Sudan University of Science and Technology
College of Engineering
School of Mechanical Engineering
(Production Department)
&
School of Electronics Engineering
(Computer Engineering & Network)

Design and Fabricate Handling Arm

A project submitted in partial fulfillment for the Requirements of the Degree of B.Sc. (Honor) in Mechanical engineering (production)
&
Electronics engineering (Computer engineering & network)

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الآية

بسم الله الرحمن الرحيم

قال تعالى:**(قَالُوا سُبْحَانَكَ لَا عِلْمَ لَنَا إِلَّا مَا عَلَّمْتَنَا ۖ إِنَّكَ أَنتَ الْعَلِيمُ الْحَكِيمُ)**

سورة البقرة (32)

Dedication

We dedicate this thesis to:

School of Mechanical Engineering – School of electronic Engineering Sudan University of Science and Technology,

Our parents: words are just not expressive enough,

They introduced us to the joy of reading from birth enabling such a study to take place today,

Our brothers, sisters and our best friends, without them none of our success will be possible.

Our gratefulness to **Dr/ Jaffer Abdulhameed** for supporting, trusting in our selves ,funding, and guide us through the project to the current success, believing in our skills, so God bless you …

Never forget **Eng/ Hamid awad Elkhier** for his precious time and help in manufacturing process with his laser cutting machine,

Acknowledgement

All praise and thanks to Allah who provide us with the ability to complete this work. We are thankful to our families who are always supportive and helpful throughout our studies.

We would like to express our special appreciation and gratitude to our advisors **Dr. Jaffar abdulhameed, Dr. Ahmed Abdallah** for being such a source of inspiration and motivation to us.

Their patience and advises on our research and writing this thesis have been invaluable.

ABSTRACT

This thesis focuses on design, implementation and control of six degrees of freedom (DOF) robotic arm using servo motors to simplify the application of robotic science in CNC (computer numerical control)lap for the students of Sudan university of science and technology. The robot arm designed to work in 0.5 m^2 workspace as an articulated educational robot, loading on the end effecter mass of 2 kg. Perspex extruded acrylic sheets were selected as a material for robotic arm. SOLIDWORKS, ANSYS software are used to modeling and analysis the robotic structure, ARDUINO for control the pulses that move the servo motors. The robot arm manufactured and loaded 2 kg with the end effector.

المستخلص

يتلخص البحث في تصميم و تطبيق و التحكم في ذراع مناولة ذات ستة درجات حرية باستخدام سيرفو موتورز لتبسيط تطبيق علم الروبوتيك في معمل التحكم الرقمي بالحاسوب لطلاب جامعة السودان للعلوم و التكنولوجيا. تم تصميم ذراع المناولة للتشغيل داخل مجال عمل نصف متر مربع لحمل كتلة مقدارها 2 كيلوجرامات. تم اختيار الواح الاكرليك كمادة لتصنيع ذراع المناولة,و استخدمت برامج سوليد ويرك و انسيس لتحليل بنية الروبوت. و أيضا تم استخدام أردوينو للتحكم في اشارات و توجيه الروبوت بواسطة سيرفو موتورز .تم تصنيع ذراع المناولة لحمل الكتلة المقدرة ب 2 كيلوجرام في المؤثر الطرفي للذراع.

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Chapter One

INTRODUCTION

Chapter One

INTRODUCTION

1.1 Introduction

With the growth of technology, the need of new devices grows. Computer and electronic sciences is mostly premier in raising the new technologies. Of course the new technology could affect different engineering fields. For instance, if the robotics and artificial intelligence are considered, it reveals that the technology with its high potential, affected many different fields of studies. Therefore related fields of study could be combined to generate new technologies that can be used in wide fields.

It has become is possible to achieve complex task with the aid of robots and a robust control system. Tasks such as industrial applications, medical operations and emergency situations requires precision, speed, low response time and certainty, this is where the need for human assisting equipment is the most.

The robots play important roles in daily lives and are able to perform the tasks which cannot be done by humans in terms of speed, accuracy and difficulty. Robots can be employed to imitate human behaviors and then apply these behaviors to the skills that lead the robot to achieve a certain task. They do not get tired or face the commands emotionally, and since they are designed by humans. They can be programmed and expected to obey and perform some specific tasks.

The idea of robotic is to create practical and useful robots that facilitate the daily tasks. Because of the independency of the robots, they have longer life time comparing with the humans and can be helpful in industry, dangerous tasks and nursing homes.

Recently, robots operate in almost human labors mostly in the fields which are unhealthy or impractical for workers.

There are situations where a robot is a replacement for human because the human does not have the capability to work under the specific conditions, such as working in the space, under the water. Therefore, while designing a robot, considering the factors such as concept and techniques, artificial intelligence and cognitive science are essential in order to obtain an effective design. The other situation is when the robot is used to ease the actions done by the human.

Obviously, building a robotic arm is not a new idea, but still the design and the specifications can differ from other designs. For instance, the circuitry, degree of freedom (DOF), algorithm, program, attachments, equipment, accuracy and speed, completely depend on the designer's tact.

The challenge is to be able to perform some physical tasks close to a human's hand actions, such as replacement and grabbing, under the conditions where a human hand is not a particular solution.

1.2 Problem Statement

The problem is the lake of application of robotic science in Sudan University of science and technology, so the experiment is to produce a unit of robotic handling arm as simple educational robots to work in CNC (computer numerical control) lap for the students.to simplify the process of handling and how to build a controlled structure of robot arm.

1.3 Project Aim

Modeling and manufacturing a unit of articulated handling robot for educational use for Sudan University's student in CNC (computer numerical control) lap.

1.4 Project Scope

Design and fabricate a unit of articulated handling robot with 0.5 m2 Workspace as an educational robot using SOLIDWORKS software in modeling ,ANSYS software for static structure analysis process, Perspex acrylic sheets as a material, and the manufacturing process via laser cutter machine, to work in the CNC lap at Sudan university of science and technology.

1.5 Project Layout

This project consist of five chapters shown the stages of work, the schedule of work is shown below.

Gantt chart											
	Dec	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**
Ch. 1	■										
Ch. 2		■	■	■							
Ch. 3				■	■	■	■	■	■		
Ch. 4								■	■	■	
Ch. 5											■

Figure 1-1 project layout (gantt chart 2015-2016)

Chapter Two

PREVIOUS STUDIES

Chapter Two

LITRATURE REVIEW

2.1 Background

Generally robots are designed, built and controlled via a computer or a controlling device which uses a specific program or algorithm. Programs and robots are designed in a way that when the program changes, the behavior of the robot changes accordingly resulting in a very flexible task achieving robot. Robots are categorized by their generation, intelligence, structural, capabilities, application and operational capabilities. In this study robots are reviewed according to their structural properties. [1]

2.2 Structural Classifications of Robots

1- Linear Robots (including Cartesian and gantry).

2- Cylindrical Robots.

3- Spherical Robots.

4- SCARA Robots.

5- Articulated Robots. [1]

2.2.1 Linear Robots

A robot which has linear actuators cooperating with linear motors linked to a linear axis is known as a linear robot (also known as gantry or Cartesian). This link can be fixed or flexible connections between the actuators and the robot. The linear motor is attached directly to the linear axis.

Robots which use two motors in controlling a linear axis defined gantry robots. Each motor has a limited distance orthogonal to the linear axis. Ball screws follow the same principles which either use linear motors or rotary motors. This kind of robots usually achieve tasks such as palletizing, unitizing, and stacking, order grasping, loading, and coordinate measuring.

The manipulator (also known as end-effector) of the linear robots is connected in an overhead way that allows the robot to move along the horizontal plane easily, where each of these movements are perpendicular to each other and are basically defined as x, y for horizontal axis and sometimes z in case of having a vertical axis.

Figure 2-1 -X-Y robot

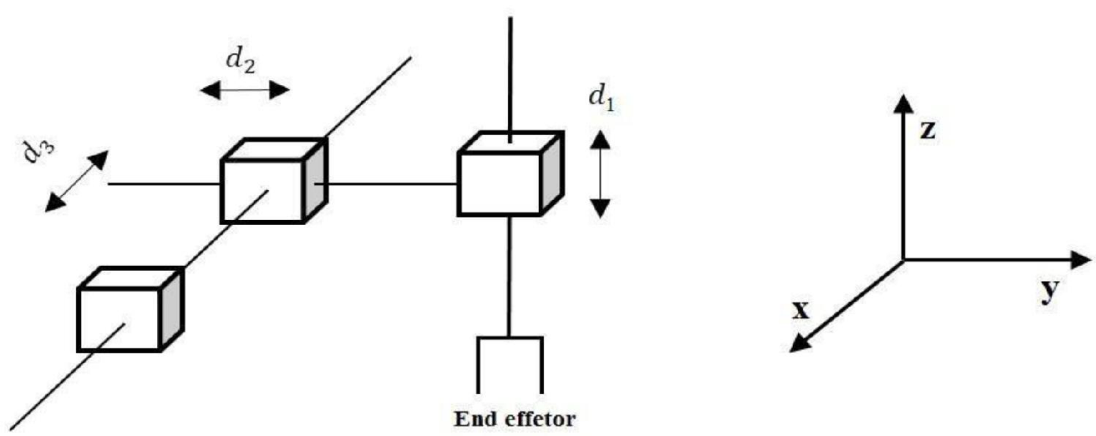


Figure 2-2 Cartesian horizontal reach and its symbol (on the right)

Advantages:

- Large workspace.
- High speed and stiffness.
- Good performance.
- Good for multiple machines and lines.
- Good handling with large loads.

Disadvantages:

- Large structural frame.
- Complex mechanical properties for linear sliding movements.
- Energy inefficiency.
- Large floor space requirement.
- Limited workspace.
- Common workspace restriction.[1]

2.2.2 Cylindrical Robots

Cylindrical robots have two prismatic joints: one rotary joint for positioning task and the end effectors of the robot forms a cylindrical workspace. The main idea of the cylindrical robots is to mount a horizontal arm which moves in forward and backward directions. The horizontal arm is linked to a carriage which goes up and down and is connected to the rotary base.

Schematic cylindrical robot and its symbol are shown in Figure below

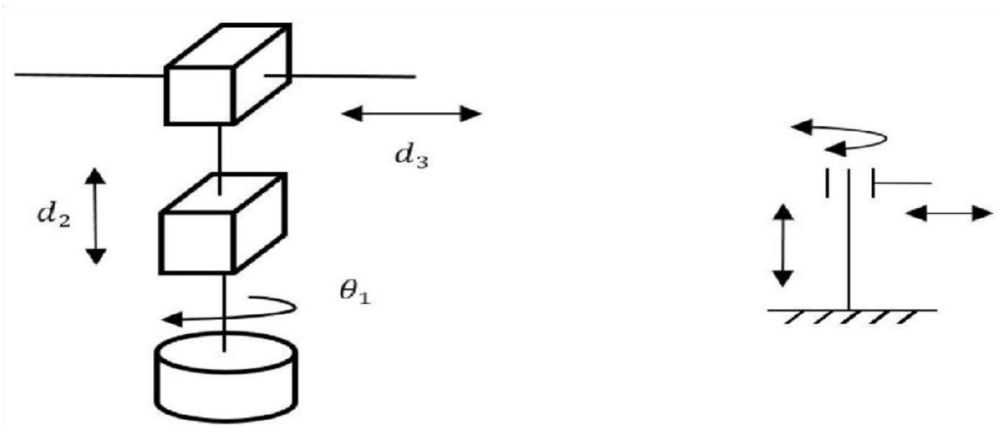


Figure 2-3 Cylindrical robot and its symbol (on the right)

When the arm of the robot has a revolute and two prismatic joints, it can operate in z-axis and each point that can be reached by this robot can be represented by the cylindrical coordinates. As shown in Figure 4, the robot can move in and out in z direction, can elevate in y direction and can rotate in θ direction. The arm can move in directions between the specific upper and lower boundaries.

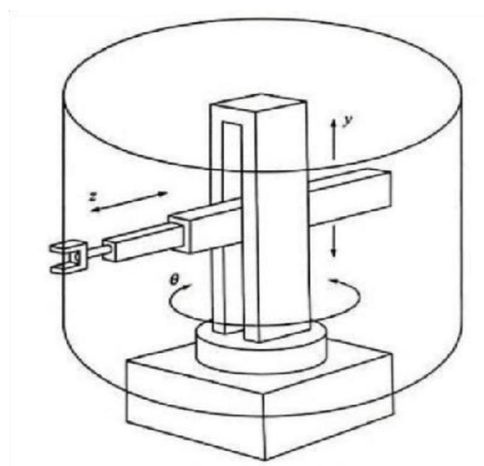


Figure 2-4 Cylindrical robot and its symbol (on the right)

Advantages:

- No collisions while moving.
- Two linear axis result in simpler design.

Disadvantages**:**

- Large structural frame.
- Incompatible with other robots.
- Inaccurate on the end resolution compared to Cartesian robot. [1]

2.2.3 Spherical Robots

The spherical robot (also known as polar robot) is huge in terms of size and has a telescopic arm. Spherical robot basic movements are rotation at the base and angularly up and down at the arm.

Spherical robots have at least two movable joints and one fixed joint. The schematic diagram and symbol of the spherical robot are shown in Figure 2.5.

The motion of the spherical robot consists of the following three movement steps; the first movement defines the rotation of the base along vertical axis. The second movement defines the rotation of the arm and finally the third movement defines the in and out motion. The workspace of the spherical robot depends on the volume of globe of the sphere.

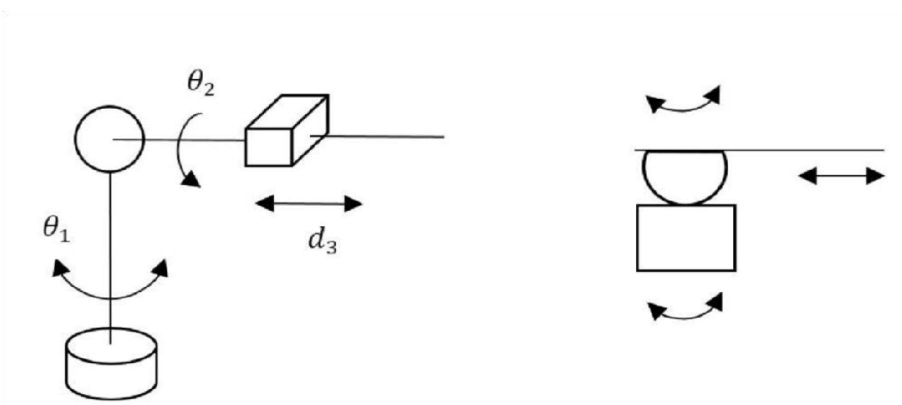


Figure 2-5 Schematic diagram of spherical robot and its symbol (on the right)

The workspace of the robot is the space between two concentric hemispheres. When the arm is fully retracted, the reach of the arm is the inner hemisphere and when the arm is fully straightened, the reach is the outer hemisphere. A typical spherical robot configuration is shown in Figure 2.6**.**

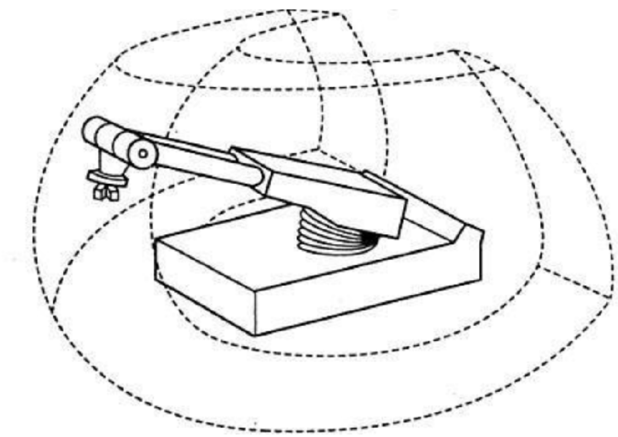


Figure 2-6 Spherical Robot Configuration

Advantages:

- Light weight.
- Simple kinematics.
- Compatible with other robots especially with ones in a common workspace.
- Sharp joints level.
- Good resolution due to perpendicularity of the end-effectors' errors.

Disadvantages:

- Need of variable torque due to the large size.
- Challenging counter balancing.
- Chance of having collision with obstacles due to bounded ability to avoid collisions.
- Large position errors due to the rotation and proportional radius.[1]

2.2.4 SCARA Robots

Selective Compliance Assembly Robot Arm (SCARA) was first designed and Invented in early 1960s in Japan. SCARA robots are perfect for the applications which require high speed and repetitive point to point movements. This is why SCARA is used widely in assembly operation. Special end-effector movement makes SCARA ideal for the tasks which require uniform motion and accelerations in a circular form.

SCARA consists of two parallel rotary joints and a prismatic joint. The rotary joints can move along the horizontal plane and the prismatic joint moves along the vertical plane. One of the special characteristic of SCARA is that the robot is smooth while operating on X and Y-axis but very strong versus the z-axis.

Figure shows the schematic diagram of SCARA.

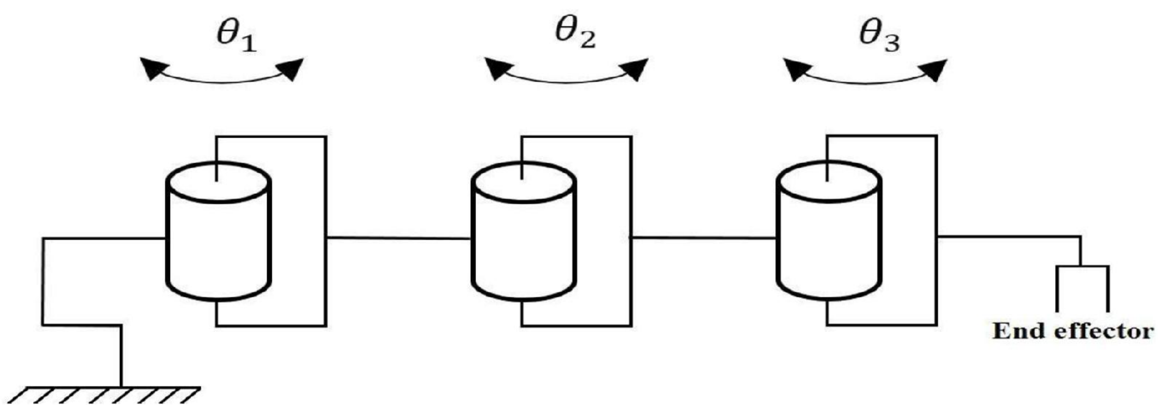


Figure 2-7 Schematic Diagram of SCARA

SCARA arm is able to pick up a part vertically from a horizontally placed table and move along the horizontal plane to a desired point and accomplish the assembly task by lowering the arm and placing the part at its proper location. Figure 8 shows a typical SCARA robot.[1]

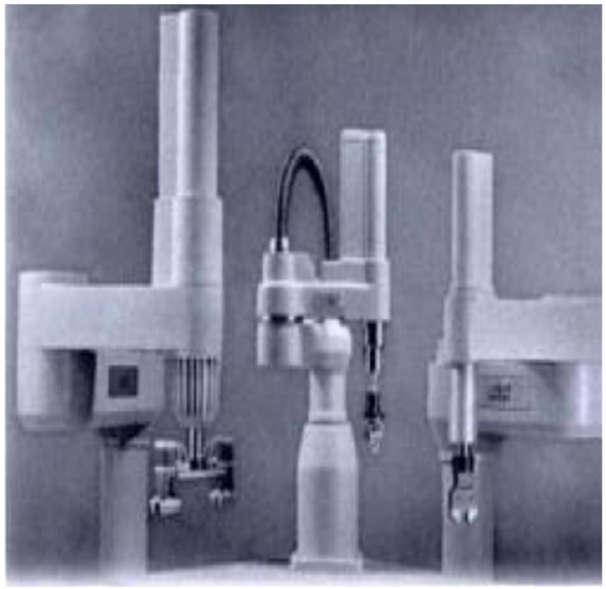


Figure 2-8 SCARA robot

2.2.5 Articulated Robots

Articulated robots (also known as revolute robots) have three fixed axis connected to two revolute base. All joints of an articulated arm are revolute and most likely represent the human arm. Figure 2.9 shows the schematic diagram and symbol of an articulated robot.

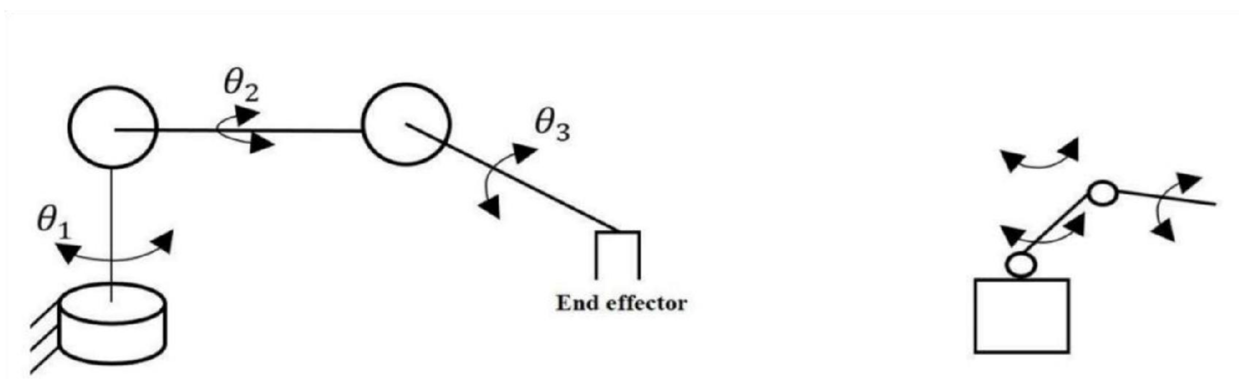


Figure 2-9 Schematic diagram of an articulated robot and its symbol (on the right)

The moving rigid objects are called links, revolute joints are called hinges and prismatic joints are called sliding joints. Each joint defines the relative motion of the other two objects it links which determines the subset of the whole configuration space. Each configuration subset is a different position for each link. These subsets are simple to measure by considering a distance or an angle with each joint.

A robotic arm can be said to be a typical example for articulated robot. An important matter which should be considered is that the dimension of the configuration space increases with the number of joints however the operation speed is limited due to the different payloads at the manipulator and nonlinear environment.

Almost 80% of the registered robots are articulated and up to 20% are linear robots. Figure 2.10 shows a typical articulated robot

Figure 2-10 Articulated Robot

Advantages**:**

- Superb structural flexibility.
- Compatible with other robots operating in common workspace.
- High rotation speed.

Disadvantages:

- Low accuracy and resolution because of rotary joints and positional errors.
- Counter balancing difficulties due to the large and variable torque.
- High chance of collision.
- Dynamic instability due to higher moment of inertia and gravity. [1]

2.3 Kinematics of Robots:

Kinematics is the most basic study of how mechanical systems behave. In mobile robotics, we need to understand the mechanical behavior of the robot both in order to design appropriate mobile robots for tasks and to understand how to create control software for an instance of mobile robot hardware, the process of understanding the motions of a robot begins with the process of describing the contribution each motor provides for motion, there are additional degrees of freedom and flexibility due to the wheel axles, wheel steering joints, and wheel castor joints. In defining the workspace of a robot, it is useful to first examine its admissible velocity space. Given the kinematic constraints of the robot, its velocity space describes the independent components of robot motion that the robot can control. The number of dimensions in the velocity space of a robot is the number of independently achievable velocities. This is also called the differentiable degrees of freedom (DDOF), A robot's is always equal to its degree of mobility. The objective of a kinematic controller is to follow a trajectory described by its position or velocity profile as a function of time. The control problem is to recomputed a smooth trajectory based on line and circle segments which drives the robot from the initial position to the final position. Feedback control: A more appropriate approach in motion control of a mobile robot is to use a real-state feedback controller. With such a controller, the robot's path-planning task is reduced to setting intermediate positions (sub-goals) lying on the requested path.[2]

2.4 Types of Electric Motors:

An electric motor is an electromagnetic device that converts electrical energy into mechanical energy.[3]

2.4.1 AC motors

AC motors are commonly found in industrial factories driving conveyor belts or other heavy machinery. There are very few robot arms that use AC motors. Some of the reasons are due to poor accuracy, low starting torque and poor dynamic response.

2.4.2 Continuous DC motors

DC motors are more commonly found in robot arms. Continuous motors move as long as power is applied and stops as soon as the power is removed. For continuous rotation the power has to be pulsed to the motor and this is done by a computer or indexer. Different types of continuous motors include brushless, permanent magnet and variable reluctance. However, these motors do not provide position control and are not very useful for precise robotic arm movement.

2.4.3 Servo motors:

A servo motor is a DC motor combined with some position sensing parts. Typically, servo motors have 3 wires coming out from the motor. Two lines are for power and the third line is a control input. A pulse width signal applied to this input tells the motor to what position it should be moved to. The inside of a servo motor consists of a DC motor, a gear train, limits stops and a potentiometer for position feedback. Robot arms using servos monitor the robot's axes and its components for position and velocity.

2.4.4 Stepper motors

A stepper motor is very simple DC motor because it has no brushes or contacts. It operates by having its magnetic field electronically switched to rotate the armature magnet around. This setup allows the motor to rotate a specific angle and stop. There are two types of stepper motors which are bipolar and unipolar types. The bipolar stepper motor consists of two coils and the current direction is reversed in each coil to achieve four separate positions. The unipolar stepper motor consists of four coils. When each coil is energized individually and in proper sequence the motor shaft turns the specified number of degrees per step.

2.5 Servo motors selection

Servo motors are preferred in applications with high duty cycles (compared to brush motors) because there is no motor wear from brushes. With no brushes present to commutate the motor, the motor driver is responsible for commutation. Voltage and current sensing circuits, combined with encoder position feedback, allow the motor driver to precisely calculate rotor position. This also allows the driver to command currents to the motor phases, which produces optimum torque at any speed. Servo actuators perform well in higher speeds, high-torque and in force-sensitive applications. [3]

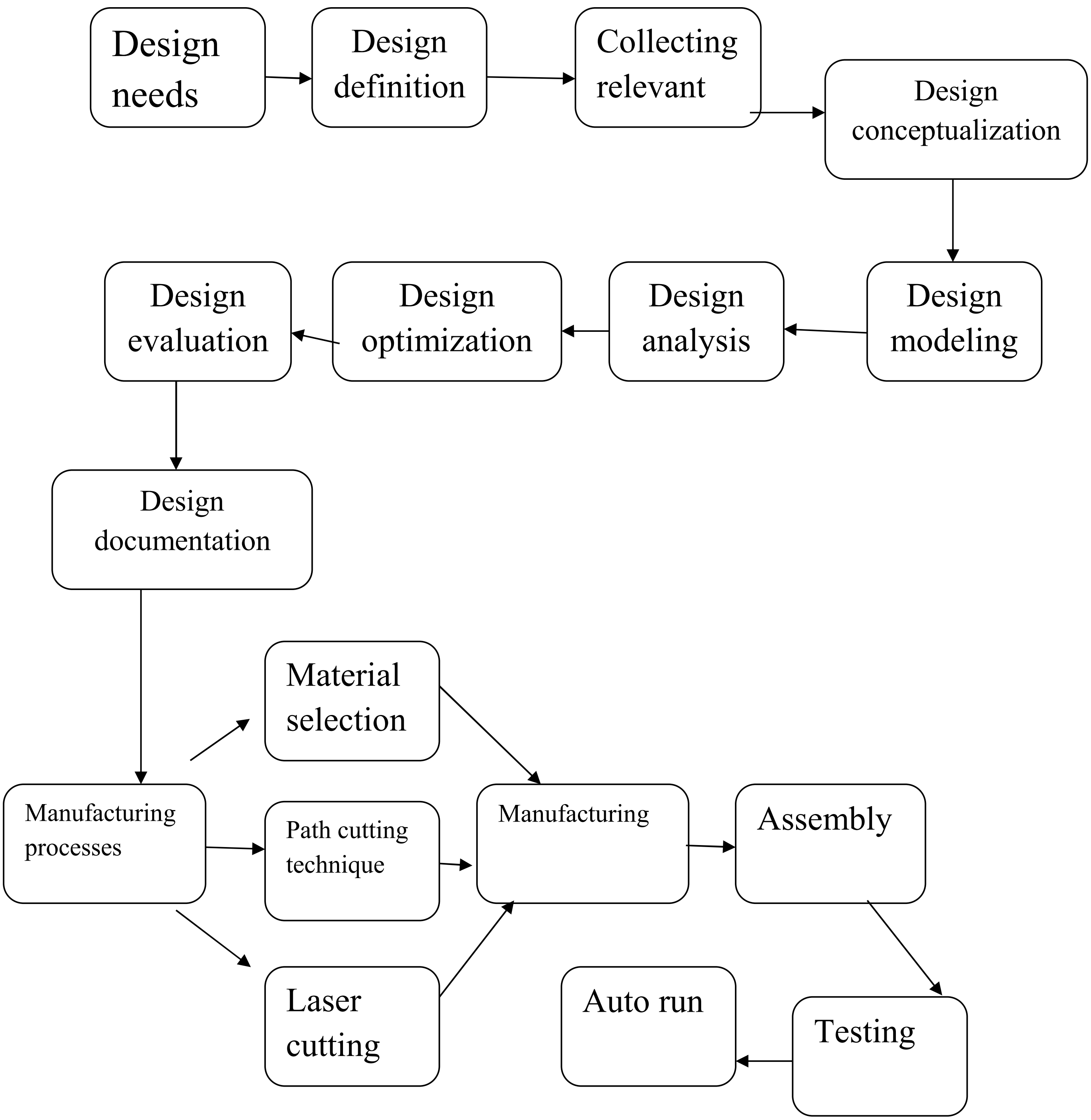
Chapter Three

METHODOLOGY

Chapter three

METHODOLOGY

3.1 Methodology Flow Chart



3.2 Assumption of Building the Kinematic Structure

The dimension and workspace configuration of the structure is to move freely in 0.5 $meter^2$.The specifications of each actuator are determined to carry out the rotary operations. The structure of the robot is built with Perspex acrylic sheets in order to decrease the overall weight of the robot. The Perspex acrylic sheets are also strong enough to keep and hold the whole parts tightly together. The arm is attached to a base which is the most bottom part of the robot. It is important to mention that the base ought to have considerably heavy weight in order to maintain the general balance of the robot in case of grabbing an object.

Although the idea of using stepper and gear motors is brilliant, but physical movement of the robot is done by using servo motors. The advantage of the servos is that they can be programmed to return to their initial position. Since the servo motors operate using the signals received from the microcontroller, they could be programmed according to the requirements. However, this characteristic of the servo motors is actually a disadvantage, because the chance of sending and receiving a wrong signal is high which causes the servo to operate incorrectly.

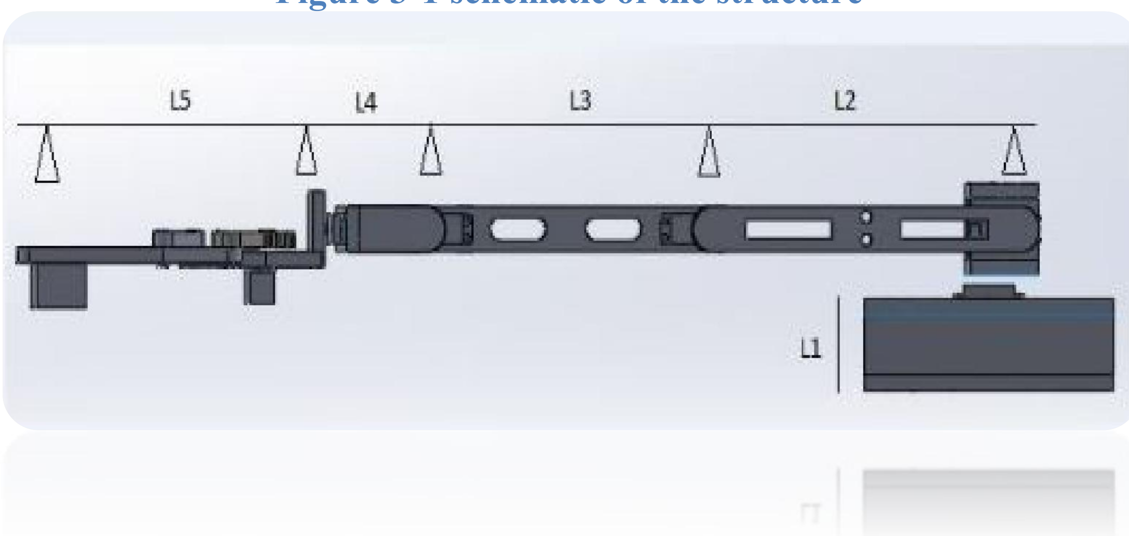
The developed robot in this study is a stationary articulated robotic arm with 6 DOF with only revolute joints which includes base, shoulder, elbow, gripper roll, gripper pitch and gripper spin.

All parts of the robot including the parts for shoulder, elbow, gripper and etc., were been manufactured accurately by laser cutting machines to avoid labor errors. The gripper of the arm is designed in a way which uses a single actuator and follows a basic physical gear concept. This means that when the mini servo actuates, it turns the gear which is attached to it causing the gripper to expand and contract.

3.3 Mathematical Model of the Kinematics

Each robot design involves mathematical modeling of the kinematics, structure design, electronic design and software design. The robotic arm has a total of five axes. Three major axis which correspond to the base, shoulder and elbow are needed to move the arm to the desired spot, and two minor axis which correspond to the gripper pitch and gripper spin. The design has six rotary joints. Although we consider the number of joints as five because two joints that move the shoulder, rotate in the same direction with the same speed. Therefore they are counted as one joint.

Figure 3-1 schematic of the structure



3.4 Material Selection

Perspex acrylic sheets are one of the most used materials for its broad applications potential. The robot hand is made from Perspex extruded acrylic sheets. The main advantage of extruded sheet is accuracy in thicknesses and lower price. All sheets have UV protection and they are resistant to weather conditions.

3.5 Robot Controller

Robot arm can be control via a mouse, And Build using Arduino and Processing Libraries. To control the robot arm, mouse can send a byte value over the serial port and then read that in the Arduino code. Depending upon the value sent different motors will be activated. For the processing sketch made a few buttons for each motor and also coded the use of the keyboard for another control method. Using either arbitrarily moves the arms motors. Sketches are the basis for all the further work as well as testing the arm, from this move to inverse kinematics as well as programming repeat actions for the arm to perform.

3.5.1 Robotic Arm Software

Robot software is the set of coded command or instructions that tell a mechanical device and electronic system, known together as a robot, what tasks to perform. Robot software is used to perform autonomous tasks. Many software systems and frameworks have been proposed to make programming robots easier.

Some robot software aims at developing intelligent mechanical devices. Common tasks include feedback loops, control, path finding, data filtering, and locating.

3.5.1.1 Processing program (IDE):

Processing is an open source language/ development tool for writing programs in other computers. Useful when you want those other computers to "talk" with an Arduino, for instance to display or save some data collected by the Arduino. You can use the serial monitor of the Arduino Software (IDE) to view the sent data, or it can be read by Processing.

Processing consists of:

- The Processing Development Environment (PDE). This is the software that runs when you double-click the Processing icon. The PDE is an Integrated Development Environment (IDE) with a minimalist set of features designed as a simple introduction to programming or for testing one-off ideas.
- A collection of functions (also referred to as commands or methods) that make up the "core" programming interface, or API, as well as several libraries that support more advanced features such as sending data over a network, reading live images from a webcam, and saving complex imagery in PDF format.
- A language syntax, identical to Java but with a few modifications.
- An active online community.

Whilst both sketches visually look different they use pretty much the same methods. The main thing is that for each point, shape or item wish to click and drag rely on detecting where the mouse is, if it's been clicked and if dragging the mouse. Can use Processing inbuilt functions mouse Pressed () and mouse Dragged () but still need to write conditional statements depending on where the mouse is.

To do this we can get the X and Y co-ordinates of the mouse using mouse X and mouse Y and to compare these values we need to store the X and Y co-ordinates of any shape as variables - the easiest way is to use the P Vector variable type which in its simplest use is an array that stores an X and Y value. Now we can mathematically compare the values and limit the movement of our shapes only moving when the mouse is in the correct area.

When getting the X, Y values from the mouse position we need to make sure these are converted to integers, for which we first use the round () method to convert our float to 1 decimal place and then use the int() method to cast the value as an integer. We also need integer values as it makes it much easier to send ints over the serial port as the libraries allow for these values. The rest of the processing code is fairly straight forward we use text (), rest (), ellipse (), line (), fill () and stroke () functions to create our visualization. The only other thing to note is that in draw () method we always write the values to the serial port.

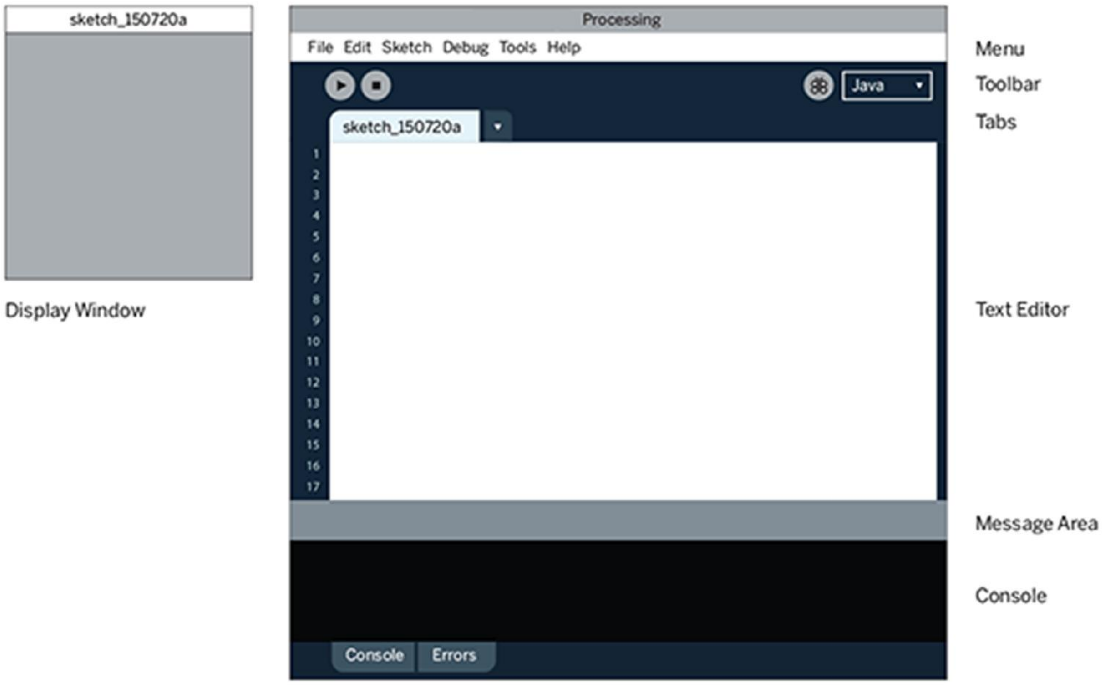


Figure 3-2 Processing program (IDE)

3.5.1.2 Standard Firmata Library

Firmata is a generic protocol for communicating with microcontrollers from software on a host computer. It is intended to work with any host computer software package. This library allows you to control an Arduino board from Processing without writing code for the Arduino. Instead, you upload a standard firmware (program) to the board and communicate with it using the library.

The firmware is called Firmata, and is included in the Arduino software. The corresponding Processing library can be downloaded below.

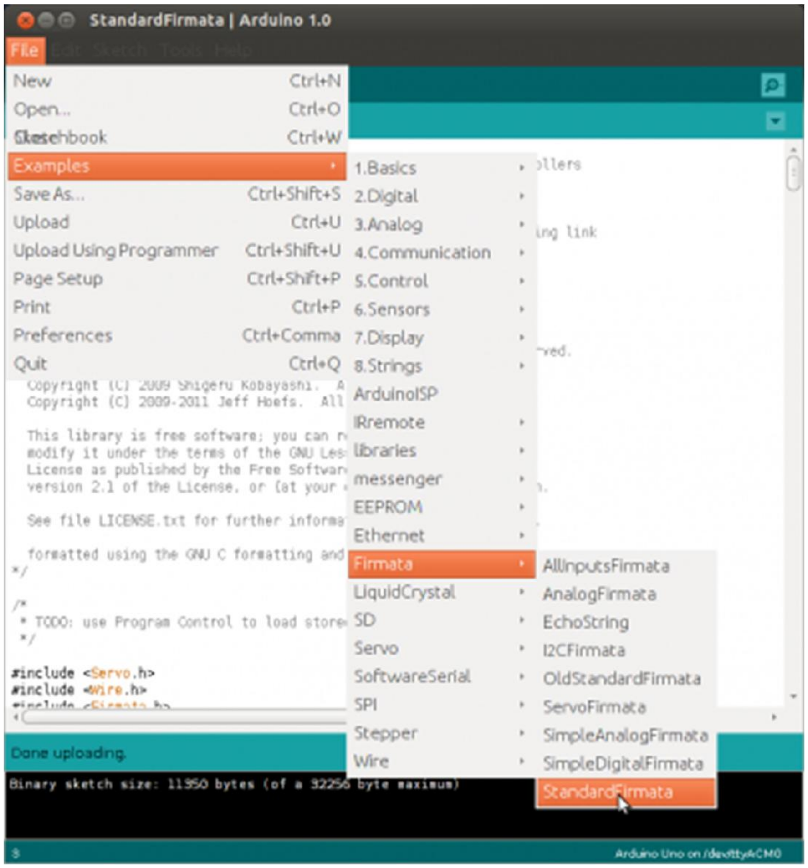


Figure 3-3 Standard Firmata library

3.5.2 Robotic Arm Hardware

The kits also come with common robotics hardware that connects easily with the software (infrared sensors, motors, microcontroller board, microphone and video camera).

3.5.2.1 Servo motor (MG996R High Torque)

This High-Torque MG996R Digital Servo features metal gearing resulting in extra high 10kg stalling torque in a tiny package. The MG996R is essentially an upgraded version of the famous MG995 servo, and features upgraded shock-proofing and a redesigned PCB and IC control system that make it much more accurate than its predecessor. The gearing and motor have also been upgraded to improve dead bandwidth and centering. The unit comes complete with 30cm wire and 3 pin female header connectors that fit most receivers, including Futaba, JR, GWS, Cirrus, Blue Bird, Blue Arrow, Corona, Berg, Spectrum and Hitch. This high-torque standard servo can rotate approximately 120 degrees (60 in each direction. The MG996R Metal Gear Servo also comes with a selection of arms and hardware to get you set up nice and fast.

Specifications of servo motors

- Weight: 55 g
- Dimension: 40.7 x 19.7 x 42.9 mm approx.
- Stall torque: 9.4 kgf·cm (4.8 V), 11 kgf·cm (6 V) (need this torque because calculate torque and load in different joint of arm used equation standard).
- Operating speed: 0.17 s/60º (4.8 V), 0.14 s/60º (6 V)
- Operating voltage: 4.8 V a 7.2 V
- Running Current 500 mA - 900 mA (6V)
- Stall Current 2.5 A (6V)
- Dead band width: 5 µs
- Stable and shock proof double ball bearing design
- Temperature range: 0 ºC –55 ºC [4]

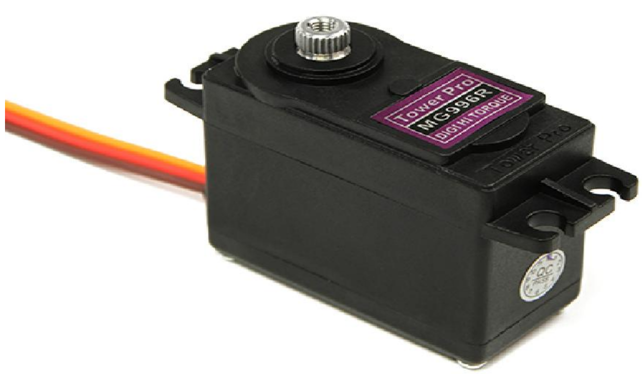


Figure 3-4 High-Torque MG996R

3.5.2.2 Arduino Board (Mega 2560)

The Arduino Mega 2560 is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 14 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started. Power of The Arduino Mega can be powered via the USB connection or with an external power supply. The power source is selected automatically. Need high response from PC to Microcontroller and Microcontroller can be send fast to motors.

Specifications of Arduino board

- Microcontroller: ATmega2560
- Operating Voltage: 5V
- Input Voltage (recommended): 7-12V
- Input Voltage (limits): 6-20V
- Digital I/O Pins: 54 (of which 14 provide PWM output)
- Analog Input Pins: 16
- DC Current per I/O Pin: 40 mA
- DC Current for 3.3V Pin: 50 mA
- Flash Memory: 256 KB of which 8 KB used by boot loader
- SRAM: 8 KB
- EEPROM: 4 KB
- Clock Speed: 16 MHz[5]

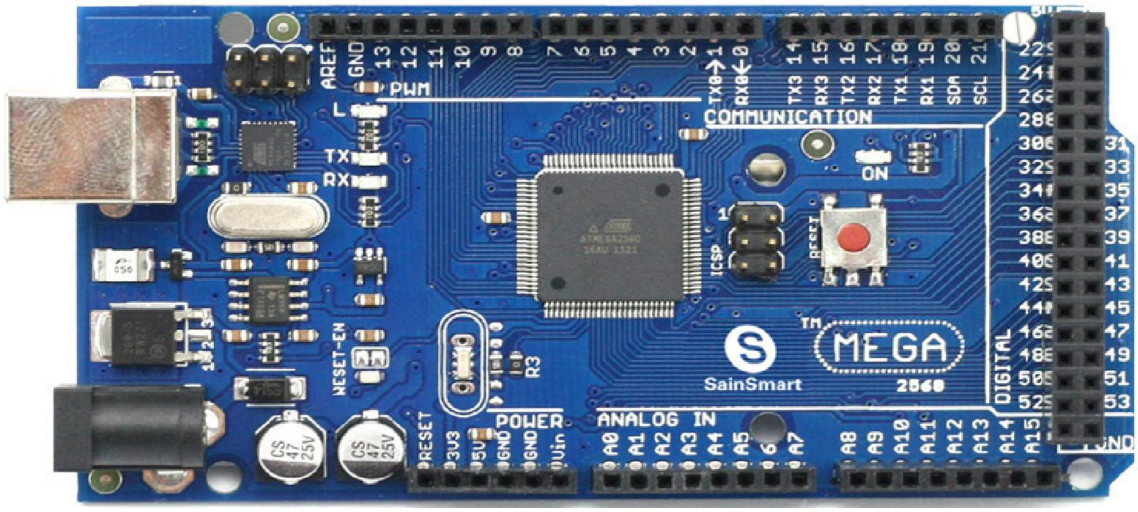


Figure 3-5 The Arduino Mega 2560

3.5.2.3 LM 7806 Regulator:

The 7806 three-terminal positive voltage regulator is available in the TO-220/D-PAK package making them useful in a wide range of applications. 7806 employs internal current limiting, thermal shut down and safe operating area protection, making it essentially indestructible. If proper heat sinking is provided, it can deliver over 1A output current. Motors need 6 voltage because selected this regulator.

<u>Specifications</u>**:**

• Input Voltage: 10 V

• Operating temperature: -40 ºC to 125 ºC

• Output current: 500 mA

• Output voltage: Min. (5.75V), Typ.(6V), Max.(6.25V) [6]

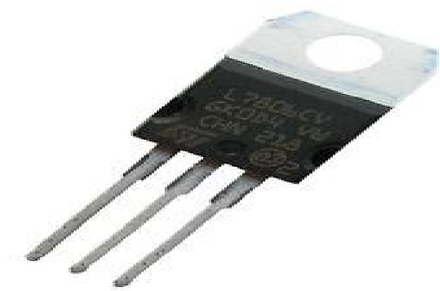


Figure 3-6 LM 7806 regulator

3.5.2.4 IR Sensor (TCRT5000):

The TCRT5000 is reflective sensor which includes an infrared emitter and phototransistor in a leaded package which blocks visible light. The package includes two mounting clips. TCRT5000L is the long lead version.

Specification:

• Package type: leaded

• Detector type: phototransistor

• Dimensions (L x W x H in mm): 10.2 x 5.8 x 7

• Peak operating distance: 2.5 mm

• Operating range within > 20 % relative collector

Current: 0.2 mm to 15 mm

• Typical output current under test: IC= 1 mA

• Daylight blocking filter

• Emitter wavelength: 950 nm

• Lead (Pb)-free soldering released

• Compliant to RoHS directive 2002/95/EC and in

accordance to WEEE 2002/96/EC.[7]

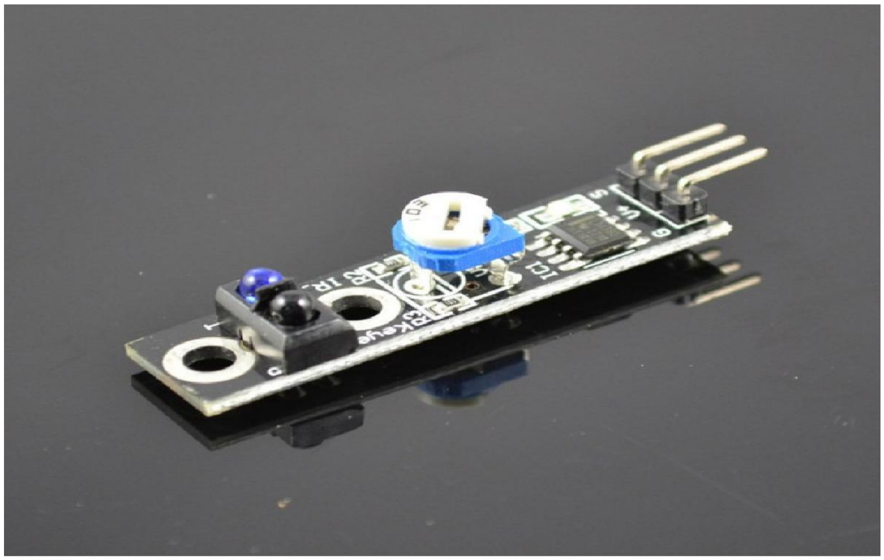


Figure 3-7 TCRT5000 sensor

3.6 Circuit Design:

The Robot Arm consist of six servo motors which controlled by mouse which passes data of mouse position and vectors to Arduino board via serial port over firmata protocol, most of the computation is done on the computer side through processing IDE which is java based development environment for interactive projects and applications, the robot arm motion can be recorded and stored into a file which can be replayed.

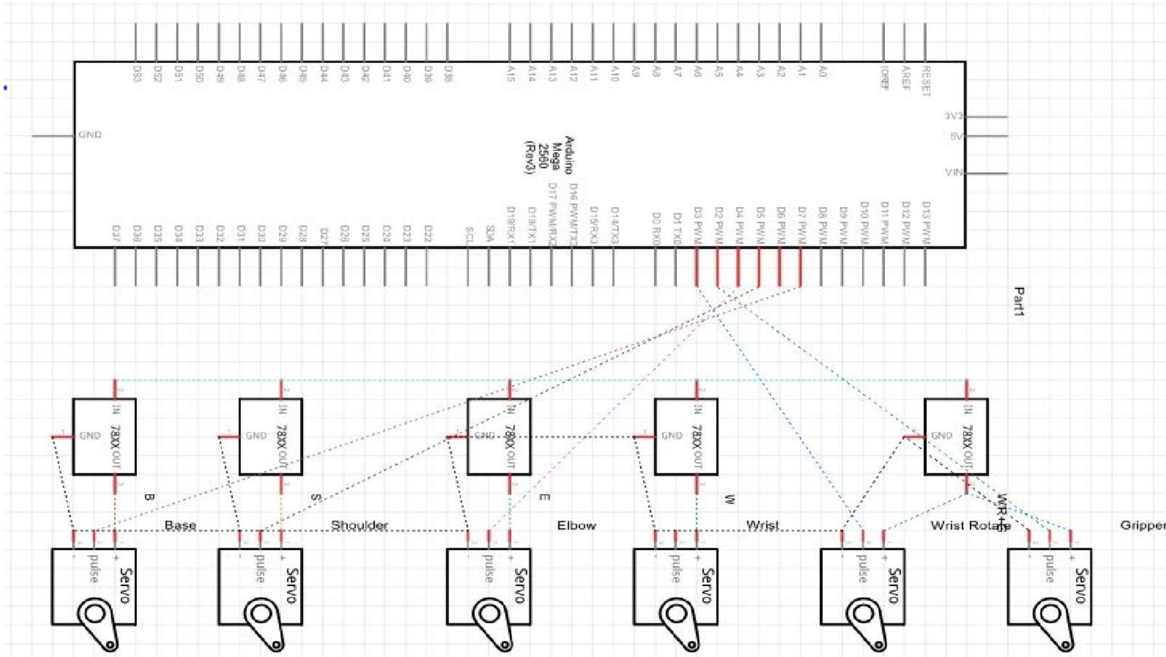


Figure 3-8 Schematic diagram

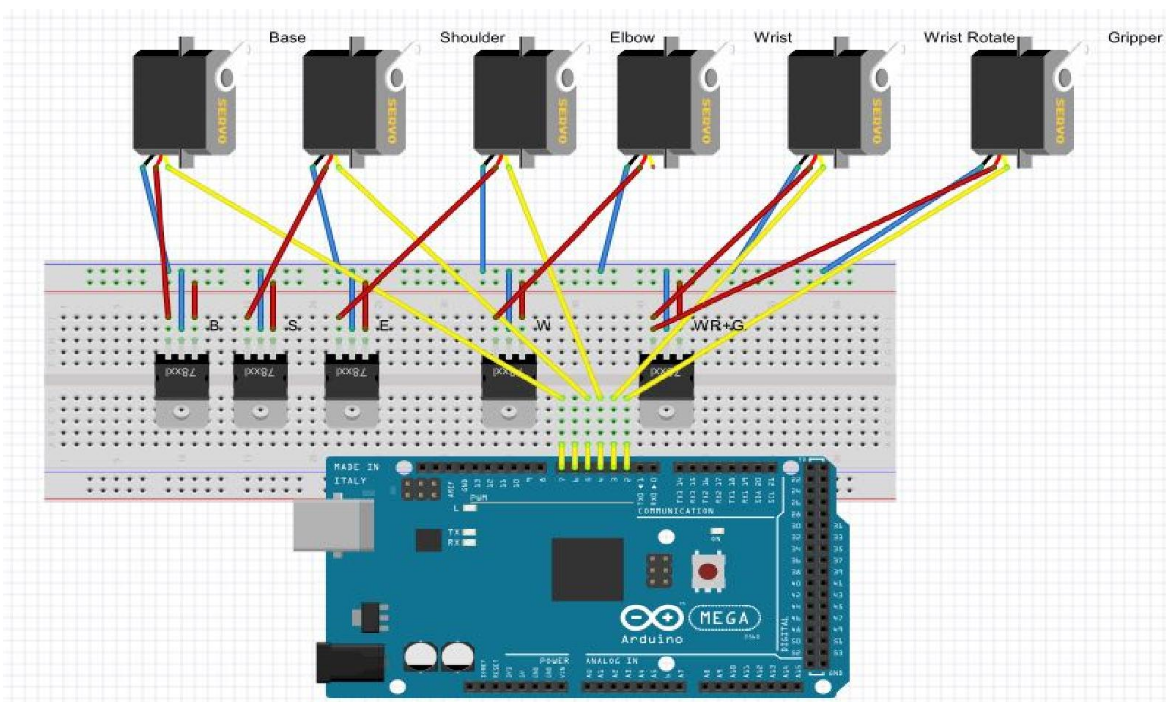
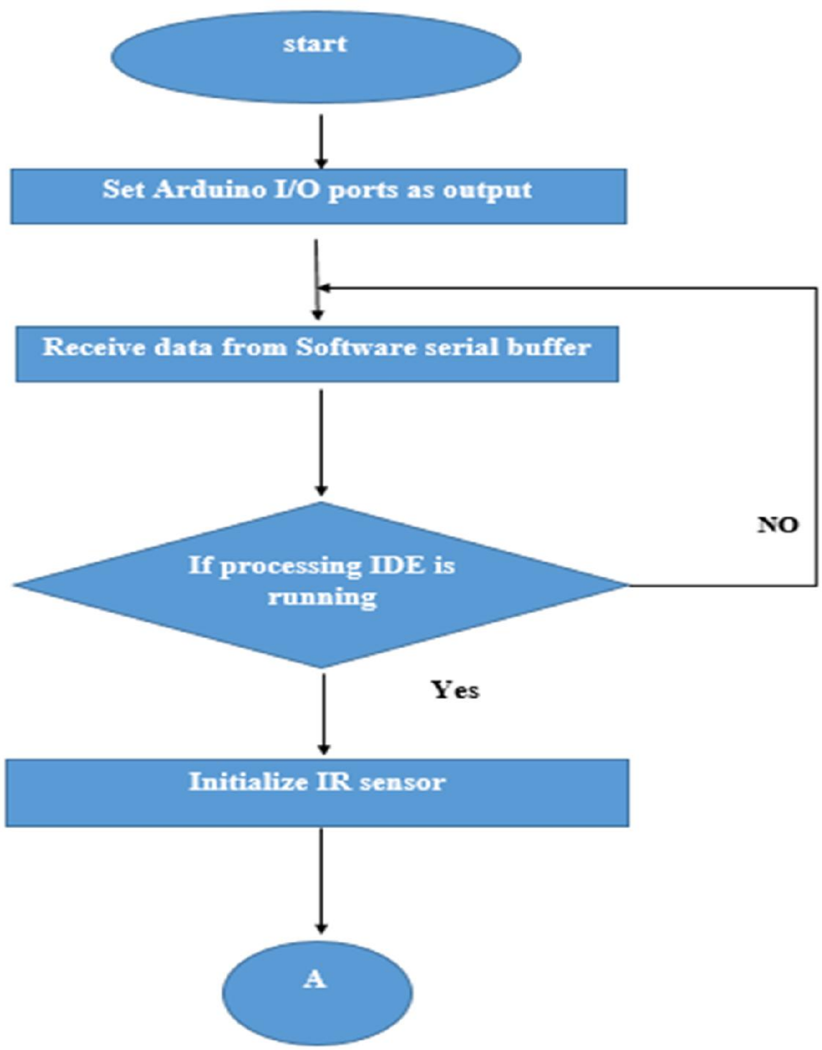


Figure 3-9 Circuit diagram

3.7 Operation:

At the system power, which is initialized by running the processing code, the Arduino start the configuration of I/O ports according to the signals received from the serial port buffer, the processing IDE proceeds to initialize the mouse controller and start reading data if sensor detected object, these data contains vector and coordination data such as X, Y and Z position of mouse, these data are then processed and fed into corresponding servo motors connected to the Arduino board.



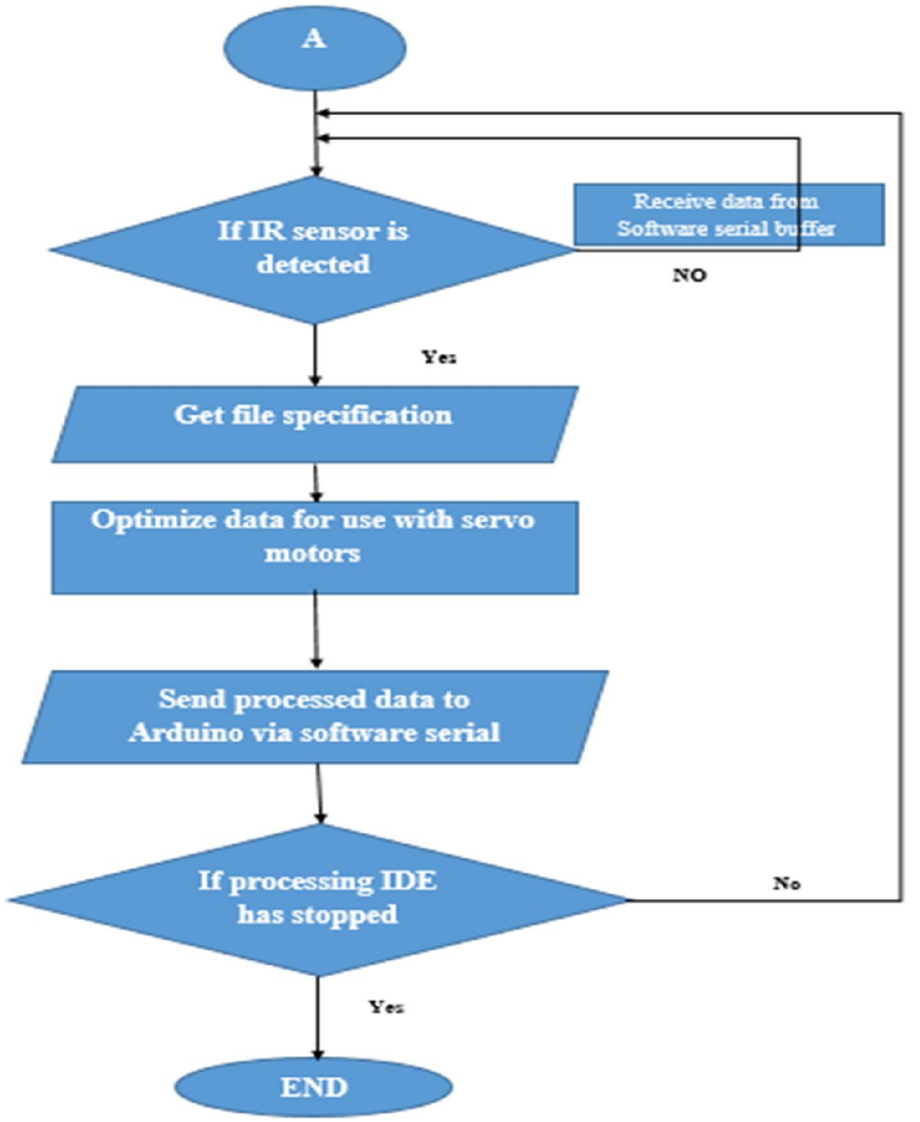


Figure 3-10 System operation flowcharts

3.8 Design

After considering all the requirements of workspace area 0.5 m^2, Perspex acrylic extruded sheets, the needed torque from servo motors, the mass of 2 kg loaded on the gripper, the robot had been designed via SOLIDWORKS and analyzed via ANSYS software. The details of drawings shown in appendix.

3.4 Design:

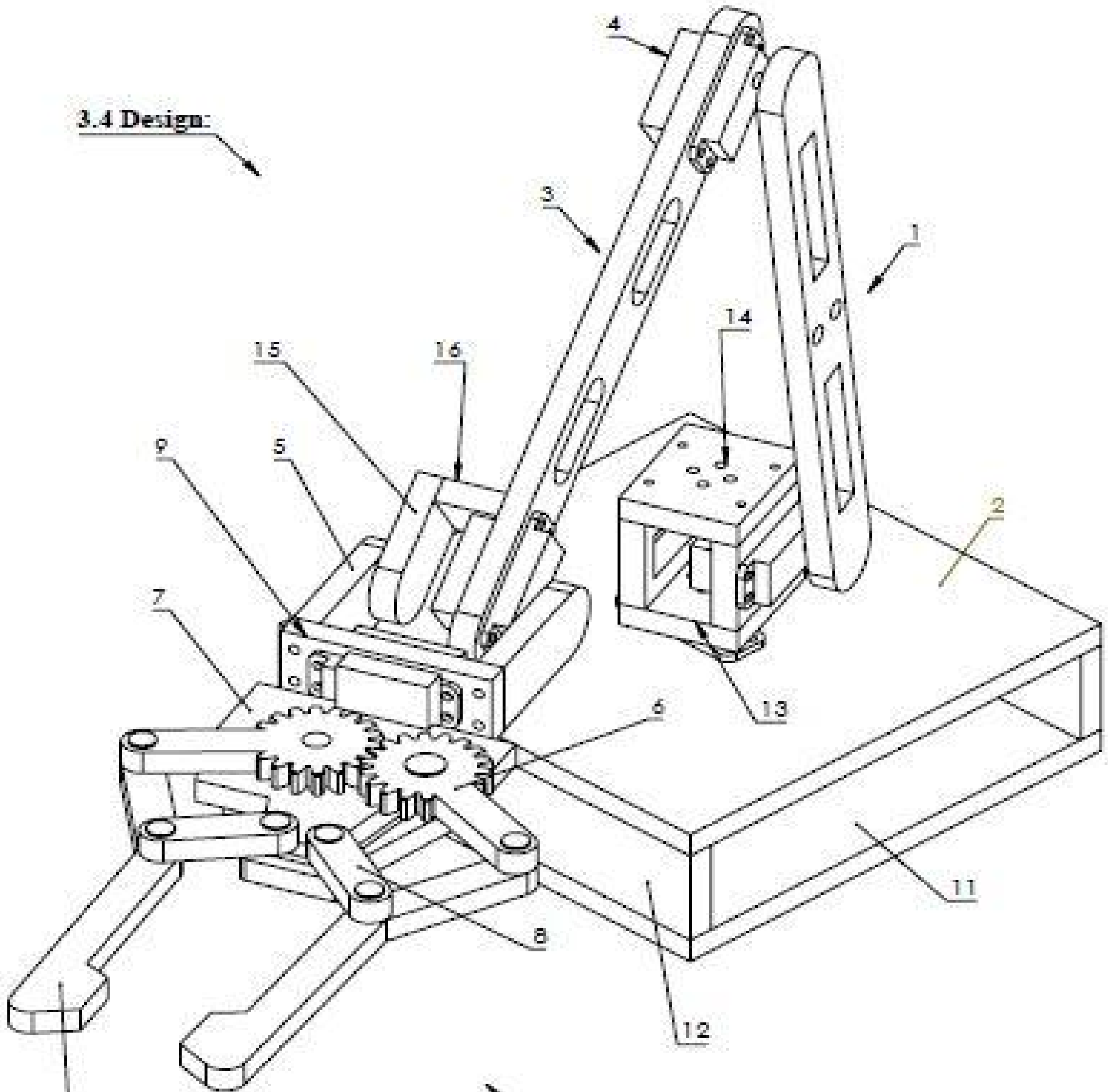


figure 3.1

1	shoulder	8	gripper assistance
2	upper base	9	wrist stand
3	elbow	10	gripper arms
4	servo motor	11	lower base
5	wrist	12	side base
6	gears	13	rolling base
7	gear stand	14	vertical stand

15	rolling wrist assistance
16	fixed wrist assistance

Figure 3-11 assembly sketch

3.9 Manufacturing Process

Figure 3-12 laser cutting machine

Laser cutting is a technology that uses a laser to cut materials, and is typically used for industrial manufacturing applications, but is also starting to be used by schools, small businesses, and hobbyists. Laser cutting works by directing the output of a high-power laser most commonly through optics. The laser optics and CNC (computer numerical control) are used to direct the material or the laser beam generated. A typical commercial laser for cutting materials would involve a motion control system to follow a CNC or G-code of the pattern to be cut onto the material. The focused laser beam is directed at the material, which then either melts, burns, vaporizes away, or is blown away by a jet of gas, leaving an edge with a high-quality surface finish. Industrial laser cutters are used to cut flat-sheet material as well as structural and piping materials.

Chapter Four

RESULTS AND DISCUSSION

Chapter four

RESULTS AND DISCUSSION

4.1 Torque Calculation

L1 = height of shoulder from base. 60 mm

L2 = length of arm 1 (shoulder). 250 mm

L3 = length of arm 2 (elbow). 250 mm

L4 = length of gripper snip. 50 mm

L5 = length of the gripper. 160 mm

M1= mass of arm 1 (shoulder). 75.28 gram

M2= mass of arm 2 (elbow). 63.23 gram

M3 = mass of arm 3 (gripper snip). 64.57 gram

M4 = mass of gripper. 98.42 gram

M^m= mass of servo motor. 500 gram

General equation of torque calculations of motors:

$$T\mu = \Sigma\, M * L$$

For μ point

<u>For the first motor:</u>

All arms and motors masses loaded on it, so:

T1= 75.28*0.250*0.125 + 500*0.250 + 63.23*0.250*0.375 + 500*0.500 + 64.57*0.050*0.525 + 500*0.550 + 98.42*0.160*0.630 + 500*0.590 + 2000*0.650= **<u>2264.9 gram/m</u>**

<u>For the second motor:</u>

All arms loaded except mass of arm 1, so:

T2= 63.23*0.250*0.125 + 500*0.250 + 64.57*0.50*0.275+ 500*0.300 + 98.42*0.160*0.380 + 500*0.340 + 2000*0.400 = **<u>1261.83 gram/m</u>**

For the third motor:

Just the gripper snip and gripper masses are loaded, so:

T3 = 64.57*0.050*0.025+ 500*0.05 + 98.42*0.160*0.130 + 500*0.090 + 2000*0.150 = 372.12 **gram/m**

4.2 Other Calculation with Different Mass of Servo Motor

M^{m}= 0.2 kg

Moment of Motor 1			
	lengths	masses	moment
Arm 1	0.125	0.06	0.0075
Motor 1	0.25	0.2	0.05
Arm 2	0.375	0.0518	0.01943
Motor 2	0.5	0.2	0.1
Gripper	0.6	0.03035	0.01821
Motor 3	0.55	0.2	0.11
Weight	0.7	2	1.4
			total of M
			1.70514

Moment of Motor 2			
	lengths	masses	moment
Arm 2	0.125	0.0518	0.00648
Motor 2	0.25	0.2	0.05
Gripper	0.35	0.03035	0.01062
Motor 3	0.3	0.2	0.06
Weight	0.45	2	0.9
			total of M
			1.0271

Moment of Motor 3			
	lengths	masses	moment
Gripper	0.1	0.03035	0.00304
Motor 3	0.05	0.2	0.01
Weight	0.2	2	0.4
			total of M
			0.41304

Figure 4-1 Torque Calculation

4.3 Mesh (Moderate Mesh)

Meshing is the process used to fill the solid model with nodes and elements to create finite element analysis model (FEA) model.

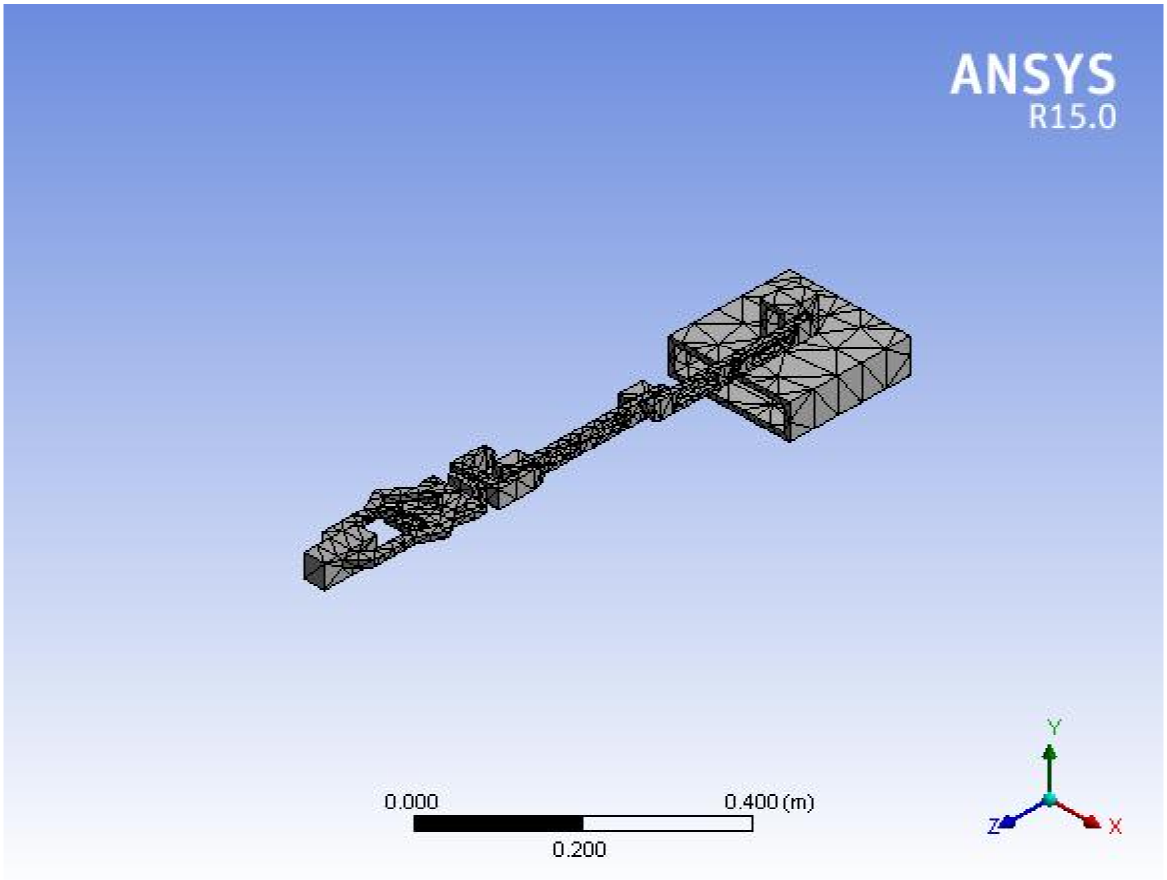


Figure 4-2 Mesh

4.4 Simulation Results

The analysis was made to get the maximum and the minimum of:

(Yield stress of acrylic sheet equal to 75 MPa)

- The total deformation.
- The stress.
- The strain.

4.4.1 Total Deformation:

Max = 0.053643m

Min = 0

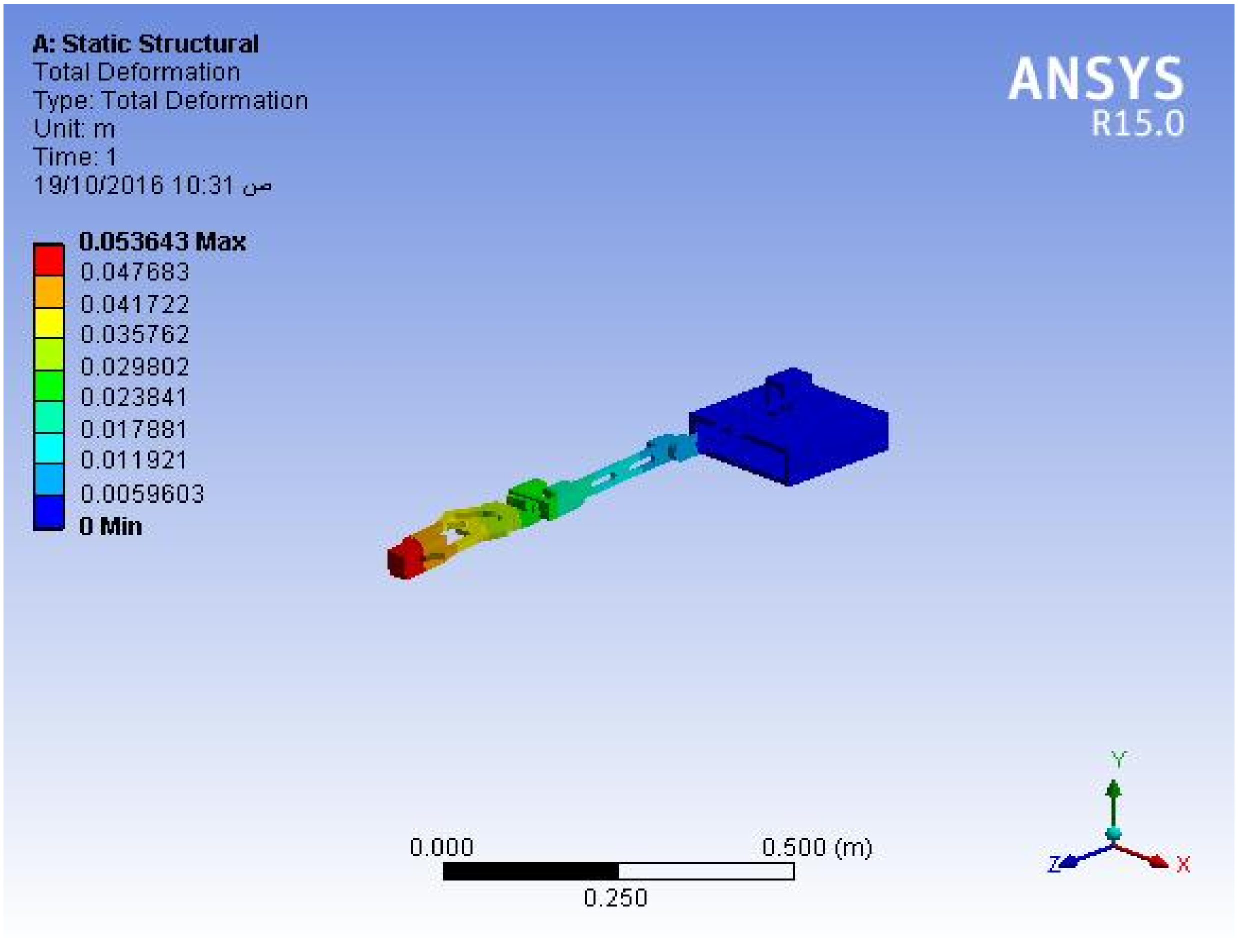


Figure 4-3 Total deformation

The maximum deformation pointed in the 2 kg load and it decrease toward the robot base. Because the mass loaded by the end effector.

4.4.2 Maximum principle stress:

Max = 1.345e7 Pa

Min = -9.1307e5 Pa

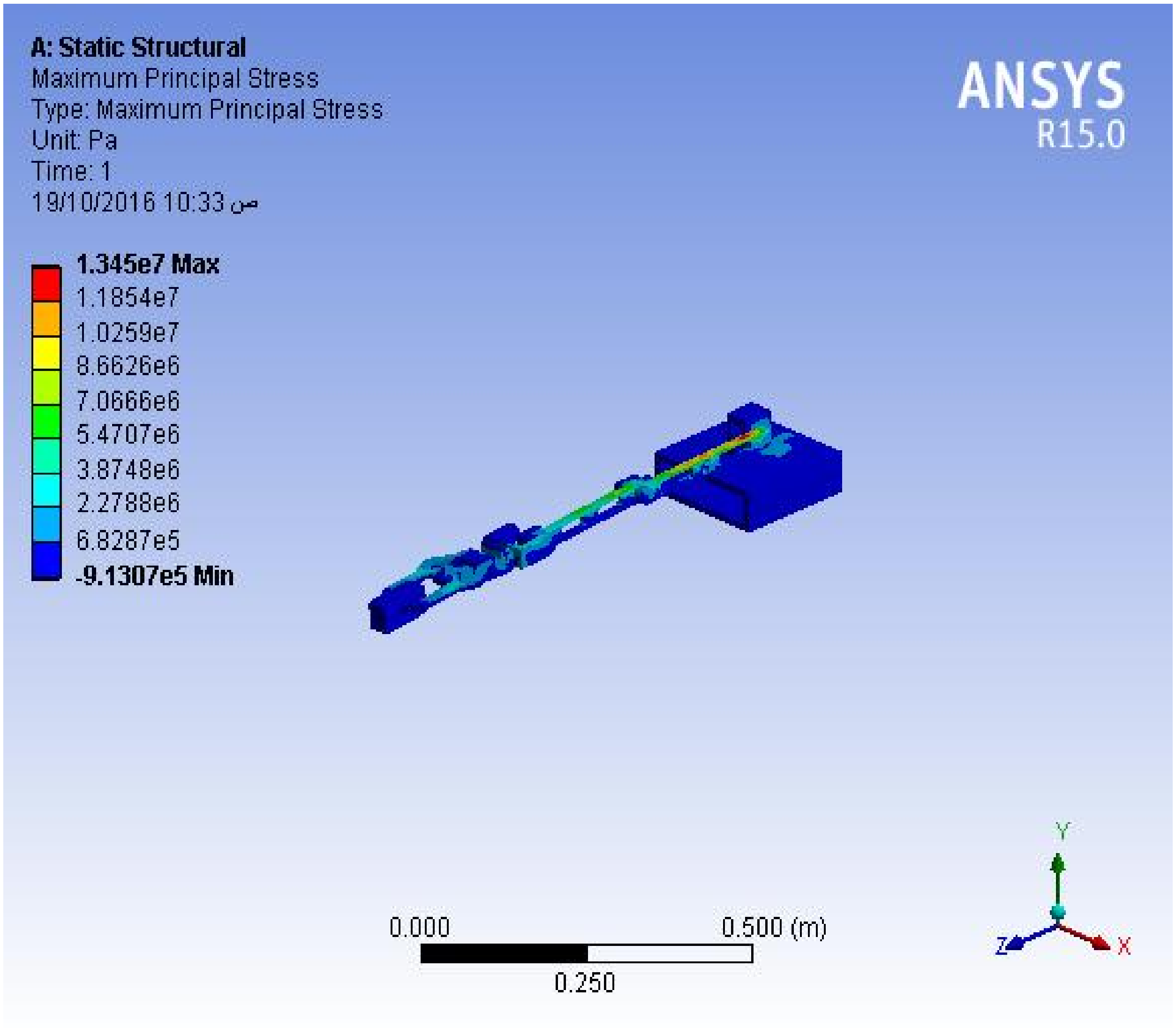


Figure 4-4 Maximum principle stress

The maximum stress pointed on the shoulder. And it decreases toward the gripper. Because the center of rotation at the shoulder.

4.4.3 Minimum principle stress:

Max = 1.0202e6 Pa

Min = -1.3828e7 Pa

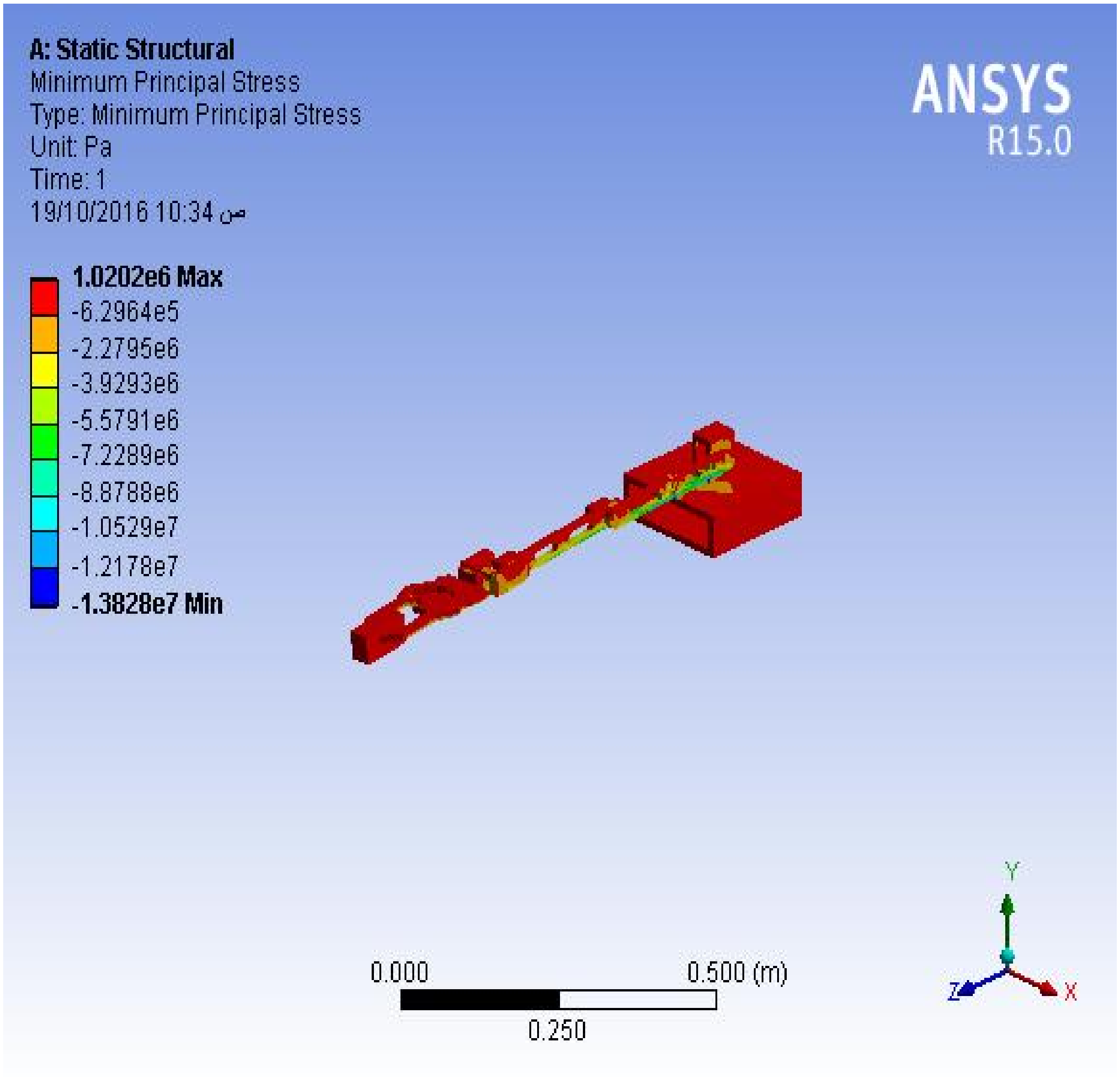


Figure 4-5 Minimum principle stress

The minimum stress pointed on the gripper. And it increases toward the shoulder.

4.4.4 Maximum Principle Elastic Strain:

Max = 0.0042168 m/m

Min = 4.9722e-9 m/m

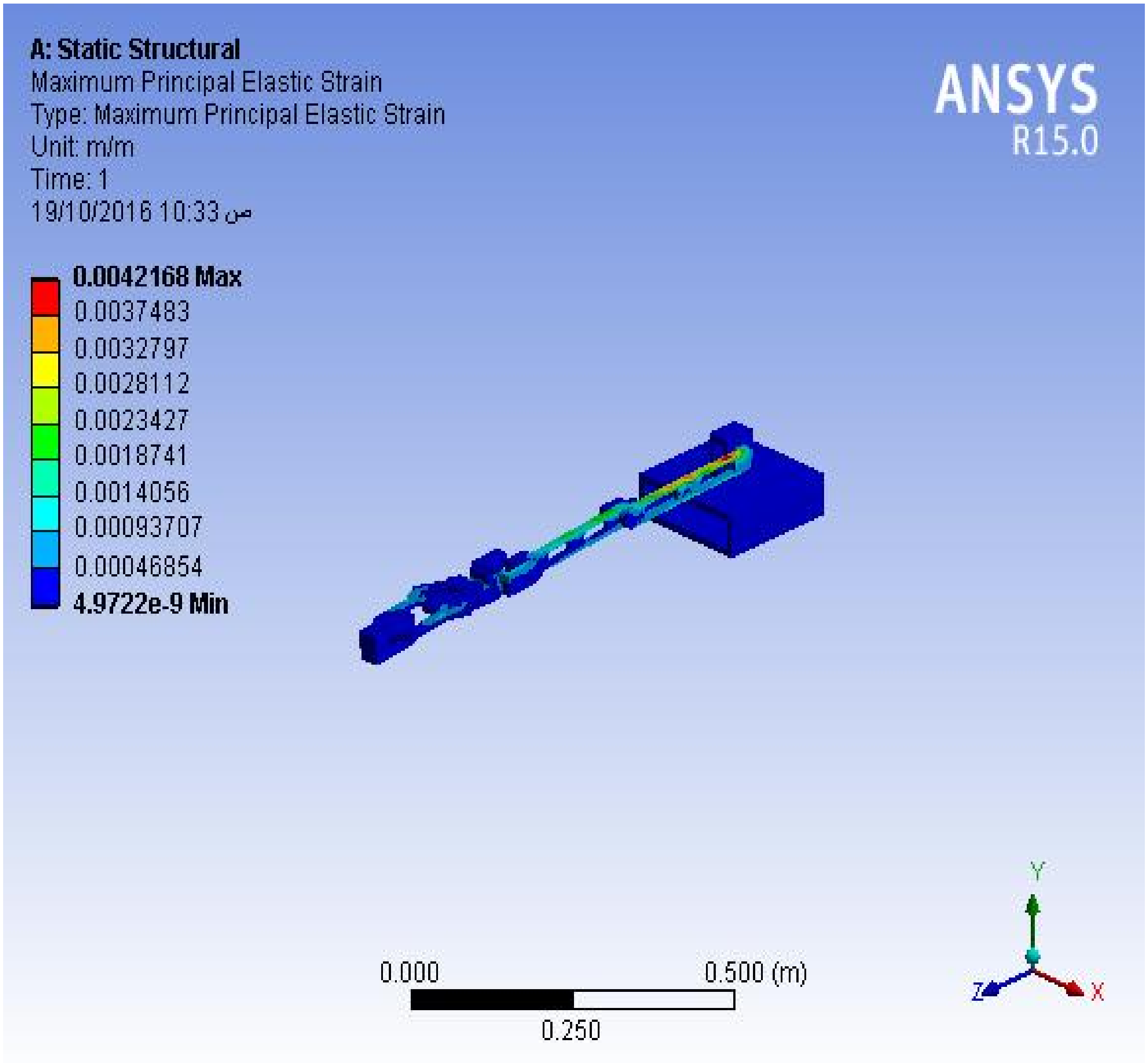


Figure 4-6 Maximum principle elastic strain

The maximum strain pointed on the shoulder. And it decreases toward the gripper. Because the center of rotation at the shoulder.

4.4.5 Minimum Principle Elastic Strain:

Max = -4.9734e-9 m/m

Min = -0.0043687 m/m

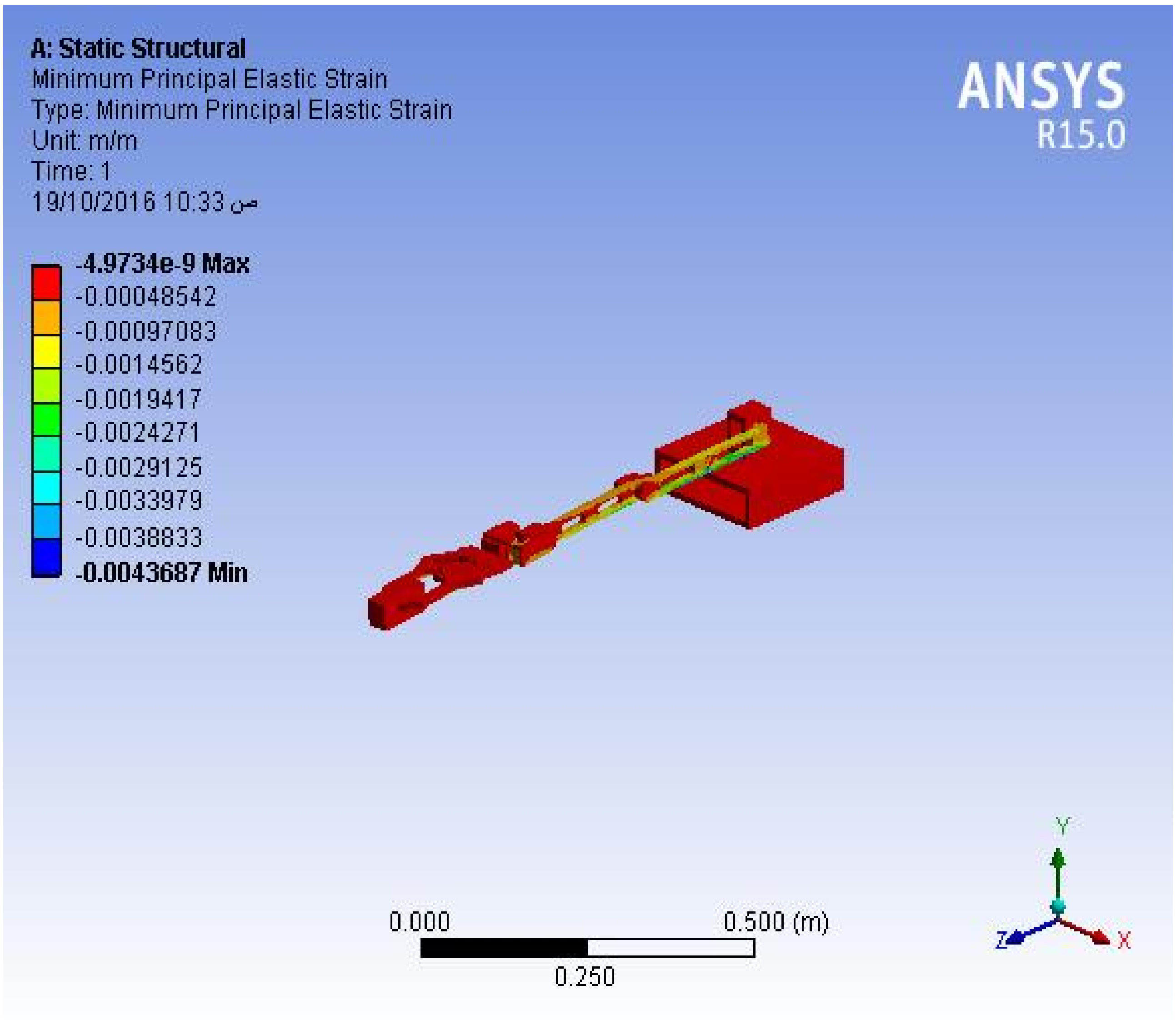


Figure 4-7 Minimum principle elastic strain

The maximum strain pointed on the shoulder. And it decreases toward the gripper.

4.5 Discussion

After applying the CAD-CAM processes, controlling system, as a result of the project the robot arm designed and manufactured to pick up and handle the load of 2 kg in 0.5 m^2 workspace. But the available servo motors don't meet the specifications of torque (base & shoulder motors). Also the available regulators output current under required. The servo motors needed is 0.9 ampere (A) to use the maximum torque; but the available regulator output is only 0.5 ampere. The motion of the system is divided to arms motion and gripper motion because of the above reasons.

Chapter Five

CONCLUSION & RECOMMENDATION

Chapter Five

RECOMMENDATION AND FUTURE USE

5.1 Conclusion

As a result of this project the robot arm will be of great use to perform repetitive tasks of picking and placing of small parts (up to 2 kg) in 0.5 m^2 workspace area as an educational robot in CNC lap at Sudan University of science and technology.

5.2 Recommendations

As the future work of the developed arm robot, a neural network-controlled robot can be considered where the user can simply control the robot by giving algorithms commands or machine learning.

We recommend for the following:

- Build a slide linear motion for the arm base with preferred transition technique (Belts, Racks).
- Improve the structure of the arm by adding other similar parts for shoulder, elbow, and wrist as a parallel connection.
- Use two head servo motors to supply the arms with more balancing.

APPENDIX

Appendix A: Robot arm mass

```
Mass properties of selected components
   Coordinate system: -- default --

The center of mass and the moments of inertia are output in the coordinate sys
Mass = 985.89 grams

Volume = 855266.98 cubic millimeters

Surface area = 255653.63  square millimeters

Center of mass: ( millimeters )
    X = 17.72
    Y = 132.58
    Z = 232.16
```

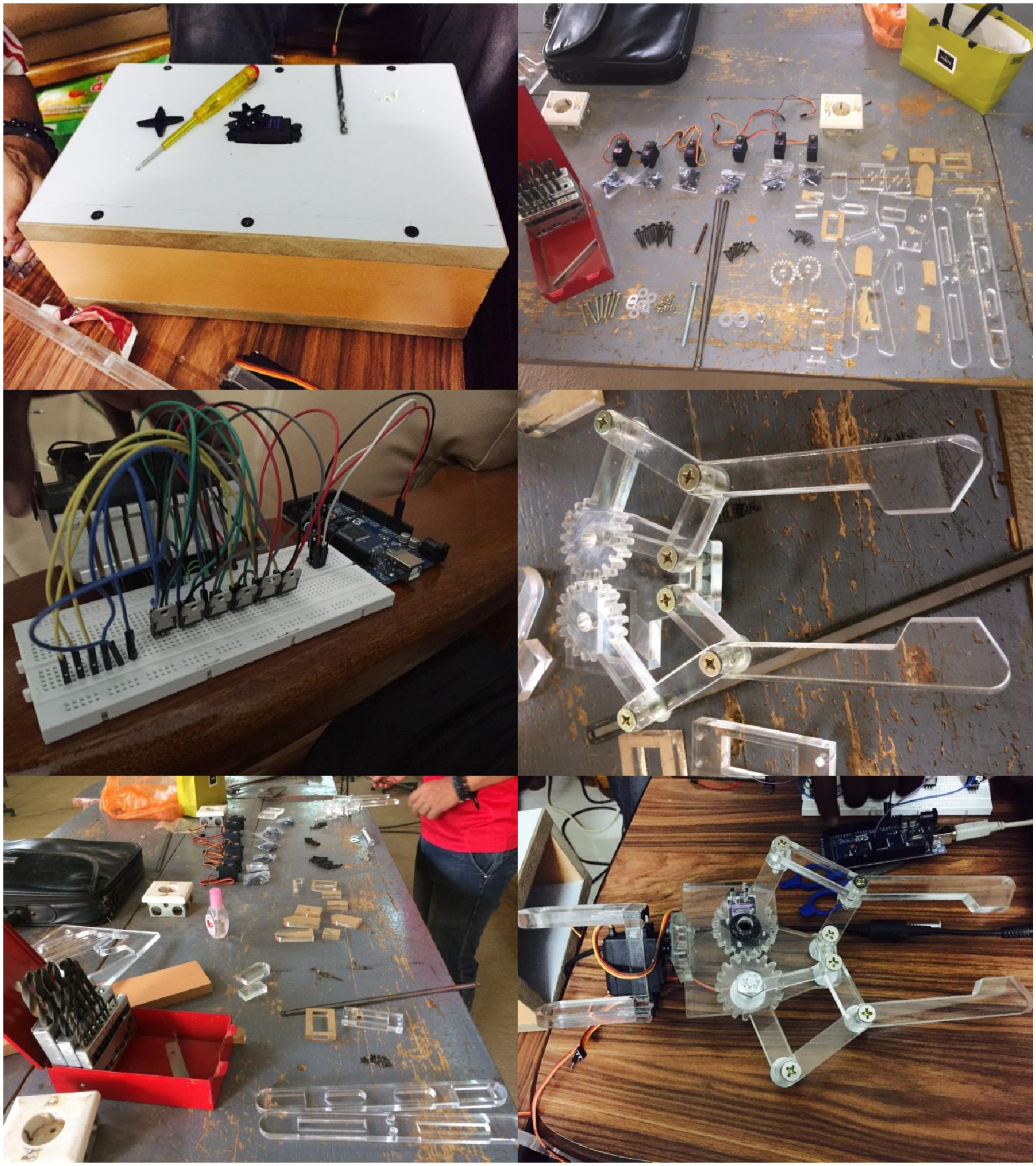
Appendix B: Material Properties

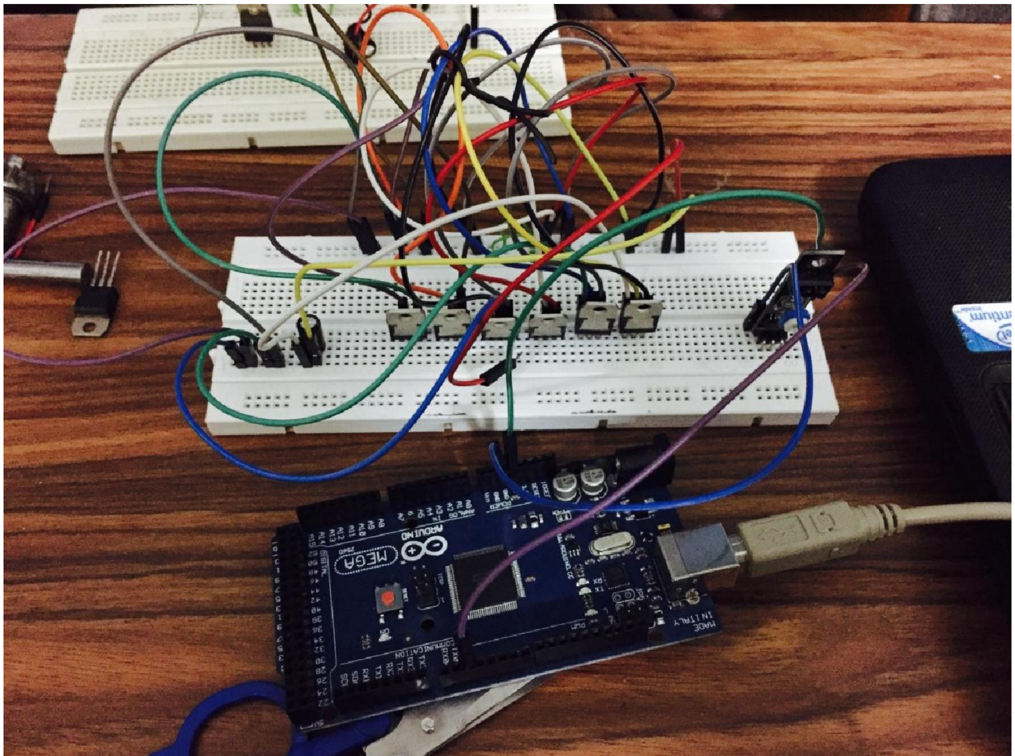
Table of Properties

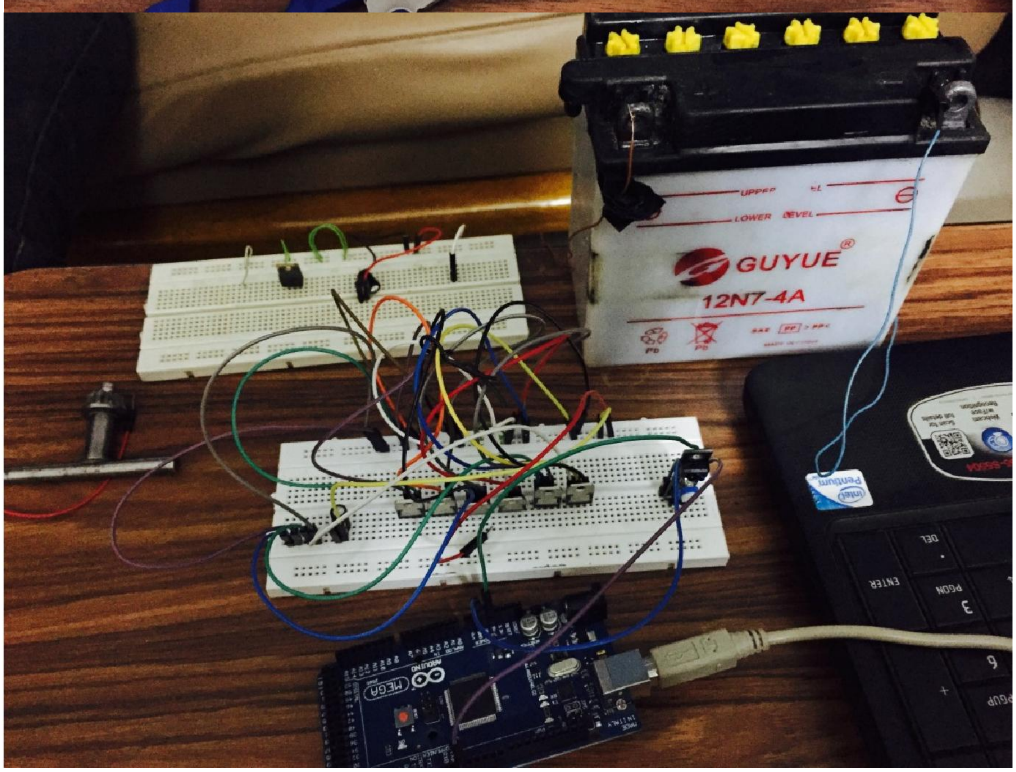
Values quoted for the properties of Perspex® extruded acrylic sheet are the results of tests on representative samples and do not constitute specifications.

Property	Test Method	Units	0X00	IM50	IM60
General Properties					
Relative Density	ISO 1183	g cm^{-3}	1.19	1.17	1.16
Rockwell Hardness	ISO 2039-2	M scale	101	65	45
Water Absorption	ISO 62	%	0.2	0.3	0.3
Flammability	BS 476 Part 7	Class	4	-	-
	DIN 4102	-	B2	B2	B2
	NFP 92-507	-	M4	-	-
	UL94	-	HB	HB	HB
	ISO 11925-2	-	E	-	-
Optical Properties					
Light Transmission	ASTM D1003	% (3 mm)	> 92	90	89
Refractive Index	ISO 489 A	-	1.49	-	-
Thermal Properties					
Vicat Softening Point	ISO 306 A	°C	> 105	> 105	> 105
Coefficient of Thermal Expansion	ASTM D696	$x\ 10^{-5}.\ K^{-1}$	7.8	-	-
Mechanical Properties					
Tensile strength	ISO 527 (5 mm/min)	MPa	70	68	50
Elongation at Break	ISO 527 (5 mm/min)	%	4	18	25
Flexural strength	ISO 178 (2 mm/min)	MPa	107	90	70
Flexural Modulus	ISO 178 (2 mm/min)	MPa	3030	2500	2000
Impact Strength – Charpy (unnotched)	ISO 179	kJ M^{-2}	10	50	65
Izod Impact Strength	ISO 180/1A	kJ M^{-2}	-	5	7
Electrical Properties					
Surface Resistivity	IEC 93	$\Omega.m^{-2}$	$> 10^{14}$	-	-
Electrical Strength	IEC 243	$kV.mm^{-1}$	-	-	-

Appendix C: Assembly stages



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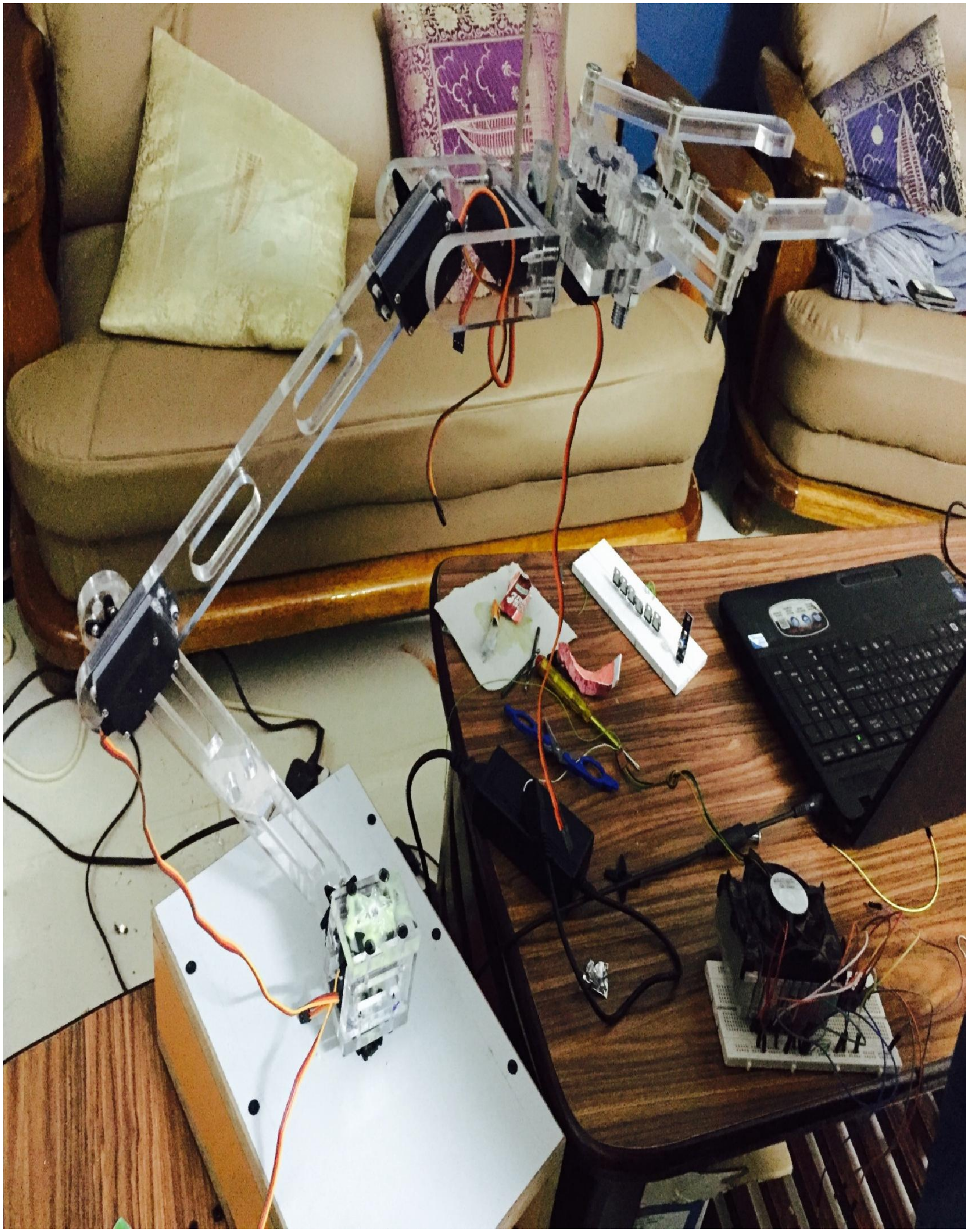
12N7-4A



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