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Design and development of a laboratory scale hydraulic arm for engineering education

Azaka Onyemazuwa Andrew[1*], Igboka Kingsley Ugonna[2], Okafor Anthony Amaechi[3], Odeh Calistus Princewill[4]

[1,3,4] Department of Mechanical Engineering, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria
[2] Ph.D Student, Department of Mechanical Engineering, Chukwuemeke Odumegwu Ojukwu University, Uli, Anambra State, Nigeria.

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ABSTRACT

Robotics are now completely necessary in contemporary industry. Its development and application in the manufacturing sector have enhanced output, improved product quality, and decreased the cost of high labor within these sectors with high labor costs. The design and construction of a hydraulic arm on a laboratory scale are included in this study. Here, a thorough and understandable description of what a robot is was given. The arm's 3D model was created using the soft AutoCAD tool during the design phase. Pascal's principle was also used to gauge the size of the forces causing the motion of the arm's various linkages. A detailed explanation of how to determine the hydraulic arm's degree of freedom was provided.

1. Introduction

The importance of Robots in modern manufacturing keeps increasing yearly, this is no surprise as global competition in the market demands continuous automation and modernization of production processes, especially in the automotive industry [1]. In recent times, robots are being increasingly employed to carry out tasks in place of humans especially in a repetitive task or in an environment that poses threat to man. Different sources have offered definitions of the word Robot. According to Rajgure et al.[2], it is simply a mechanical device that performs predetermined automated tasks and movements under human supervision. In [3], a robot is defined as an automotive device that performs functions normally ascribed to humans or a machine in the form of humans. A hydraulic robotic arm is simply a mechanical arm, usually programmable, with similar functions to a human arm. It may be the sum total of the mechanism or may be part of a more complex robot [4]. Here the links are connected by joints that facilitate either rotational or translational motion, these links are considered to form a kinematic chain. At the end of this kinematic chain is found a device that interacts with the environment called the end effector. This end effector is analogous to the human hand, its nature varies with the task it is desired to carry out. The robotic arm can be autonomous or manually controlled and could be employed to achieve a great variety of tasks efficiently.

Robots are of various types such as Articulated Robots, SCARA Robots, Cartesian coordinate Robots, Delta Robots, Cylindrical Robots, and Polar Robots. There are different ways of classifying Robots but based on their uses or applications it is classified as industrial robots, service robots, medical robots, entertainment robots, space robots and military robots. It finds application in many fields such as the health sector, manufacturing, national defense, consumer goods sector, and so on. But it is unfortunate to point out that in developing countries like Nigeria, the knowledge of this technology is purely-theory based since most University laboratories are under-equipped. As such, undergraduate students in engineering disciplines are usually taught theories with little or no practical demonstration and applications. We intend to solve the aforementioned problem by designing and fabricating a laboratory-scale hydraulic robotic arm to be used for demonstrative and educational purposes, especially in the mechatronics laboratory of the mechanical engineering department, Nnamdi Azikiwe University, Awka. It will serve as a demonstrative tool in teaching students the practical application of Pascal's law of pressure, in addition to stimulating their interest

*Corresponding author: oa.azaka@unizik.edu.ng

in robotics. The objectives of this study are to: select a suitable material for the construction by taking into consideration the pressure input and output, obtain suitable design parameters by selecting a material that can withstand stresses, create a 3-D model of the robotic arm using Solid Works, simulate the movement of the robotic arm on the Computer software to ensure that the design will operate efficiently, and to construct the robotic arm after making sure that all design parameters will operate efficiently.

It is important to note that this work encompasses material selection, design, simulation, and fabrication of a basic robotic arm system. It also covers the implementation of the kinematics of the arm but does not consider the details of the derivation of the kinematic equations. This robotic arm is purely a mechanical device to carry out any task involving motion in a circular axis. It does not have any electronic circuit design attached to it. Movement of all its linkages is initiated and controlled using fluids and piston–cylinder mechanism.

Huang et al., [5] designed and analyzed a certain hydraulic system through which the design references were a key factor for optimizing the system’s properties via hydraulic system force and changes in torque. They reported that a typical mechanical and electronic hydraulic lifting appliance has many working conditions and properties due to its peculiarities. These properties of hydraulic systems decide high efficiency, security as well as stability under different working conditions. Their simulation analysis on a simple hydraulic lifting appliance under different working conditions outlined the properties of a hydraulic system can be improved and a hydraulic system with stable performance can be obtained. The Simulation Model is on the basis of the AMESim Jacking system model of the hydraulic crane which mainly consists of establishing the model, selecting model types, and setting up model parameters.

A hydraulic cylinder with double action and double ends has been successfully designed and studied by [6]. The piston's diameter with a seal is 48mm, and the external and internal diameters of the cylinder were found to be 55mm and 48mm, respectively. 140mm is the length of the stroke, and the piston rod diameter is 12mm. The reliability, usability, and safety of the hydraulic cylinder design were credibly validated by the FEA study performed on the hydraulic cylinder. When made for industrial automation, such as hydraulics systems for cutting and crimping hydraulics pipe hoses, and power steering for earthmoving equipment, among other industrial applications, this designed double-acting double-end hydraulic cylinder can be efficiently used.

The modeling of a pneumatic robotic arm for automation in two machines, for material handling purposes, was evaluated by Rajgure et al.[2]. Extrusion and belt grinding machines were the subjects of the comparison. The creation of a pneumatic arm with the ability to pick up and position cylindrical objects like steel bars was ordered. It has shown the robot arm's forward and inverse kinematics and demonstrated how cellular titanium and nanocrystalline aluminum can be used to construct lighter robotic arms. The arm robot is sometimes controlled by PLC programs, although its construction and connection to the arm require additional resources.

For Pick and Place applications, Kaustubh et al.,[7] employed the Node MCU from Microchip Technology to operate the system and all other actions taken by the Robot Arm. The Node MCU will receive an Android application and reply accordingly. The robot's numerous sections are modeled using CAD software. Components of pneumatic systems are more commonly used in robot arms.

Pick-and-place robots have been created by Vishakha and Andurkar [8] for use in industrial settings. For the development of pick and place objects, a low-cost robot platform is used in the design process. Both wireless and serial connections are made between the remote base station and the GUI application as well as the mobile robot and the remote base station. The base station needs to be hardwired with the radio packet controller and requires a serial connection with the GUI application. The project's goal was to remotely command and control a robot using a GUI program, and it was effective in implementing both serial and wireless communication in an educational setting.

Elfasakharmy [9] designed and developed a competitive, reasonably priced robot arm with four degrees of freedom. Outlined a straightforward process for the design, development, and implementation of a 4-DOF robot arm that can carry out basic activities such as light material handling. Servo motors were used in the design and construction of the acrylic robotic arm to create links between the arms. Here, the controller is unnecessary because the servo motors essentially only use encoders. The motor's limited rotation range, however, limits the area that the arm may reach and, consequently, the range of feasible postures. Without taking into account the articulation, the robotic arm has four degrees of freedom.

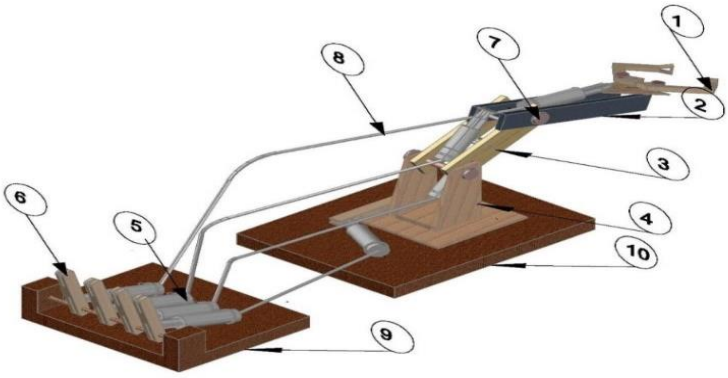
2.0 Materials and Methods

The materials used for the construction of the robotic arm were carefully studied and analyzed to ensure they satisfy the required properties to enhance the maximum efficiency of the simple arm. These materials were selected due to its lightweight and easy machinability.

2.1 Materials Used:

The basic materials used are:

S/N	Material	Property	Function
1	Ply Wood	Easy machinability, does not corrode	Used to construct the body frame, base, the claw and other parts of the robotic arm.
2	Syringe with Seal	Flexible, and does not corrode	This is a special type of syringe which has a seal attached to the plunger to ensure there is no pressure loss as well as the penetration of dirt into the system.
3	Vinyl Tube	Flexible, and does not corrode	Serves as the channel through which the fluid travels from the plunger to the ram
4	Bolts, Nuts, & Clamps	does not corrode	apart from the assembling done by joining, the movable parts such as the claw, arm, and the rotating parts were assembled using bolts and nuts.



S/N	MEMBER	NAME	TYPE OF LINK	MATERIAL	QTY
1		JAW	BINARY	PLYWOOD	1
2		ARM	BINARY	PLYWOOD	1
3		FOREARM	BINARY	PLYWOOD	1
4		BASE FRAME	BINARY	PLYWOOD	1
5		CYLINDER (PISTON)	--		8
6		CONTROL LEVER		PLYWOOD	4
7		BOLTS, NUT AND WASHER	--	STEEL	1
8		FLEXIBLE PIPE		PLASTIC	4
9		CONTROL LEVER BASE	STRUCTURE	PLYWOOD	1
10		RECTANGULAR	STRUCTURE	PLYWOOD	1

Fig 1: 3D Model of the Robotic arm showing the parts.

2.2 Construction and Assembling

The construction of the component part involves various operations, thus different tools, equipment, and machines were used during the construction of the project. The following are the tools, equipment and machines used: Measuring tape, Vernier caliper, Chisel, Hammer, Vice, Electric powered drill, and Power filling machine.

The components of the simple hydraulic robotic arm were coupled in a sequential procedure to make the simple hydraulic lifting machine (crane). The base frame was marked and cut out from plywood. Stands were attached to the base frame to provide sufficient height. Thereafter the control box was fixed at one end of the base. The rotating member of the arm containing the bearing was mounted on a round plywood which was joined on the base of the arm, thereby making it detachable when there is a need for maintenance. The arms were then assembled with the aid of the bolts and nut due to the fact that they are to be movable, afterwards the claws were mounted and bolted with bolts and nuts.

In addition, the syringes (with seal) were then attached to the sittings provided for them and are clamped using clamps to make sure they do not move. The vinyl tubes are then connected to the syringes and the other is connected to the control box containing syringes which will control the ones attached to the mechanical arms and joints, this is done after they have been filled with the fluid (water).

3.0 Motion Analysis

Fundamental fluid mechanics equations adapted from [10] were employed to model the motion, friction and leakage losses in the hydraulic components.

3.1 Motion analysis for cylinder 1 and 5 responsible for the base rotation

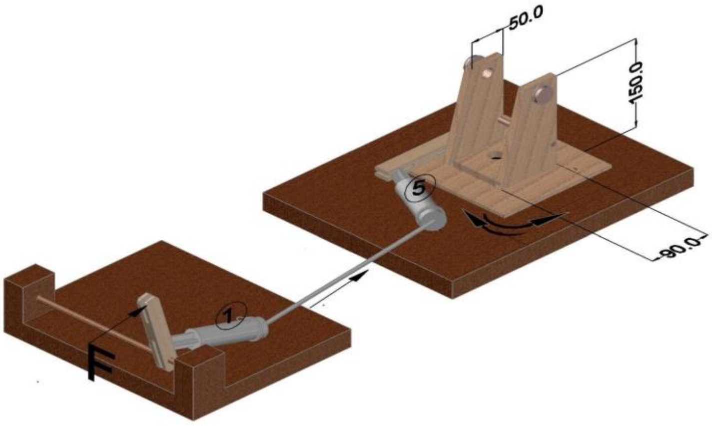


Fig 2: Rotation of the base

Fluid used = water, density = 1000kg/m^3

D_1 = Diameter of cylinder 1 (i.e. diameter of the input cylinder)

A_1 = Area of cylinder 1

F_1 = Input force

P_1 = Pressure due to F_1

L_{15} = Length of the hose connecting cylinder 1 and cylinder 5

But, Pressure = Force/Area

$$P_1 = \frac{F}{A} \qquad 3.1$$

Similarly:

D_5 = diameter of cylinder 5

A_5 = Area of cylinder 5

F_5 = output force

P_5 = Pressure due to F_5

$$P_5 = \frac{F_5}{A_5} \qquad 3.2$$

Applying Pascal's principle along C_1 and C_5 connected by the hose L_{15}

$P_1 = P_5$

$$\frac{F_1}{A_1} = \frac{F_5}{A_5} \qquad 3.3$$

Re-arranging equation 3.3

$$F_5 = F_1 \times D_5 \qquad 3.4$$

A1 which represents the magnitude of the force that causes the rotation of the model.

Or $F_5 = \frac{F_1 \times D_5}{D_1}$ in terms of diameter [Tips A α D] 3.5

Deductions from equation 3.5

i) F_5 increases as F_1, D_5 increases

ii) F_5 decreases as D_1 increases or F_5 increases directly with the increase of D_1

3.2 Motion analysis for cylinder 2 and cylinder 6 responsible for the upward and downward movement of the forearm (boom)

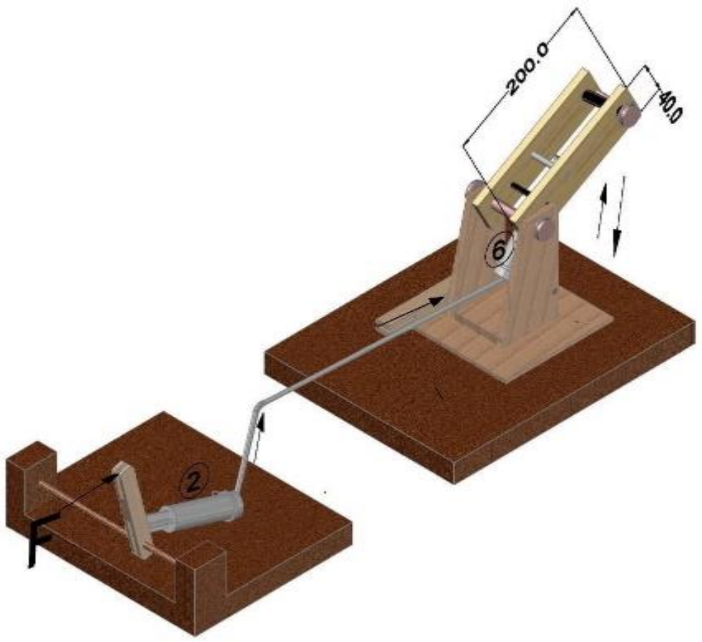


Fig 3: Movement of the Forearm

D_2 = Diameter of cylinder 2

A_2 = Area of cylinder 2

F_2 = Input force

P_2 = Pressure due to F_2 at cylinder 2

L_{26} = Length of the hose connecting cylinder 2 and cylinder 6

$P_2 = \frac{F_2}{A_2}$ 3.6

Similarly:

D_6 = diameter of cylinder 6

A_6 = Area of cylinder 6

F_6 = output force i.e. the force causing the upward and downward movement of the forearm

P_6 = Pressure due to F_6

$P_6 = \frac{F_6}{A_6}$ 3.7

Applying Pascal's principle along C_1 and C_5 connected by the hose L_{26}

$P_2 = P_6$ 1.e equation 3.6 = equation 3.7

ie $\frac{F_2}{A_2} = \frac{F_6}{A_6}$ 3.8

$F_6 = F_2 \text{ x } A_6$ 3.9

A2 which represents the magnitude of the force that causing the upward and downward movement of the forearm

Or $F_6 = \frac{F_2 \times D_6}{D_2}$ in terms of diameter 3.10

Deductions from equation 3.10

i) F_6 increases as F_2, D_2 increases

ii) F_6 decreases as D_2 increases or F_6 increases directly with the increase of D_2

3.3 Arm motion analysis for cylinder 3 and 7 responsible for upward and downward movement of the arm.

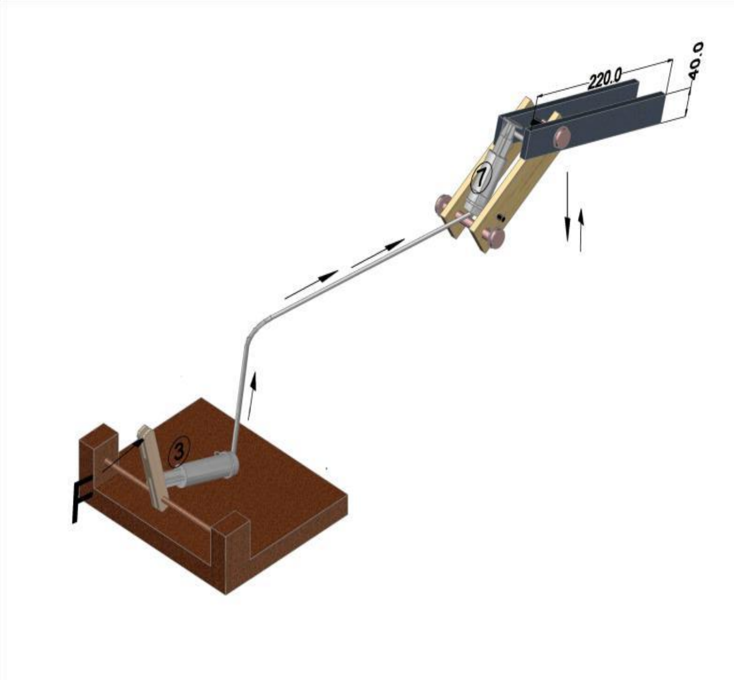


Fig .4: Movement of the Arm

D_3 = Diameter of cylinder 3

A_3 = Area of cylinder 3

F_3 = Input force

P_3 = Pressure due to F_3 at cylinder 3

L_{37} = Length of the hose connecting cylinder 2 and cylinder 6

$P_3 = \frac{F_3}{A_3}$ 3.11

Similarly:

D_7 = diameter of cylinder 7

A_7 = Area of cylinder 7

F_7 = output force i.e. the force causing the upward and downward movement of the forearm

P_7 = Pressure due to F_7

$P_7 = \frac{F_7}{A_7}$ 3.12

Applying Pascal's principle along C_3 and C_7 connected by the hose L_{37} we have;

$P_3 = P_7$ 1.e equation 3.11 = equation 3.12

i.e. $\frac{F_3}{A_3} = \frac{F_7}{A_7}$ 3.13

Re-arranging equation 3.13

$F_7 = F_3 \text{ x } A_7$ 3.14

A3 which is the magnitude of the force causing the upward and downward movement of the arm

Or $F_7 = \frac{F_3 \times D_7}{D_3}$ in terms of diameter 3.15

Deductions from equation 3.15

i) F_7 increases as F_3, D_7 increases

ii) F_7 decreases as D_3 increases or F_7 increases directly with the increase of D_3

3.4 Jaw motion analysis for cylinder 4 and cylinder 8 responsible for the opening and closing of the grasping hand.

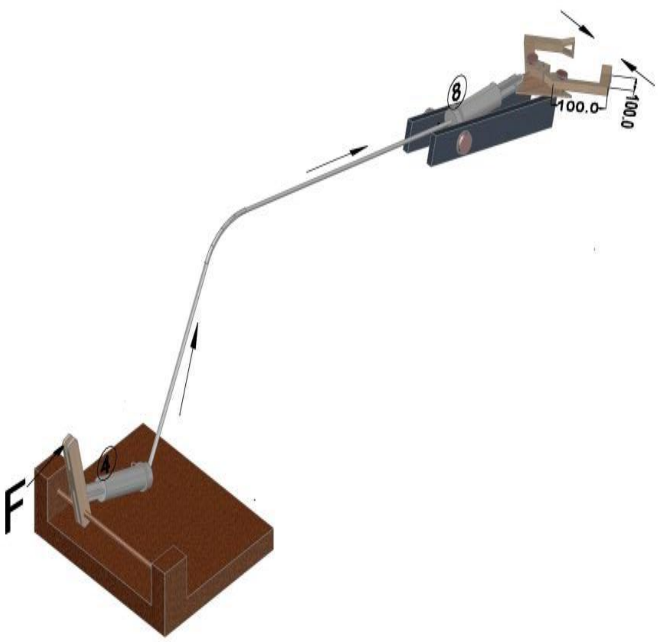


Fig 5: Movement of the Jaw

D_4 = Diameter of cylinder 4

A_4 = Area of cylinder 4

F_4 = Input force

P_4 = Pressure due to F_2 at cylinder 4

L_{48} = Length of the hose connecting cylinder 4 and cylinder 8

$P_4 = \frac{F_4}{A_4}$ 3.16

Similarly:

D_8 = diameter of cylinder 8

A_8 = Area of cylinder 8

F_8 = output force i.e. the force causing the opening and closing of the grasping hand
P_8 = Pressure due to F_8

$P_8 = \frac{F_8}{A_8}$ 3.17

Applying Pascal's principle along C_4 and C_8 connected by the hose L_{48} we have;

$P_4 = P_8$ i.e. equation 3.16 = equation 3.17

i.e. $\frac{F_4}{A_4} = \frac{F_8}{A_8}$ 3.18
Re-arranging equation 3.18
$F_8 = F_4 \text{ x } A_8$ 3.19
A4 which is the magnitude of the force causing the opening and closing of the grasping hand.
Or $F_8 = \frac{F_4 \times D_8}{D_4}$ in terms of diameter 3.20

The following deductions could be made from equation 3.20

i) F_8 increases as F_4, D_8 increases

ii) F_8 decreases as D_4 increases or F_8 increases directly with the increase of D_4

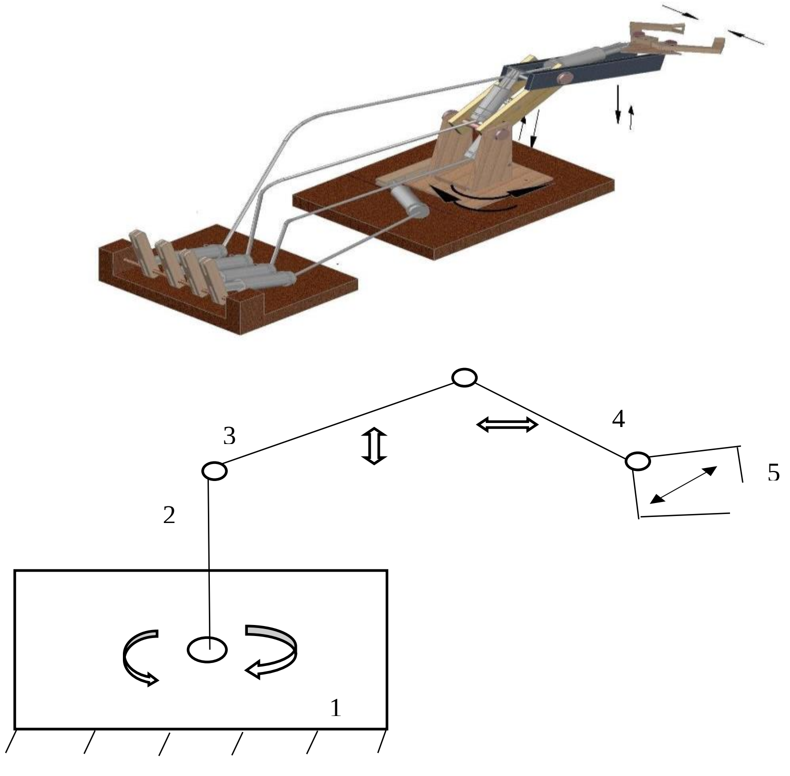


Fig 6: The model and skeletal diagram of the robotic arm

3.5 Degree of Freedom

The degree of freedom (mobility) was determined using equation 4.1 (Gruebler's Equation) adapted from [11].

Employing mobility equation;

$DOF = 3(L-1)-2J_1-J_2$ 4.1
Where DOF = Degree of Freedom
L = Number of Links

J_1 = Number of lower pair joints

J_2 = Number of higher pair joints

From the skeletal diagram (fig. 6)

DOF = 12 – 8 = 4

4.0 Result and Discussion

A robotic arm that is hydraulically powered, guided by fluid-filled syringes, and composed of multiple components coupled to one another in a pre-planned manner to produce the desired output has been created. Each component of the system has been given a certain amount of flexibility to move in a restricted manner, guide other components, and pick up and place light objects as needed. A fixed base, four binary linkages (arm, forearm, jaw, and base frame), four cylinders (syringes), and control levers make up the entire system. The laboratory-scale hydraulic robotic arm was tested with a 20g load when it was finished, and it was moved from one position to another. This load was moved successfully from its starting place to a new one. To prevent leaks in the system or an abrupt drop in load, the pressure retention was closely monitored. The law proposed by Blasé Pascal also stated that the pressure in the plunger was equivalent to that in the arm. The robotic arm's performance was efficient; the mechanical advantage is the difference between the machine's force output and its force input.

6.0 Conclusion

The purpose of this work has been achieved successfully which, as earlier stated, was to fabricate a laboratory scale hydraulic arm to pick and place light objects from one position to another, which will be used for demonstrative and educational purposes. The fabricated hydraulic robotic arm picked up an empty can of malt and successfully transferred it to another location. This model can be used anywhere due to its lightweight and portable nature. For a wider demonstration, the end effector could be replaced with other devices such pontoon or shovel. This model is of low cost and no doubt engineering students will be thrilled and their interest stimulated in robotics which is valuable as well as indispensable in modern manufacturing.

LIST OF ABBREVIATIONS

Di = Diameter of cylinder (i = 1, 2, 3,4, 5)

Ai = Area of cylinder (i = 1, 2, 3, 4, 5)

Fi = Input force (i = 1, 2, 3, 4, 5)

P_i = Pressure due to F (i = 1, 2, 3, 4, 5)

Li = Length of the hose connecting cylinder (i = 1, 2, 3, 4, 5)

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