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Development of A Robotic Pick-Up Material Handling Arm

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ABSTRACT: The demand for effective mobility that minimizes or eliminates human exposure to hazardous and toxic materials requires the development of a robotic arm. The robotic arm was designed base on an assumption of a maximum carrying capacity of 10kg and an arm length of 0.7m. The motors specification were 3hp stepper motor to drive the base, 736Watt permanent magnet motor to power the actuator and 1Hp for hybrid synchronous motor to drive the gripper. The developed robotic arm has a carrying capacity of 8kg, and could move its materials to a maximum height of 0.9m with an orientation of 180^o. The robotic arm has an efficiency of 80%

KEYWORD: actuator, capacity, degree of freedom, material handling, robotic arm

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I. INTRODUCTION

Robots are increasingly being integrated into working tasks to replace humans especially to perform the respective task. In general, robotics can be divided into two areas, industrial and service robotics (Paul and Smith, 2012). International Federation of Robotics (IFR) defined a service robot as a robot which operates semi- or fully autonomously to perform services useful to the well-being of human and equipment, excluding manufacturing operations, besides, it might be difficult or dangerous for human to do work (Wan *et. al.*, 2012).

A robotic arm is a robot manipulator, usually programmable, with similar function to a human arm. The links of such manipulator are connected by joints allowing either rotational motion (such as in an articulated robot) or translational (linear) displacement. The links of the manipulator can be considered to form a kinematic chain. The business end of kinematic chain of manipulator is called the end effectors and it is analogous to the human hand.

The end effectors can be designed to perform any desired task such as welding, gripping, spinning etc., depending on the application. The robot arm can be autonomous or controlled manually and can be used to perform variety of tasks with great accuracy. The robotic arm can be fixed or mobile and can be designed for industrial or home applications. The addition of a control arm is refer to as “mobile manipulator,” (Tzafesta, 2014). However, further advancement in the study of robot for better performance has given rise to the application of programmable logical controller (PLC). PLC is a digital computer used for the automation of typical industrial electro-mechanical processes, such as machineries on factory assembly lines, amusement rides fixture. Basically, this write-up is dealing with the use of PLC device in automating a robotic arm. Early PLC was designed to replace relay logic systems. This PLC was programmed in ladder logic which strongly resembles a schematic diagram of relay logic. Other early PLC used a form of instruction list programming, based on a stack based logic solver. Modem PLC can be programmed in a variety of ways, from the relay-derived ladder logic programming languages such as, specially adapted dialect of BASIC. The functionality of PLC has evolved over the year to include sequential relay control, motion control, distributed control system, where-as most of this abilities are needed essentially in the operation of a PLC- based robotic arm. The main difference from other computer is that PLC is armored for severe conditions and have the facilities for extensive input/output arrangement and all these has made PLC suitable for the operation of robotic arm.

In this work, a robotic arm was developed, capable of lifting materials of 8kg to a 0.9m elevation

II. Methodology

In completing these works there were several steps that were executed. It was important to ensure that the developed arm consists of hardware and software development that can be executed successfully. This project involved the following tasks

- Considering the anthropomorphic requirement of a robot: the motivation behind the strongly humanoid design is the embodied cognition hypothesis, that human-like manipulation plays a vital role in the development of human cognition. A baby learns many cognitive skills by interacting with its environment and other human using its limbs and senses, and consequently its internal model of the world is largely determined by the form of the human body. This robot was designed to test the hypothesis by allowing cognitive learning scenarios to be acted out by an accurate reproduction of the perceptual system and articulation of a small child so that it could interact with the world in the same way that such a child does.

- Design a robotic arm that will be able to perform a wide range of tasks: for the hardware, the program is mainly focused on developing a multi-fingered hand and arm with greater dexterity. This work was programmed with series of individual actions that will allow the robot to manipulate various objects with quick commands, such as picking and placing object that is up to 10kg in weight.
- Fabricate a robotic arm with less weight: most of robotic arm previously developed was heavy and difficult to move from one place to another, therefore to solve this difficulty we have designed a robotic arm with very light materials such as aluminum and mild steel.

2.1 Design Selection of the Robotic Arm

In choosing the materials and the shape for the fabrication of the robotic arm, the following were taken into consideration:

- The ease of manufacturing the parts, the mode of manufacturing, ease of assembly, strength and durability of the parts, weight of robot
- The principal requirements for power transmission of robots are:
- Small size
- Low weight and moment of inertia
- High effective stiffness
- Accurate and constant transmission ratio
- Low energy losses and friction for better responsiveness of the control system.
- Elimination of backlash.

Hence, the combination of these factors has greatly influenced all the choices made in the design selection of the robotic arm.

2.2 Design Concept

The concepts considered in this design of the robotic material handling arm include the following;

I. Robotic Arm Configuration.
II. Robotic arm Manipulation.
III. Robotic Arm Loading Capacity.
IV. The Degree of Freedom.
V. Robotic Arm reach.

I. Robotic Arm Manipulation: Robotic arm manipulation majorly deals with the means which the robot can achieve the variation of movement required of the Robot. A manipulator can be set as a set of body connected to a chain of joints. These bodies are called links, Joint from a connection between neighboring pair of links. The term lower pair is use to describe a pair of body when the relative motion is characterized by two bodies sliding over one another, which shows the six possible lower pair joints.

II. Due to mechanical consideration, manipulator generally experience one degree of freedom. Most manipulators have revolute joints, or have sliding joints called prismatic joint. In the rare case that a mechanism is built with a joint having n degree of freedom, it can be modeled and n joints of one degree of freedom connected with n-1 link of zero length. Therefore, without loss of generality, manipulators which have joints with a single degree of freedom are considered.

III. Robotic Arm Loading Capacity; The Robotic loading capacity deals with the level of load that a robot is designed to carry. The various robot are for multi-use, hence they do not only hold end effectors, but also carry various work pieces and heavy jigs. This design is however a prototype that is not to hold more than 10kg of load from one place to another.

IV. Degrees of Freedom; the degree of freedom of the robot is three. The robot will move on three axes; x, y and z.

V. Robotic Arm Reach;

VI. The reach of the robot which we also describe as the work volume describes the limitation of the robot is expected to work.

2.3 Robotic Arm Configuration

Robotic arm configuration is generally categorized base on the way system move. Four various types are recognized based on the way the system move.

I. Cartesian(3P)
II. Cylindrical(R2P)
III. Spherical (polar) (2RP)
IV. Articulated (3R)
V. Cartesian (3P): Due to their rigid structure they can be manipulated, high loads so they are commonly used for pick and place operation.

VI. Cylindrical (R2P): They have a rigid structure, giving them the capability to lift heavy loads through a large working envelops, but they are restricted to area close to the vertical base or the floor.
VII. Spherical (Polar) (2RP): These robots can generate a large working envelope and they can also allow large load to be lifted.
VIII. Articulated Arm (3R): This is the most widely used arm configuration because of its flexibility in reaching any part of the working envelope.

2.4 Design Calculation

Design calculation for each component is important in order to ascertain their specifications. This analysis establishes the number of parts can be combined and which parts are genuinely contributing to product function.

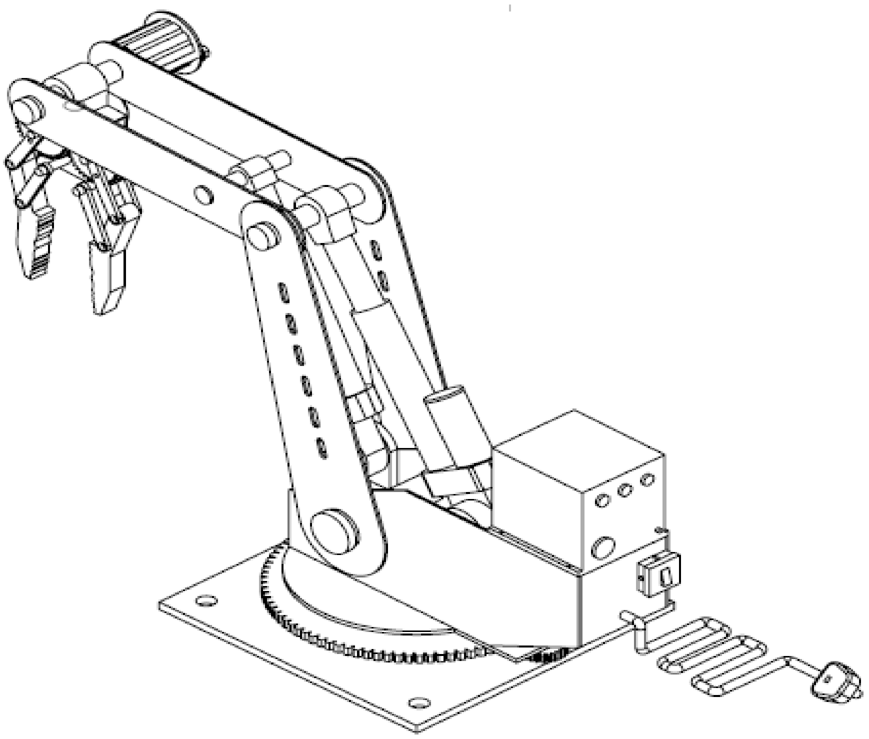

Figure 1: The Designed Robotic Arm

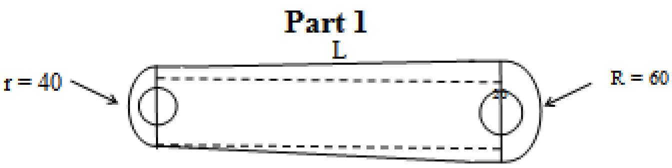

Fig. 1: Arm joint 1

Material: Aluminum

Density =3960kg $/ m^3$ (Khurmi, 2005)

The solid was analyzed based on various standard shapes and the corresponding volume computed as follows:

For the triangle part

$$Area_1 = \frac{1}{2}bh \quad (1)$$

$\frac{1}{2} \times 380 \times 20 = 3800\text{mm}^2$

For the square part

Area of square

$$Area_2 = l^2 \quad (2)$$

$380 \times 8030400\text{mm}^2$

For the circular part
Area of a circle

$$Area_3 = \frac{\pi r^2}{2} \qquad (3)$$

$\frac{22}{7} \times \frac{1}{2} \times 40^2 = 2514.24\text{mm}^2$

$$Area_4 = \frac{\pi r^2}{2}$$

$$= \frac{22}{7} \times \frac{1}{2} \times 60^2 = 5657.04mm^2$$

Total area of solid $= (Area_1 \times 2) + Area_2 + Area_3 + Area_4$

$$= (3800 \times 2) + 30400 + 2514.24 + 5657.04 = 46171.28mm^2$$

$$Volume = area \times thickness = A \times t \qquad (4)$$

Where t = 3m

$$V_{part_1} = 138513.84mm^3$$

The cut out solid will be evaluated using equation 5 given by Dass, (2002)

$$V = \pi r^2 h \qquad (5)$$

Where,

$V = 2121.39mm^3$ and $\phi = 30mm$

Total volume $= (138513.84 - 2121.39)mm^3 = 134271.45mm^3$

$$V = 0.0001343m^3$$

Recall that density $= \frac{mass}{volume}$

$$Mass = \rho \times v = 0.5317kg$$

$W = m \times g$ (John et. al., 2005) (6)

$$W = 5.216N$$

Part 2: Arm Joint 2

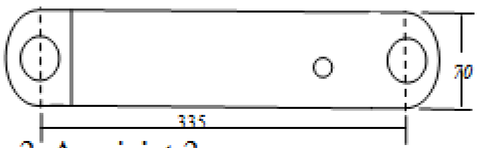

Fig 2: Arm joint 2

Material: Aluminum

$$Density = 3960kg/m^3$$

$Area_1$: Using equation (2)

$$Area = lb$$

$$= 335 \times 70 = 23450mm^2$$

$Area_2$: Using equation (3)

$$= \frac{1}{2} \times \pi r^2$$

Where

$$r = 3.5mm$$

$$= \frac{1}{2} \times \frac{22}{7} \times 3.5^2 = 1924.97mm^2$$

For the cylinder, applying equation (5)

$$V = \pi r^2 h$$

Where

$r = 14.5mm$

$V = \frac{22}{7} \times 14.5^2 \times 3 = 1982.32mm^3$

$Where_r = 9mm$

$V = \frac{22}{7} \times 9^2 \times 3 = 763.7mm^3$

The total cut away part (volume)

$= (2 \times 1982.32) + 7637$

$= 4728.34mm^3$

Total area for solid $= (2 \times 1924.97) + 23450$

$= 27299.94mm^2$

$Volume = a \times t$

$= 81899.82mm^3$

Net volume $= 81899.82 - 4278.34 = 77171.48mm^3$

$V = 0.00007717m^3$

$Mass = \rho \times v = 3980 \times 0.00007717$

$M = 0.307kg$

$W = mg$ (John *et. al.*, 2005)

$= 0.307 \times 9.81 = 3.013N$

The electric controller box expected

$Mass = 0.577kg$

$Weight = 5.66N$

Part 3

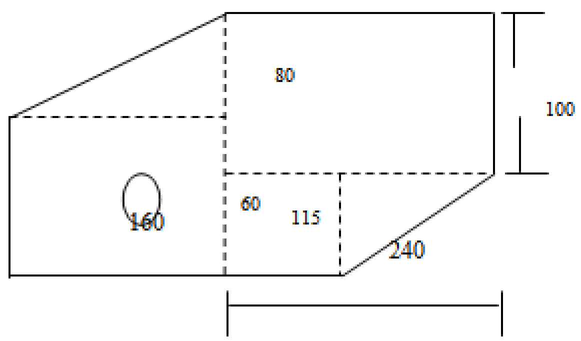

Fig. 3: Controller case

Controller case side plate

Material: mild steel

Density: 7850kg $/ mm^3$ (John *et. al.*, 2005)

$Area_1 = lb = 160 \times 80 = 12800mm^2$

$Area_2 = \frac{1}{2}bh = \frac{1}{2} \times 160 \times 80 = 6400mm^2$

$Area_3 = lb = 240 \times 100 = 24000mm^2$

$Area_4 = 115 \times 60(lb) = 6900mm^2$

$Area_5 = \frac{1}{2}bh = \frac{1}{2} \times 125 \times 60 = 3750mm^2$

$Total_{area} = 53850mm^2$

$V = 53850 \times 2mm$

$Volume = 107700mm^3$

The cut away cylinder

$R = 17.5mm$

Volume of a cylinder $= \pi r^2 h$

$V = \frac{22}{7} \times 17.5^2 \times 2$

$V = 1924.965mm^3$

Net volume of part

$= 107700 - 1924.965$

$= 105775.04mm^3 = 0.0001058m^3$

$Mass = density \times volume$

$= 7850 \times 0.000105$

$Mass = 0.83053kg$

$N = mg = 8.1475N$

Part 4

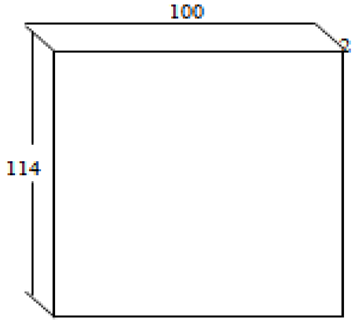

Fig. 4: Housing box

Housing box side plate

Material mild steal

$Density = 7850kg / m^3$

$Volume = lbh$ (7)

$= 100 \times 114 \times 2$

$= 22800mm^3$

Volume of cylinder $= \pi r^2 h$ (8)

$r = 5mm$, h = 2

$V = \frac{22}{7} \times 5^2 \times 2 = 157.14mm^3$

$Net_{volume} = (22800 - 157.14)mm^3 = 22642.86mm^3$

$V = 0.0000226mm^3$

$Mass = \rho \times v = 7850 \times 0.0000226$

$M = 0.177kg$

$W = mg = 0.177 \times 9.81$

$= 1.7364N$

From the robotic design

$w_0 = (0.5317 \times 2)$

$w_0 = 1.034kg = 10.45N$

$w_{1=}$ Linear actuator load $= 2.105kg = 20.65N$

$= (0.307 \times 2)$

$= 0.614kg = 6.023N$

$w_3 = 0.3kg(Motor_{load}) = 2.943N$

$w_4 = Gripper_{load}(1.51189)kg = 14.832N$

$w_5 =$ Expected load to lift $= 0.15kg = 1.4715N$

$w_6 = 2.105kg = 20.65N$

length ;

$l_0 = 380mm = 0.38m$, $l_1 = 335mm = 0.335m$, $l_2 = 238mm = 0.238m$, $l_3 = 388mm = 0.388m$,

$l_4 = 625.5mm(l_1 + l_3 - 97.5) = 0.626m$

$l_5 = 1.1035m$

- Torque calculation

Torque about joint 0 was determine by equation (9) below as given by Rajput, (2011).

$$M_o = w_5 + (l_o + l_4) + w_4(l_0 + l_1 + \frac{l_2}{2}) + w_3(l_0 + l_1) + w_2(l_0 + \frac{l_1}{2}) + w_1 \times l_0 + (w_0 \times \frac{l_0}{2}) + w_6 \times (l_5 - l_4) \qquad (9)$$

$$Substituting\ Mo = 0.15(0.38 + 0.626) + 1.512(0.38 + 0.335 + \frac{0.238}{2})$$

$$+ 0.3(0.38 + 0.335) + 0.614(0.38 + \frac{0.335}{2}) + 2.105 \times 0.38 + (1.0634 + \frac{0.38}{2}) + 2.105(1.1035 - 0.626)$$

$$= 3.9696kgm$$

$$T_1 = 38.942Nm$$

Total at joint 1

$$M_1 = w_5 + (l_1 + l_3) + w_4(l_1 + \frac{l_2}{2}) + (w_3 + l_1) + (w_2 + \frac{l_1}{2}) + (w_6 + \frac{97.5}{1000})$$

$$= 0.15(0.335 + 0.388) + 1.512(0.335 + \frac{0.238}{2}) + 0.3 \times 0.335 + (5.614 \times \frac{0.335}{2} + (2.105 \times \frac{97.5}{1000})$$

$$= 1.203kgm$$

$$T_1 = 11.8056Nm$$

Total at joint 2

$$M_2 = (w_5 \times l_{3)} + w_4(\frac{l_2}{2})$$

$$= (0.15 \times 0.388) + 1.512 \times \frac{0.238}{2}$$

$M_2 = 0.23813kg$ = 2.336Nm

After determining the three rotating effect, to calculate the shaft diameter, recall that the shafts are subjected to bending.

The bending moment of the shaft was obtained using equation (10) below as given by Khurmi and Gupta, (2005) and Ejiko *et al.*, (2015).

$$\frac{M}{I} = \frac{\sigma b}{y} \qquad (10)$$

where,

$M -$ Bending moment

I – moment of inertia of cross – sectional area of the shaft about axis of rotation

$\sigma b =$ Bending stress

$Y =$ Distance from neutral axis to the outer – most fibred

$$\frac{m / \pi d^4}{64} = \frac{\sigma_b / b}{2} \qquad (11)$$

$$M = \frac{\pi d^4}{64} \times \frac{2}{d} \times \sigma_b = \frac{\pi}{32} \times \sigma_b \times d^3$$

For the shaft at joint 1 (m)

$\sigma_b =$ Allowable shear stress $(42mp_a) = 42Nmm^2$

$$M_o = 38.942Nm = 38942Nmm$$

$$38942 = \frac{\pi d^3}{32} \times 42$$

$$d^3 = 8629670.1$$

$$d = \sqrt{29670.1}$$

= 30.96mm

Solid shaft

From standard shaft sizes (35mm) is chosen
For the second shaft

$$M_1 = 11.8056Nm = 11805.6Nmm$$

$M = \frac{\pi}{32} \times \sigma_b \times d^3$ (Khurmi and Gupta, 2005).

$$11805.6 = \frac{\pi}{32} \times 42 \times d^3$$

$$d^3 = 8994.74$$

$d = \sqrt[3]{8994.74}$, $d = 20{,}8mm$

The diameter of shaft chosen is $25mm$

The third shaft

$$M_2 = 2.336Nm = 2336Nmm$$

For solid shaft

$$M = \frac{\pi}{32} \times \sigma_b \times d^3$$

$$d^3 = 1779.84$$

$d = \sqrt[3]{1779.84}$, $d = 12.12mm$

Table 1: Showing the various arms joint

Motor location	**Base**	**Linear actuator2**	**Linear actuator2**	**End effector**
Torque (Nm)	14.164	11.806	11.806	2.336

Calculation of the torque acting on the base disc

Total load = mass of linear actuator x 2+ mass of side plates + mass of actuator support + 2 + mass of shaft (12)

$$= (3.5 + 2) + (0.83053 + 2) + 0.177 + 0.5 + 2 + 1.351$$

$$= 11.1891kg$$

$$Total_{mass} = 11.1891kg$$

$$W = mg$$

$$F = 11.1891 \times 9.81$$

$$F = 109.765N$$

The radius of the plate $= 129.04mm = 0.129m$

Torque acting on the base plate $= 14.164N$

Consideration of this torque is needed for the motor selection

The Ac motor Description
Operating rage $-220v\ Ac$
Torque $42N-m(12v)$
Stall current $0.4A220V\ Ac$
Shaft diameter $=12mm$
Load speed = $20RPM$
Weight $=60N/m$

Gear calculation
Spur gears
Specification of the pinion gear
Pitch circle $=45mm$
No of teeth $=18$
Module
Module of the gear was obtained using equation (13) below as given by Hannah and Stephens, (1984)

Module $=\dfrac{D}{T}$ (13)

Module $=\dfrac{45}{18}=2.5$

Circular pitch
The circular pitch of the gear was obtained using equation (14) below as given by Hannah and Stephens, (1984)

$$P_c=\frac{\pi D}{T} \qquad (14)$$

$$=\frac{(22/7)\times 45}{18}$$

$$Circular_{pitch}=7.857$$

$$R.P.M=20-Speed$$

From the relationship that angular velocity can be determined with equation 15 as given by Martin, (2000)

$$\frac{Cv_1}{Cv_2}=\frac{D_2}{D_1} \qquad (15)$$

$$Cv_1=Angular_{velocity}$$

$$Cv_1=\frac{2\pi N}{60} = 2.0952 \text{ rad/s}$$

$$\frac{2.0952}{Cv_2}=\frac{290}{45}$$

$$Cv_2=\frac{2.0952\times 45}{290}$$

$$Cv_2=0.3251rad/s$$

$$0.3251=\frac{2\pi N}{60}$$

$$N=\frac{60\times 0.3251}{2\times(22/7)}$$

$$N=3.103RPM-Sun_{gear}$$

Hub for sun gear $=20mm$
Also recall that

$$\frac{D_2}{D_1}=\frac{T_2}{T_1} \qquad (16)$$

$$\frac{290}{45} = \frac{T_2}{18}$$

$$T_2 = \frac{290 \times 18}{45} = 116$$

No of Teeth $= 116$

This is when a desired end effectors position derived, but there is a need to obtain the joint angles required to achieve it

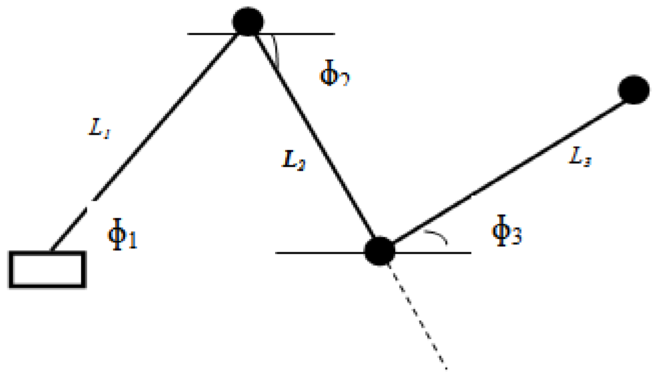

Fig. 5: Gear Calculation Using Joint Angle

Equation (17) is given by Willard, (2010)

$$\phi_1, \phi_2, \phi_3 = f^{-1}(p)$$

(17) $X = L_1 \cos\phi_1 + L_2 \cos\phi_2 + L_3 \cos\phi_3$ as given by (Malhotra and Subramaniah, 1994) (18)

$$Y = L_1 \sin\phi_1 - L_2 \cos\phi_2 + L_3 \cos\phi_3$$

The resultant can be determined using equation 19 as given by Young and Timoshenko, (2001)

$$R = \sqrt{x^2 + y^2} \qquad (19)$$

Using analytical methods

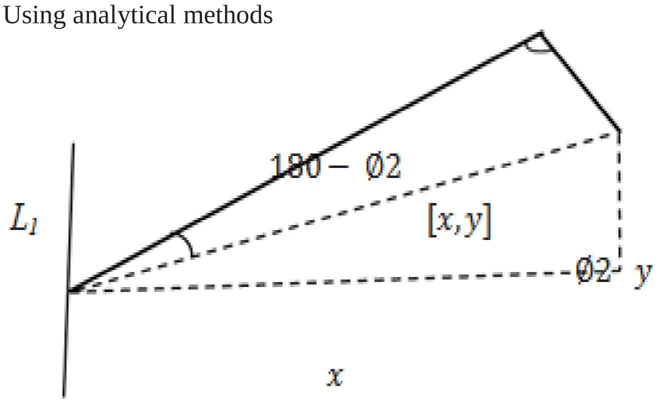

Fig. 6: Gear Calculation Using Analytical Method

Degree of freedom was estimated through equation 20 as given by Robert, (2013)

$$F = 3(n-1) - 2F_1 \qquad (20)$$

$N =$ Total no of links

$F_1 =$ Total numbers of joints

For this scenario

$N = 5$

$F = 5$

$F = 3(5-1) - 2(5)$

$= 3 \times 4 - 10 = 2$

$DOF = 2$

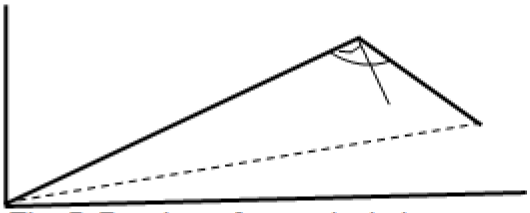

Fig. 7: Resultant force calculation

$$\phi_2 = \phi_3 - 90^0 \quad R = \sqrt{x^2 + y^2}$$

$$\phi = \tan^{-1}\frac{y}{x}$$ (Malhotra and Subramaniah, 1994)

2.5 Component of the Robotic Arm

The materials recommended for use in this work are

- Aluminum
- Mild steel
- Stepper motor
- Linear actuator
- Spur gear
- Pinion gear

i. The Gear System

In this work, spur gear was chosen, due to the advantage of high torque amplification within a relatively small space. The necessary data for the selection and choice of the gear arrangements at each joint includes:

i. Power transmitted
ii. Transmitted speed
iii. Torque developed
iv. Bending stress
v. Ultimate tensile strength
vi. Factor of safety
vii. Module of gear
viii. Number of teeth

ii. Control Panel

The control panel consists of the transformer connected in series with bridge rectifier to convert the linear actuator and the stepper motor from Direct current to Alternating current.

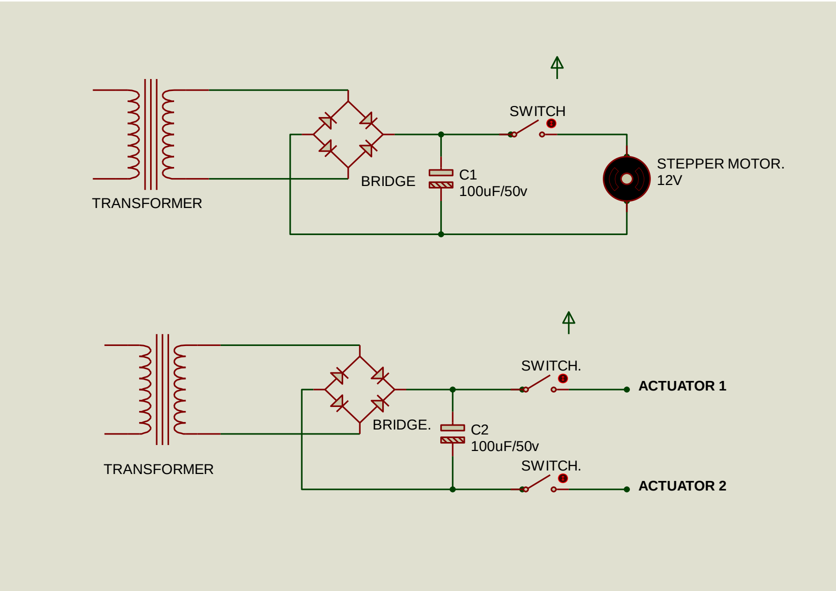

Fig. 8: Circuit diagram of the control panel

III. RESULT AND DISCUSSION

The developed robotic arm was subjected to various performances testing to yield several reactions known as results. These results generated from the robotic arm includes; the maximum load it can carry before showing signs of failure, such as the motor become noisy or increased motor temperature, maximum arm length, orientation and the degree of freedom.

3.1 The Maximum Load Capacity

The load designed for this work initially was 10kg, but after the completion of the work, the machine was subjected to testing to know the maximum load it can carry before showing signs of failure or fatigue

3.2 Performance Evaluation

The performance evaluation of the machine was based on the loading capacity before the machine makes an unusual noise, the lifting capacity of the robot before the machine gives sound and the radius of the arm and the total space covered by the robot.

Table 2: Performance Evaluation of the Robotic Arm

S/N	Load (Kg)	Motor Temp. (^{0}c)	Noise Without Counter Weight	Noise With Counter Weight
1	2kg	Normal	normal	
2	4kg	Normal	normal	
3	6kg	Normal	normal	
4	8kg	Normal	normal	
5	10kg	Normal	abnormal	Normal with weight of 15kg
6	12kg	Normal	abnormal	Normal with weight of 20kg

The machine was designed for load of 10kg, but after testing, the machine was able to lift a load of 8kg successfully. Therefore the efficiency of the machine is calculated as

Efficiency = $\frac{input}{output} \times 100$

Efficiency = $\frac{8}{10} \times 100\%$

Efficiency = 80%

3.3 Maximum Length of the Arm

The maximum length is 3m. This length of the arm at horizontal level at this stage the arm move the load in horizontal plane before taking it to the expected destination where the load is needed. The length at this point depends on the length at which the first actuator shot out. Therefore the maximum length is 0.7m while the minimum length is 0.6m.

Table 3: Loading Capacity of the machine

S/N	**Load (kg)**	**Height (mm)**	**Orientation**
1	2kg	3000	180^0
2	4kg	3000	180^0
3	6kg	3000	180^0
4	8kg	2500	135^0
5	10kg	2100	105^0

3.4The Degree of Freedom

The degree of freedom of a mechanical system is driven by the number of link and independent parameters that define its configuration. The degree of freedom of any material or machine is established in equation 15 as given by Robert, (2013) as;

F=3(n-1)-2f. (24)

Where;

N is total number of links, n=5

F is total number of joints, f=5

Therefore the degree of freedom

F= 3(5-1) – 2(5)

F= 3(4) -10 =2

The degree of freedom from the calculations above indicates the level of free movement of the arm with respect to its mobility to be two (2).

IV. CONCLUSION AND RECOMMENDATIONS

The robotic arm was developed and tested. The movement of materials from one place to another is paramount and important. This has been achieved by various methods. In minimizing or even eliminating the human contribution which can be hazardous and injurious, a robotic arm was developed. The development stages includes making assumptions such as expected maximum load required to be move and the space the machine can cover. Based on the maximum required lifting load and length of the arm, specification on actuators and stepper motors were derived. The developed robotic arm has an efficiency of 80% before introducing counter weight, and has 90% efficiency after applying 20kg Counter weight.

Considering the nature of the machine developed, the following recommendations are hereby suggested:

1. The robotic arm is highly recommended for handling of small load at home, and offices and small weight production component firm.
2. Effort should be made to develop large one for its effective used in industry.
3. The arm should be made dynamically orbiting to increase the efficiency.
4. Research should be conducted on the materials to develop a lesser weight robotic arm.

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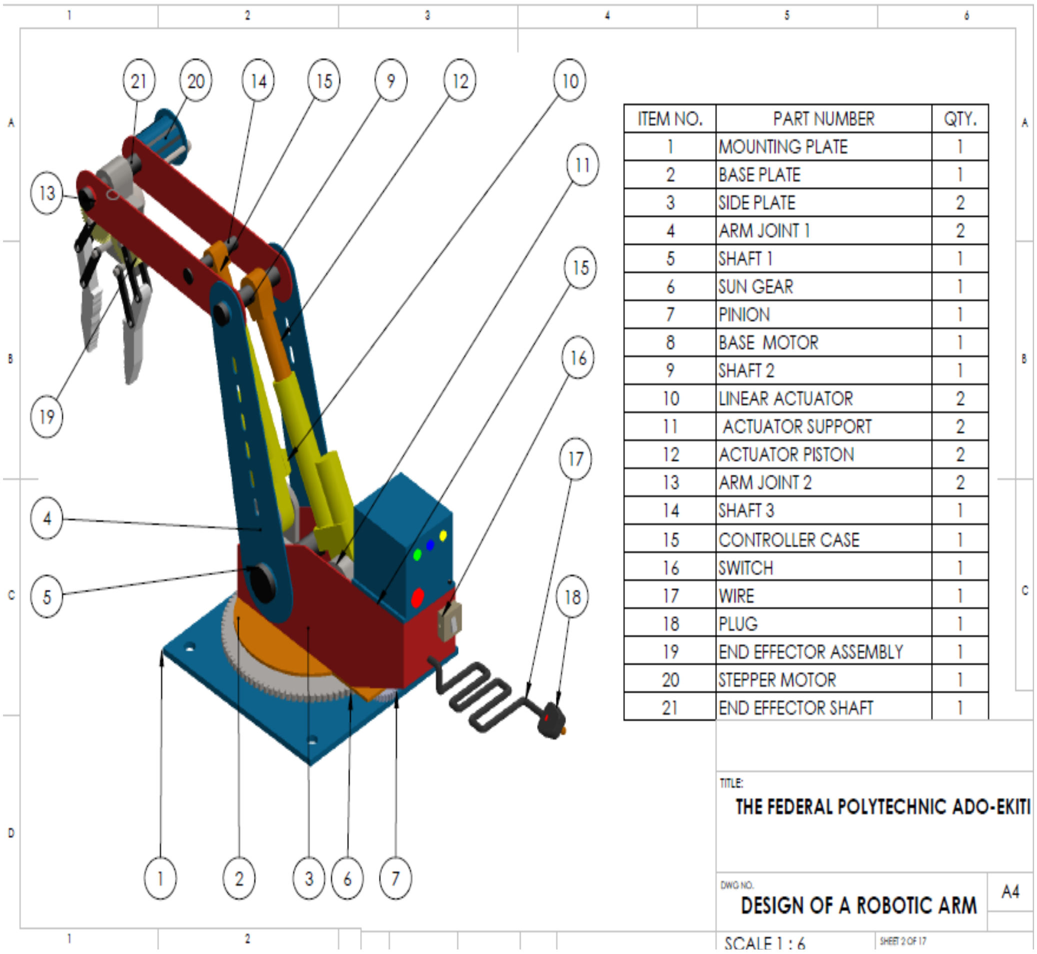
APENDIX



ITEM NO.	PART NUMBER	QTY.
1	MOUNTING PLATE	1
2	BASE PLATE	1
3	SIDE PLATE	2
4	ARM JOINT 1	2
5	SHAFT 1	1
6	SUN GEAR	1
7	PINION	1
8	BASE MOTOR	1
9	SHAFT 2	1
10	LINEAR ACTUATOR	2
11	ACTUATOR SUPPORT	2
12	ACTUATOR PISTON	2
13	ARM JOINT 2	2
14	SHAFT 3	1
15	CONTROLLER CASE	1
16	SWITCH	1
17	WIRE	1
18	PLUG	1
19	END EFFECTOR ASSEMBLY	1
20	STEPPER MOTOR	1
21	END EFFECTOR SHAFT	1

Fig. 9: Part List of the Robotic Arm

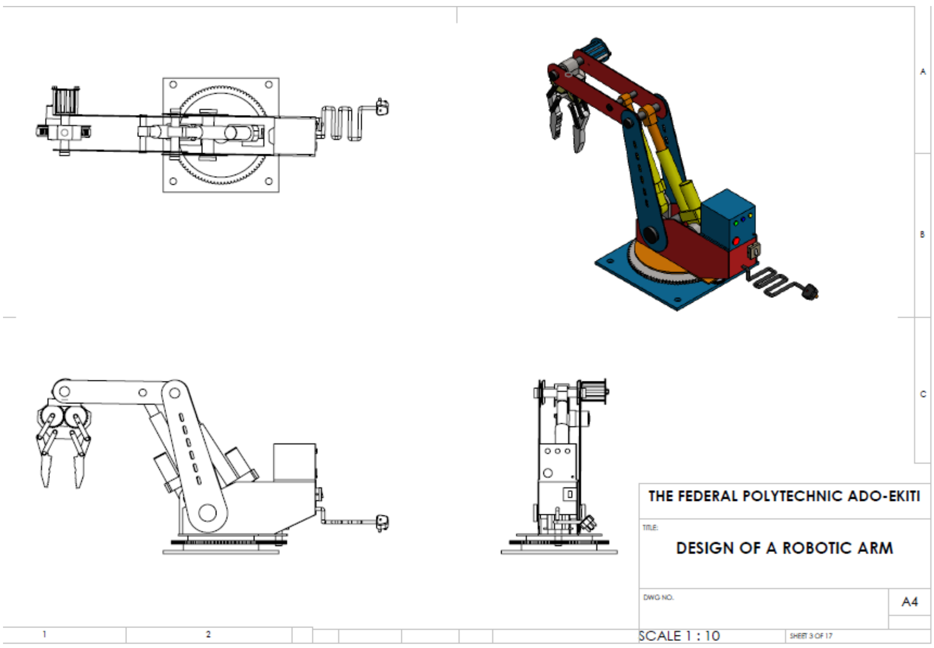


Fig.10: Autographic View of the Robotic Arm

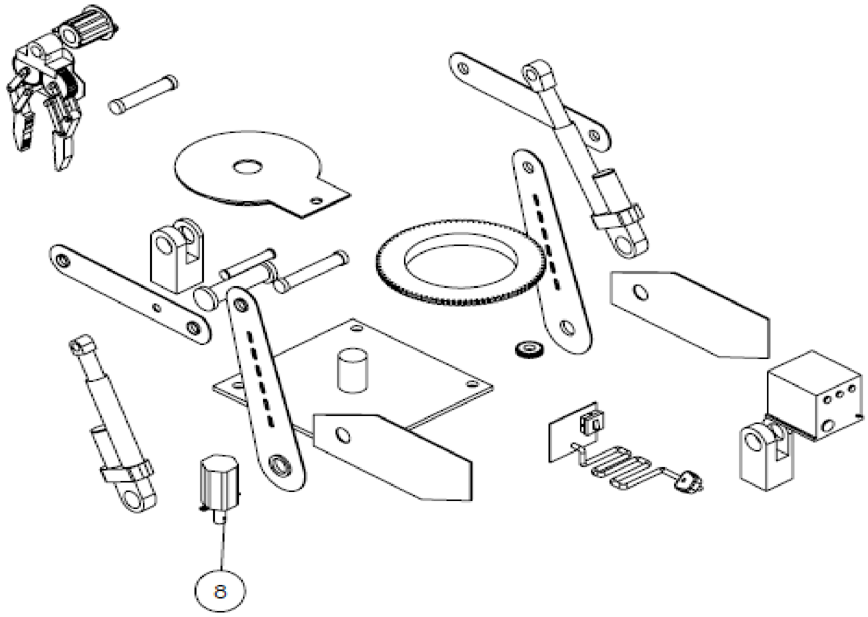


Fig.11: Exploded View of the Robotic Arm

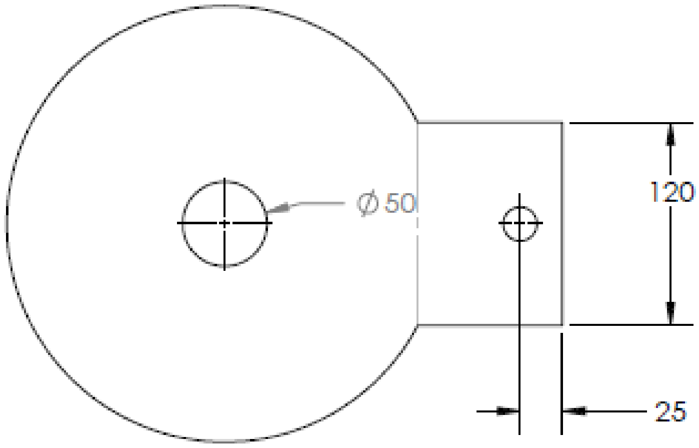


Fig.12: Base Plate

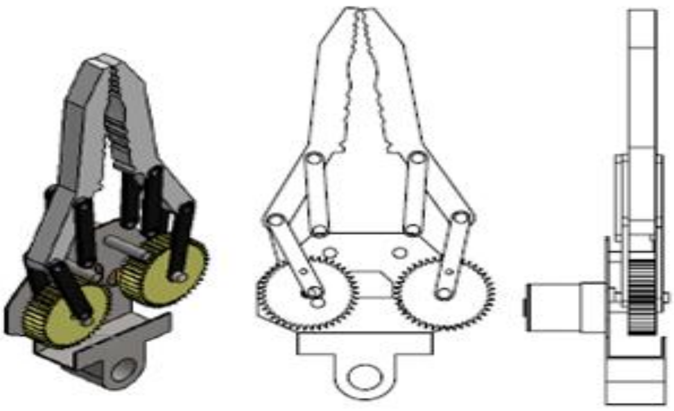


Fig.13: Wrist and End Effector

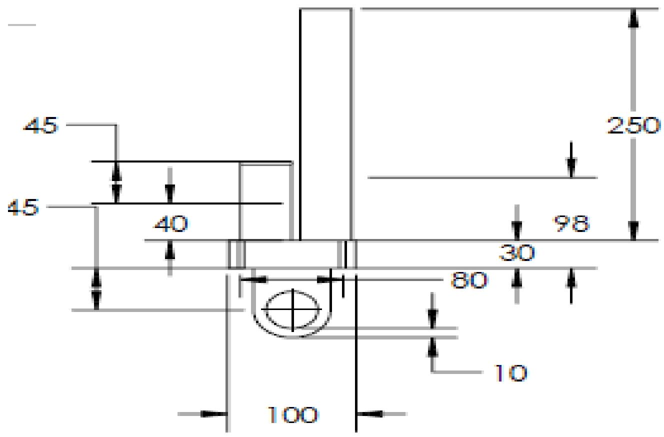


Fig.14: Linear Actuator

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