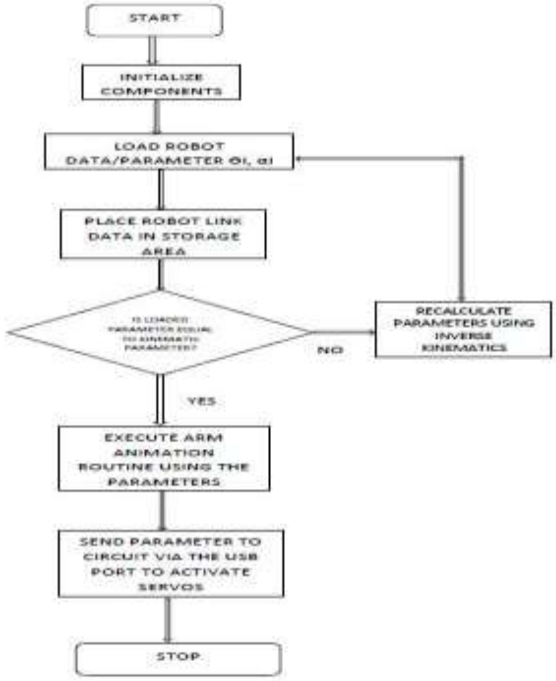

Fig 3.4.2 Flowchart showing the sequence of software events.

4.0 DISCUSSION
In the following sections, the results of the simulation of the pick and place operations, the relationship between the torque, current, voltage, and speed characteristics of the arm, as well as the testing of the different parts of the project will be presented.

4.1 SIMULATION OF THE ROBOTIC ARM
The robotic arm was simulated using a GUI designed with Matlab. The simulation was such that the arm could be rotated to any direction within its allowable range of operation; by sliding the bars provided for each servomotor at each joint on the GUI.

4.1.1 SIMULATION RESULTS
The robotic arm was able to carry out real-time pick and place operations. It moved its joints in the direction of sliding the bars. The figures below are the screenshots of the pick and place operation carried out by the simulated arm:

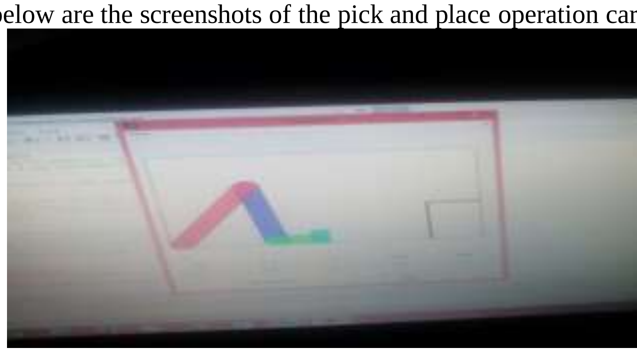
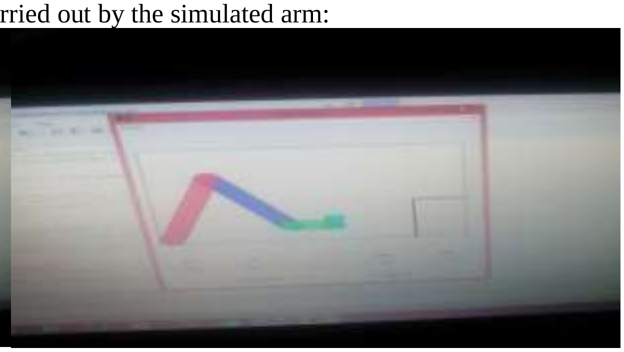

Fig 4.1a: Pick and place operation Fig 4.1b: Pick and place operation

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EPRA International Journal of Research and Development (IJRD)
Volume: 8 | Issue: 5 | May 2023 - Peer Reviewed Journal

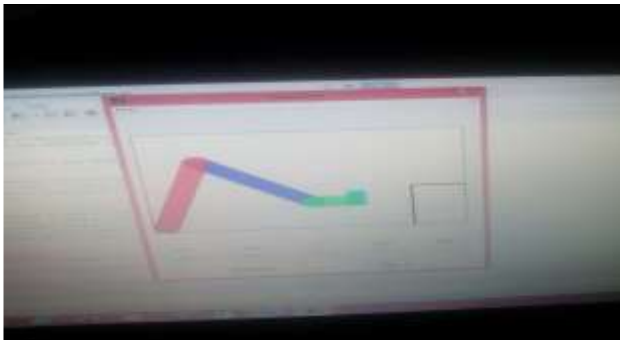


Fig 4.1c: Pick and place operation Fig 4.1d: Pick and place operation

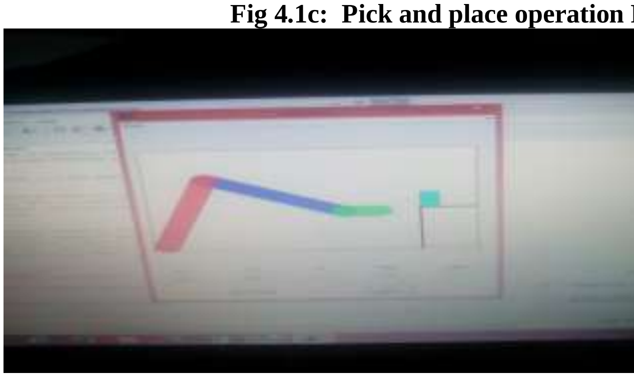


Fig 4.1e: Pick and place operation Fig 4.1f: Pick and place operation

From the screenshots of the simulation of the arm; it was able to pick the set object from a pre-set coordinate and place the object at a particular point. This means that the simulation is rigid and the position of the object is constant as well as the exact place the object will be placed. Also, the object the arm was able to handle was exactly 125g. This weight of the object confirms the accuracy of the theoretical analysis of the arm; which gives the maximum weight of the object as 125g.

4.2 TEST AND RESULTS FROM THE ARM MOVEMENT
Tests were carried out to ascertain that the project met the desired specifications. A multimeter was used to test for various electrical parameters such as voltage, current, and continuity at each stage of the implementation of the servo-driver circuit, to ensure that the desired inputs and outputs were to specification.

Also, the angles of rotation of the servomotor were tested and measured to ascertain that the servomotor rotated in a synchronized manner. The serial port connected with the microcontroller and the PC was tested to ensure proper connection. The software was tested to ensure it works with the Robotic Arm. Finally, every sub-system of the project was built to specification.

This section presents the data obtained by measuring the parameters of the gripper and base servos, which are the main servomotors that produce the lifting force, and torque, and determine the speed and distance covered by the arm.

4.2.1 Measuring the Torque and Distance covered by the Arm
These data were obtained by applying equation 1: $T_{APP}=F*D$
Where: T_{APP} is the torque produced by the gripper servomotor (NM);
F is the lifting force of the gripper servomotor= 250N.
D is the distance covered by the arm in M.
The maximum torque produced by the gripper, $T_{max}=F*D_{max}$
$T_{max}= 250N * 0.73M=182.5NM$
Where D_{max}= Maximum distance (total length of the arm).
From the datasheet of the servomotor, the Lifting force was given as 250N. By varying the distance and applying the above equation the following results were obtained, as shown in Table 4.2.1 below:

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Table 4.2.1 Data showing values of Object distance with variation in gripper Torque.

TORQUE, T_{APP} (NM)	DISTANCE (M)
50	0.20
55	0.22
60	0.24
65	0.26
70	0.28
75	0.30
80	0.32
85	0.34
90	0.36

Figure 4.2.1 shows a graphical plot of the distance covered by the arm against the torque for the shoulder servomotor from the data in Table 4.2. From the graph, it is evident that as the torque of the servomotor increases the distance of the arm increases linearly. This is because as the current in the coil increases, the strength of the electromagnetic field increases, thereby producing a greater force. Since torque is equal to the product of the force due to rotation and distance of the shaft, therefore the torque increases as the distance covered by the object increases.

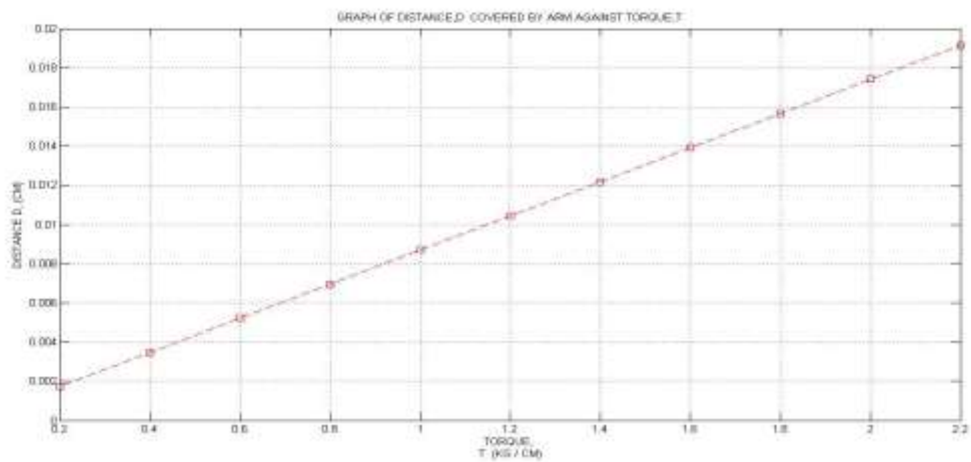


Fig 4.2.1: Plot of Distance covered by the object against Torque.

4.2.2: Measuring the Torque and Angular Speed.

Equally by using equation 2: $P_m = T*W$

Where: P_m is the power of the motor.

T is the electromechanical torque (Nm)

W is the angular velocity in rad/ sec.

From the datasheet of the base servomotor, the power of the servomotor was given, then by varying the torque and applying the above equation the following results were obtained, as shown in Table 4.3 below:

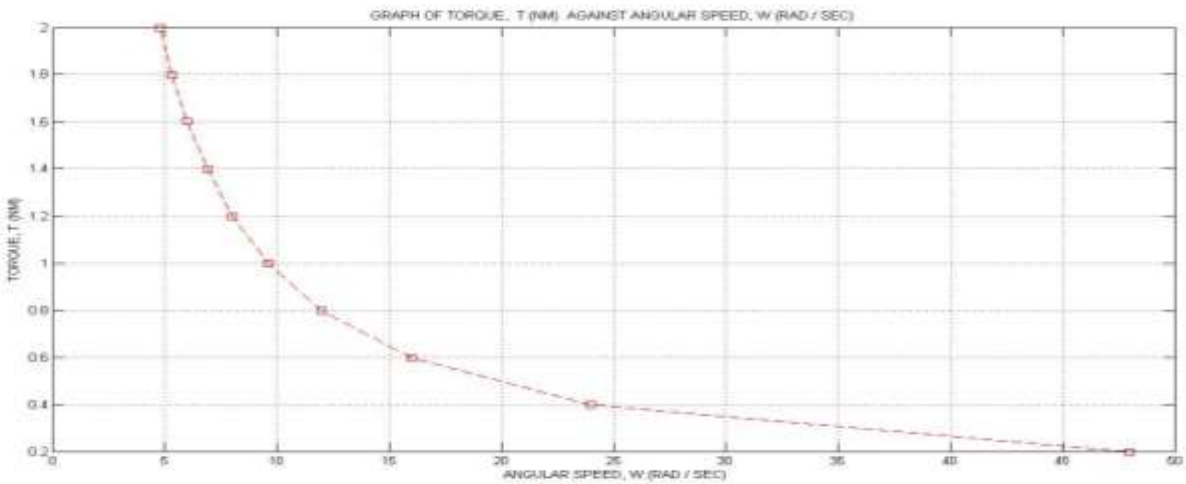
Table 4.2.2 Data showing values of Angular speed with variation in Torque.

TORQUE (NM)	ANGULAR SPEED, W(rad/sec)
50	0.192
55	0.175
60	0.160
65	0.148
70	0.137
75	0.128
80	0.120
90	0.107

Figure 4.2.2 shows a graphical plot of Torque against Angular Speed for the shoulder servomotor from the data in Table 4.2.2. From the graph, it is evident that as the torque increases, the angular speed of the servomotor decreases linearly.

Fig 4.2.2: Plot of Torque against Angular speed

4.3 Comparison of Simulated Arm Movement and Prototype Operation



The simulation of the movement of the arm provided all the necessary details in line with its design and movement of the arm. Data such as speed of movement, torque, distance, gripping force, and lifting force were painstakingly analyzed. From the simulation, the arm was able to show flexibility in its 3 DOF design. It was able to pick up the 125g object, move it towards the set platform and place it accurately at a set point on the platform.

Also, in the actual test of the prototype's operation, the arm movement was not as accurately synchronized as the simulated arm movement. The joints showed time lapses (delay) before responding to control signals. The prototype was not able to carry the stipulated maximum weight of 125g, although the simulated arm was able to handle objects up to 125g in weight.

The inability of the prototype to carry up to 125g object can be attributed to the material used in making the arm frames (acrylic material), they are very light and could fracture when carrying heavy objects. Also, the shoulder servomotor could not produce a lifting force of 250N required to lift the maximum weight of 125g.

In summary, the simulated arm worked perfectly and produced results by the stipulated theoretical analysis of the arm, when compared to the prototype which was able to lift objects less than 125g in weight. This can be attributed to limitations in the design such as battery voltage drop, materials chosen for the body frame, and weakening of arm joints.

5.0 CONCLUSION

For the development and future related studies of this project, the following recommendations are given:

1. The Pick and Place algorithm can be enhanced using other techniques such as neural networks, fuzzy logic, etc.; to produce a more efficient system that can precisely pick and place objects.
2. The number of servomotors can be increased especially for industrial applications to ensure greater movement and rotation of the arm.
3. Research can be made on other reliable and faster Microcontrollers that can be used straight away without the need for conversion or step down of signal. A breakthrough in this area will greatly increase the speed of movement of the robot.
4. Use of other high-level languages like Hardware Description Language (HDL) and more efficient compilers can be used to produce more efficient programs and hex code.
5. Since the designed system is dependent only on a 7V dc source, it is much recommended that future researchers should provide alternate power sources in case of brownouts such as batteries or solar power systems.

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