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Manufacturing a Robotic Arm Prototype for Minimally Invasive Surgeries

Bahaa Al-Din Rokan Aziz
Al Salam University College Medical Devices Technology Engineering

Rana Alaa Nasser Hussein
Middle Technical University, College of Medical Device Technology Engineering

Safa Mahdi Ali Ahmed
Northern Technical University/Technical Engineering College / Mosul Medical Instrumentation Technology Engineering Department

Omar Ali Jassim Mohammed
Middle Technical University Electrical Engineering Technical College Department of Medical Devices Engineering Technology

Hussein Wathiq Muhammad Deeb
Al-Hadi University College, Department of Medical Device Technology Engineering

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Annotation: In conclusion, the design and development of the 6DOF robotic arm of small surgical operations appear enormous to provide advanced and effective health care. Through accuracy tests and duration, arm performance has been evaluated and analyzing the results to determine which areas can be improved. This technique is an important development in medicine, where they can improve accuracy, speed and efficiency in surgical operations. With more development and improvement, robotic arm can become a valuable and effective solution in small and minute surgery. The development of robotic arms for small surgical operations requires closely interaction between mechanical engineers, software and doctors, to ensure reliable and precise performance. Thanks to advanced technology and continuous innovation, robotic arm can play a major role in improving surgical results and reducing risk in surgical operations. As

research and development continues in this area, more progress and innovations can be expected in the field of design and use of future robotic arm, promoting health care and improving the quality of life for patients.

Chapter One

Introduction

1. Background

The project to manufacture a robotic arm model for microsurgery takes into account the increasing need to develop advanced medical technologies that contribute to improving surgical outcomes and reducing risks and surgical interventions. The project revolves around designing and manufacturing a model of an advanced robotic arm, which has the ability to precisely control and move freely within the patient's body.

The background of the project includes an in-depth study of the needs of surgeons and patients and the challenges faced in microsurgery. In addition, the project requires research and development in areas such as engineering design, advanced manufacturing techniques, computer programming, and robotics control technologies.

This background aims to find innovative and effective solutions that help develop a robotic arm model that can perform microsurgery safely and with high accuracy, which contributes to improving the quality of health care and providing advanced treatments to patients.

2. Problem statement

In a project to manufacture a robotic arm model for microsurgery, we may encounter several problems, including:

1. Robot technology: You may face difficulties in developing advanced technologies to precisely control the movement of the robotic arm and determine its location with high accuracy within the patient's body.
2. Design: Challenges may arise in designing the robotic arm so that it is compatible with the patient's body structures and provides full access to the area targeted for surgery.
3. Raw Materials: It can be difficult to find suitable raw materials that comply with the safety, sterility and durability requirements required for medical use.
4. Programming and control: You may face difficulties in programming complex computer systems that manage the movement of the robotic arm and control surgical operations accurately and effectively.
5. Costs: It may be a challenge to secure financing for the project due to the high costs associated with research, development and manufacturing.
6. Time Availability: It may take a long time to develop and manufacture a prototype, which may result in a delay in launching the product to the market.

Identifying these potential problems in advance can help devise a strategy to deal with and overcome them during the development and manufacturing stages of the robotic arm.

3. Objectives

The objectives of the project to manufacture a robotic arm model for microsurgery include:

1. Developing a precise robotic arm for microsurgery.
2. Improving the quality of health care.
3. Reducing surgical intervention and surgery risks.
4. Improving the accuracy of surgical operations.
5. Increase the productivity of surgeons.
6. Providing a comfortable working environment for surgeons.
7. Promoting technological progress in the field of medicine.

4. Scope of the study

The scope of the study on manufacturing a robotic arm model for microsurgery includes several important elements:

1. Mechanical design: It includes studying and developing the design of the robotic arm so that it allows the precise control and flexibility necessary for surgeons during delicate surgical operations.
2. Electronic technologies and mechatronics: It includes studying and developing the technologies necessary to control the robotic arm accurately and effectively, such as motion sensors and electronic control systems.
3. Programming and Control: It includes developing the software necessary to direct the movements of the robotic arm accurately and efficiently, in addition to identifying and applying appropriate control algorithms.
4. Performance testing and evaluation: It includes evaluating the performance of the robotic arm under different conditions, and analyzing the results to ensure that the desired performance is achieved.
5. Materials and Manufacturing Processes: It involves selecting the appropriate materials and manufacturing processes to manufacture the mechanical parts of the robotic arm at the lowest cost and highest quality.
6. Safety and medical compatibility: This includes designing the robotic arm to comply with safety and medical compatibility standards, and ensuring that it does not cause any harm to the patient.

These elements represent the basic scope of the study of manufacturing a robotic arm model for microsurgery, and identify the main areas of focus during the manufacturing and development process.

1. Robotic arms

What is robotic arms?

Chapter Two Literature Review

Robotic arms are mechanical devices designed to mimic the movements of a human arm. They typically consist of a series of joints and links, allowing them to move with multiple degrees of freedom. Robotic arms are often used in various applications, including manufacturing, assembly lines, surgery, and space exploration. They can be controlled manually by an operator or programmed to perform tasks autonomously using sensors and algorithms. Robotic arms are versatile tools known for their precision, efficiency, and ability to perform repetitive tasks with high accuracy. Robotic arms can be found in a wide range of sizes and configurations, from small, lightweight arms used in desktop applications to large, industrial-scale arms capable of lifting heavy loads. They are equipped with various end-effectors, such as grippers, tools, or sensors, depending on the specific task they are designed to perform. In manufacturing, robotic arms are used for tasks like welding, painting, and assembly, where precision and efficiency are essential. In surgery, robotic arms are employed for minimally invasive procedures, allowing surgeons to perform delicate operations with enhanced precision and control. Overall, robotic arms play a crucial role in increasing productivity, improving safety, and advancing automation in various industries.

Fig. 1 robotic arm

19th century (1800 - 1899): In this period, early ideas about robots and robotic arms first began to emerge. In 1821, British scientist Charles Biggs developed one of the first mechanical mechanisms that may be an early example of robotic arms.

The twentieth century (1900 - 1999): During this century, robots witnessed remarkable development. In 1954, George Davids developed the first industrial robot called Ray, which was intended for use in manufacturing operations. Then, in 1961, Joseph Engelberger founded International Robotics to develop and market the Ray for use in manufacturing and industry.

21st century (2000 - present): In recent decades, we have witnessed tremendous progress in robotics and artificial intelligence technologies. New robotic arms have emerged with more precise and efficient features. Currently, robotic arms are used in multiple fields, including manufacturing, medicine, scientific research, aerospace, and more.

Use in medicine: One of the most prominent modern applications of robotic arms is in the field of medicine, where they are used in microsurgery and less invasive surgical interventions. This includes the use of the robotic arm in heart surgeries, bone and joint surgeries, eye surgeries, etc., which has improved treatment outcomes and reduced surgical risks.

Fig. 2 The use of robotic arm in medicine

The use of robotic arms in the field of medicine is considered a tremendous development in the field of surgery and treatment, as this unique technology allows doctors to perform precise and effective surgical operations without the need for large parts or long recovery periods. Here is a detailed explanation of some of the main applications of robotic arms in the medical field:

1. Microsurgery and minimally invasive surgical interventions: Doctors use robotic arms in many surgeries that require high precision and minimal surgical intervention. For example, in cardiac surgery, robotic arms can be used to perform heart valve correction operations or to perform arterial bypass operations with high precision and minimal injury to surrounding tissue.
2. Bone and joint surgery: Robotic arms can be used in joint replacement surgeries such as the knee and hip, as this technology allows the removal of damaged tissue with high precision and the perfect installation of artificial joints. Robotic arms can also be used in surgeries to repair broken bones accurately and effectively.
3. Tumor surgery: Robotic arms can be used to remove cancerous tumors with high accuracy and with the least possible surgical intervention. This helps preserve surrounding tissue, reduces the risks of surgery, and contributes to improving treatment outcomes for patients.
4. Eye surgery: In eye surgery, robotic arms can be used to perform delicate operations such as LASIK surgery and implantation of artificial lenses. The high precision of robotic arms allows to reduce surgical risks and improve treatment outcomes for patients.
5. Training and education: In addition to surgeries, robotic arms can be used in medical training and education, where doctors and students can practice performing surgeries without the need for live subjects, which helps develop their skills and improve their performance in the future.

2. Types of robotic arms

Robotic arms come in various types, each designed for specific applications and tasks. Here are some common types of robotic arms:

1. Articulated Robotic Arms:

Articulated robotic arms are a common type of robotic arm used in a wide range of applications in various industries. These arms consist of several parts connected to each other by rotating joints, allowing them to move in multiple ways. The ability of the arm depends on the number of joints available, as each degree of freedom of movement increases the flexibility of the arm and its ability to achieve a wide range of tasks. Articulated robotic arms work based on the principles of cinematics, as these principles are used to determine the movement of parts and joints. Joint angles are controlled to achieve desired positions and manipulations accurately and effectively. These arms find widespread use in industries such as manufacturing, automotive, electronics, aerospace, and healthcare, where they are used for purposes such as assembly, welding, material handling, robot-assisted surgery, and more. Among the advantages of articulated robotic arms are their flexibility and precision, as they can Reaching objects from different angles and manipulating them with high precision. Thanks to these advantages, it can be used in a variety of applications and tasks in various industries, making it a valuable tool in automating processes and improving productivity and efficiency in the industrial process.

Fig. 3 Articulated Robotic Arm

2. Cartesian Robotic Arms:

Cartesian robotic arms are a type of mobile robotic arms that move on parallel paths along three main axes: X, Y, and Z, in a rectangular coordinate system. These arms represent an important part of industrial robotic systems as they are used in a variety of applications, including assembly, CNC machining, material handling, packaging, 3D printing, and many others. Cartesian levers are precise in movement, easy to program, and able to use small spaces, making them ideal for meeting the demands of modern industrial manufacturing.

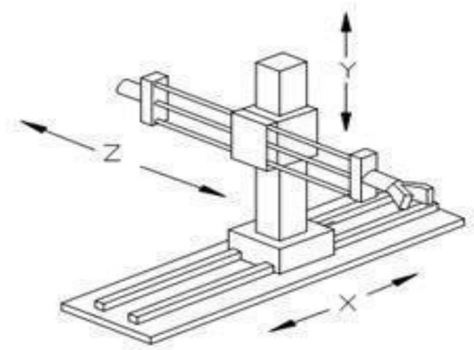

Fig. 4 Cartesian Robotic Arm

3. SCARA Robotic Arms:

SCARA stands for Selective Compliance Assembly Robot Arm or Selective Compliance Articulated Robot Arm. These arms have two parallel rotary joints that provide compliance in the vertical direction while maintaining rigidity in the horizontal plane. SCARA robots are commonly used in assembly applications, packaging, and material handling.

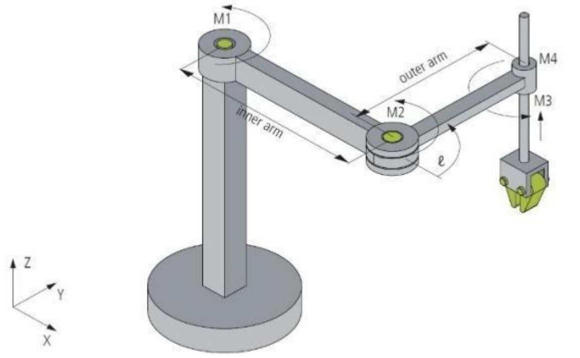

Fig. 5 SCARA Robotic Arm

4. Delta Robotic Arms:

Delta robots, also known as parallel robots, feature multiple parallel arms connected to a common base. They use parallelograms to maintain a fixed orientation of the end-effector while providing high-speed and precision movements. Delta robots are commonly used in applications requiring fast and precise motion, such as pick-and-place operations in the food industry and electronics assembly.

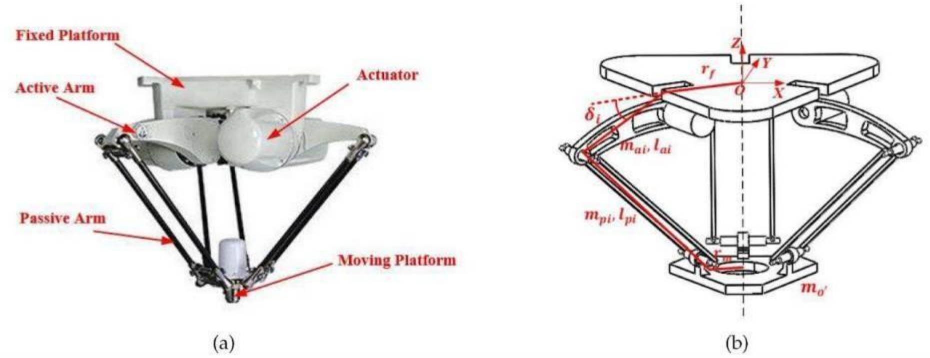

Fig. 6 Delta Robotic Arm

5. Cylindrical Robotic Arms:

Cylindrical robots consist of a vertical column attached to a horizontal arm, resembling a human arm with a single rotary joint at the base and a prismatic joint for vertical movement. They are suitable for tasks requiring extended reach and vertical motion, such as machine loading and unloading, welding, and painting.

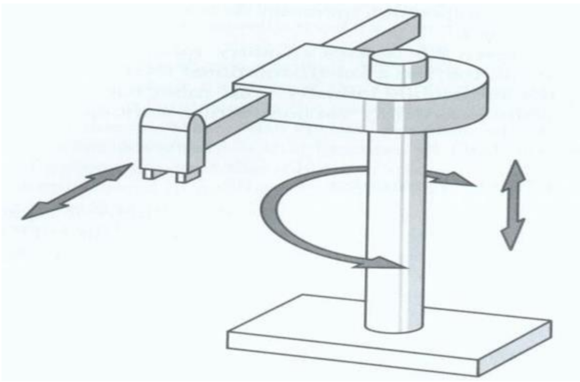

Fig. 7 Cylindrical Robotic Arm

6. Collaborative Robotic Arms (Cobots) :

Collaborative robots are designed to work alongside humans in shared workspaces safely. They feature advanced sensors and control systems that allow them to detect and respond to human presence, reducing the need for safety barriers. Cobots are used in various industries for tasks like assembly, packaging, and quality inspection.

Fig. 8 Cobots

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Chapter Three Overview and planning

1. Proposed System Overview

The goal of designing the robotic arm for small surgeries is to provide a precise tool for surgeons to perform surgeries that require high precision and precise access to sensitive areas inside the body. The robotic arm helps improve the accuracy of surgery, reduce risks and improve treatment outcomes for patients. The robotic arm offers the ability to reach narrow areas within the body with small, precise cuts, reducing damage to surrounding tissue and accelerating the healing process. Advanced precise robotic control technology also enables the surgeon to perform precise and complex movements while remaining in their seat, reducing fatigue and physical stress during the surgical procedure.

Ultimately, the design of the robotic arm for small surgeries aims to improve the surgeon's experience and achieve better patient outcomes by providing a precise and advanced tool for surgical intervention.

2. Challenges

- Accuracy: The robotic arm must be able to achieve high accuracy in movement and control, especially when dealing with sensitive tissues inside the body.
- Durability and reliability: The robotic arm must be durable and reliable to ensure continuous and reliable performance during repeated surgeries.
- Biological compatibility: The design of the robotic arm should be compatible with the human body environment, and should not cause any irritation or damage to the surrounding tissue.
- Cost: Medical robotics technology can be expensive, and designing a robotic arm requires high costs for research, development and experimentation.
- Control and guidance: An advanced and effective control system must be available so that surgeons can precisely control the robotic arm during the surgical procedure.
- Training and education: The use of the robotic arm requires specialized training for surgeons and medical teams to ensure its effective and safe use.

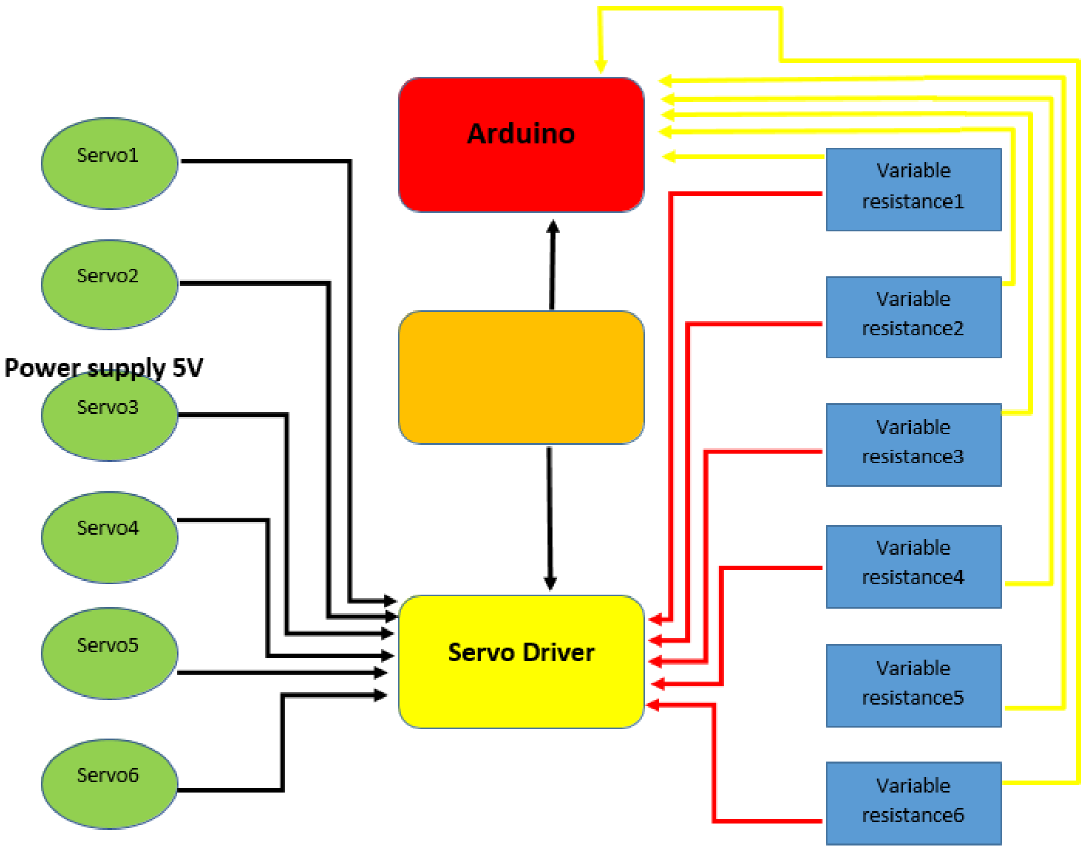
3. Assumptions

Table 1. Assumptions for the project

S. No		category	Assumptions	Actions

1		Requirements gathering	Requirements of the project are analyzed and collected	met the project guide that the requirements are ready and working properly
2		Software programming	The coding of the program is done	The Arduino have programmed
3		Implementation	This done for each phase of the project	Some of the phases of implementation is shown in the documentation.
4		Testing	This is done after the project is complete and each phase is tested and modified	After the testing is completed successfully it is shown to the project guide and the documentation is prepared

4. Architecture Specifications



5. Software and hardware requirements

1. Software

✓ Computer for programming

2. Hardware

- ✓ Arduino Nano
- ✓ 6 variable resistors
- ✓ 6 servo motors
- ✓ servo driver
- ✓ Power supply 5V
- ✓ Breadboard
- ✓ Arduino Nano

The Arduino Nano is a small, complete, and breadboard-friendly microcontroller board based on the ATmega328 (Arduino Nano 3.x) or the ATmega168 (Arduino Nano 2.x). It has more or less the same functionality of the Arduino Uno, but in a different package. It lacks only a DC power jack and works with a Mini-B USB cable instead of a standard one.Here are some key features of the Arduino Nano:

.Microcontroller: ATmega328

.Operating Voltage: 5V

.Input Voltage (recommended): 7-12V

.Input Voltage (limits): 6-20V

.Digital I/O Pins: 14 (of which 6 provide PWM output)

.Analog Input Pins: 8DC

.Current per I/O Pin: 40 mA

.Flash Memory: 32 KB (ATmega328) of which 2 KB used by bootloader

.SRAM: 2 KB (ATmega328)

.EEPROM: 1 KB (ATmega328)

.Clock Speed: 16 MHz

.Dimensions: 18 x 45 mm

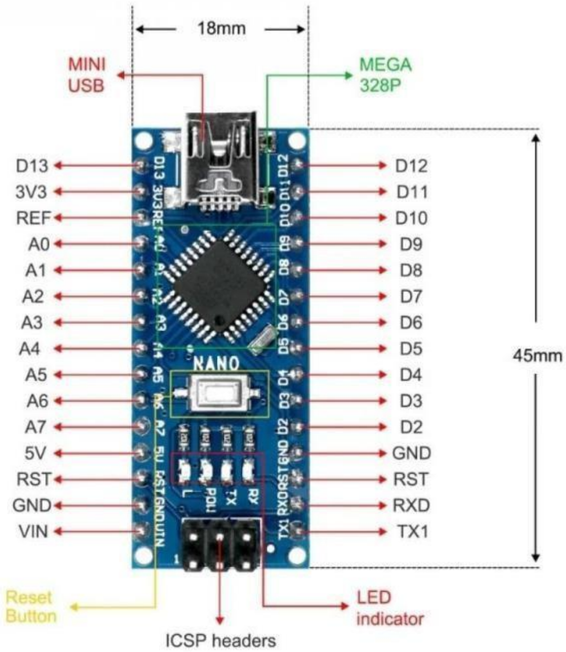


Fig. 9 Structure of Arduino Nano

➢ Variable resistance

Variable resistance refers to an electrical component whose resistance can be adjusted manually or automatically. This adjustment allows for control over the amount of current flowing in a circuit. Potentiometers and rheostats are common examples of variable resistors. They are used in various electronic devices for controlling volume, brightness, speed, and other parameters.

✓ servo motor

Fig. 10 Structure of variable resistors

A servo motor is a type of rotary actuator that allows for precise control of angular position. It consists of a motor coupled with a sensor for position feedback, along with a control circuit. Servo motors are commonly used in robotics, remote-controlled vehicles, industrial automation, and other applications where accurate and controlled movement is required. They are known for their high precision, reliability, and ability to maintain position even under varying loads.

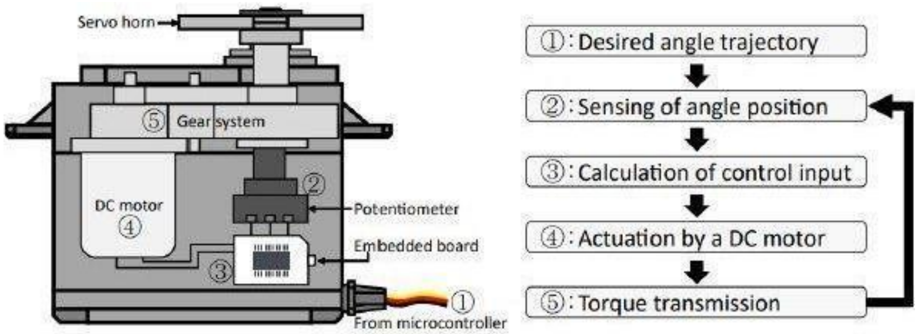


Fig. 11 Structure of servo motor

Chapter Four System Implementation

1. Hardware

In our project, we connect the parts of hardware that explained in chapter three.

1. connects the Arduino with power supply
2. connects the servo driver with power supply
3. connect the servo driver in the pins of Arduino

✓ ground to ground

✓ Vcc to 5V pin

✓ SDA to A4 pin of Arduino

✓ SCL to A5 pin of Arduino

4. Connect variable resistors to the circuit

✓ Vcc to 5V pin in Arduino

✓ Ground to ground pin in Arduino

✓ Connect the first variable resistor to A0

- ✓ Connect the second variable resistor to A1
- ✓ Connect the third variable resistor to A2
- ✓ Connect the fourth variable resistor to A3
- ✓ Connect the fifth variable resistor to A6
- ✓ Connect the sixth variable resistor to A7

5. Connect servo motors to the servo driver

- ✓ Connect the first servo motor to PWM0
- ✓ Connect the second servo motor to PWM1
- ✓ Connect the third servo motor to PWM2
- ✓ Connect the fourth servo motor to PWM3
- ✓ Connect the fifth servo motor to PWM4
- ✓ Connect the sixth servo motor to PWM5

2. Software

The programing of the software is

- ✓ programing of the Arduino

The Arduino programmed by the open-source Arduino Software (IDE) that makes it easy to write code and upload it to the board. It runs on Windows, Mac OS X, and Linux. The environment is written in Java and based on Processing and other opensource software. This software can be used with any Arduino board. The code below explained the hardware circuit code.

```
// Include Wire Library for I2C Communications
#include <Wire.h>

// Include Adafruit PWM Library
#include <Adafruit_PWMServoDriver.h>

#define MIN_PULSE_WIDTH       650
#define MAX_PULSE_WIDTH       2350
#define FREQUENCY             50

Adafruit_PWMServoDriver pwm = Adafruit_PWMServoDriver();

// Define Potentiometer Inputs
int controlBase = A0;
int controlElbow = A1;
int controlWrist = A2;
int controlPivot = A3;
int controlFifthServo = A6;
int controlSixthServo = A7;

// Define Motor Outputs on PCA9685 board
int motorBase = 0;
int motorElbow = 1;
int motorWrist = 2;
int motorPivot = 3;
int motorFifthServo = 4;
int motorSixthServo = 5;

void setup()
{
  // Setup PWM Controller object
  pwm.begin();
  pwm.setPWMFreq(FREQUENCY);
}

// Function to move motor to specific position
void moveMotorDeg(int moveDegree, int motorOut)
{
  int pulse_wide, pulse_width;

  // Convert to pulse width
  pulse_wide = map(moveDegree, 0, 180, MIN_PULSE_WIDTH, MAX_PULSE_WIDTH);
  pulse_width = int(float(pulse_wide) / 1000000 * FREQUENCY * 4096);
```

```
  //Control Motor
  pwm.setPWM(motorOut, 0, pulse_width);
}

// Function to convert potentiometer position into servo angle
int getDegree(int controlIn)
{
  int potVal,srvDegree;

  //  Read  values  from  potentiometer
  potVal = analogRead(controlIn);

  // Calculate angle in degrees
  srvDegree = map(potVal, 0, 1023, 0, 180);

  //  Return  angle  in  degrees
  return srvDegree;

}

void loop() {

  //Control Base Motor
  int        mtrDegreeBase        =        getDegree(controlBase);
  moveMotorDeg(mtrDegreeBase, motorBase);

  //Control Elbow Motor
  int        mtrDegreeElbow        =        getDegree(controlElbow);
  moveMotorDeg(mtrDegreeElbow, motorElbow);
  //Control Wrist Motor
  int        mtrDegreeWrist        =        getDegree(controlWrist);
  moveMotorDeg(mtrDegreeWrist, motorWrist);
  //Control Pivot Motor
  int        mtrDegreePivot        =        getDegree(controlPivot);
  moveMotorDeg(mtrDegreePivot, motorPivot);
  //Control Fifth Servo Motor
  int        mtrDegreeFifthServo        =        getDegree(controlFifthServo);
  moveMotorDeg(mtrDegreeFifthServo, motorFifthServo);
  //Control Sixth Servo Motor
  int  mtrDegreeSixthServo  =  getDegree(controlSixthServo);
  moveMotorDeg(mtrDegreeSixthServo,        motorSixthServo);
  delay(20);
}
```

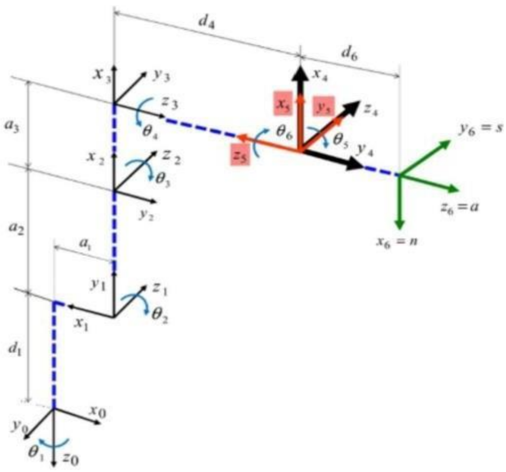
Chapter Five Testing and Results

1. Tests

To ensure the accuracy and duration of Manufacturing a Robotic Arm prototype for minimally invasive surgeries. We doing some tests:

1. Accuracy test

Evaluate the ability of the 6DoF robotic arm to reach specified locations



I define a set of different locations in 3D space (x, y, z) that the robotic arm must reach. And I sent movement commands to the arm to reach each target location. And I used Euler's matrix to find the direction of the angles

$$DH_{i-1} = \begin{bmatrix} \cos(\theta i) & -\sin(\theta i)\cos(\alpha i) & \sin(\theta i)\sin(\alpha i) & ai\cos(\theta i) \\ \sin(\theta i) & \cos(\theta i)\cos(\alpha i) & -\cos(\theta i)\sin(\alpha i) & ai\sin(\theta i) \\ 0 & \sin(\alpha i) & \cos(\alpha i) & di \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

T0-6 = T0*T1*T2*T3*T4*T5*T6

$\beta = Atan2\left(-r31, \sqrt{r11^2 + r21^2}\right)$

$\alpha = Atan2\left(r21/c\beta, r11/c\beta\right)$

$\gamma = Atan2\left(r32/c\beta, r33/c\beta\right)$

Table 2 some results using Euler's matrix

Joint	θ	α	d	a
1	0	-90	169.77	64.2
2	-90	0	0	305
3	0	90	0	0
4	0	-90	-222.63	0
5	0	90	0	0
6	180.01	0	-36.25	0

2. Duration test

This test measures the average time it takes the robotic arm to complete the task. I measured the time to move one motor and it takes 6 seconds to move.

2. Results and discussion

In this section, the results of the impact of Altered Joint Angles of each joint (1 rad) are presented with the fixed angles of the five remained joints of an arm on the position and orientation of the end effector, and compared to the position and orientation of the end effector at the initial arm pose (Home Position), where all angles of the joints are zero. To validate the position and orientation, the performed experiments with seven cases are carried out. All experiments are performed with the experiment setup and methodology discussed in this section. These cases are first presented visualized in the xsarm_description_rviz-RViz software. Table 4 compares EE-Coordinates using the Rviz platform in the ROS of the seven situations inspected in this investigation to EE coordination in the initial arm condition, which was designated case 0

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