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Original article

Design, Control and Implementation of Robotic Shoulder Girdle Using Electro Pneumatic System

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Abstract: The proponents used the concept of pneumatic actuators such as cylinders and rotary actuators to represent the muscles of human shoulder girdle. The pneumatic system is ideal in carrying heavy loads which need a great force to sustain. The proponents also used the directional solenoid valve to drive the pneumatic actuator's motion. The valve has the ability to hold the air inside the cylinder because it traps the air from escaping the cylinder; thus, the proponents can maintain the position of the pneumatic actuator to achieve the desired angle of the robotic shoulder girdle. A wearable controller is also designed to measure the angle of DOF for the human movement. Through this the robot can mimic the different DOF movement of humans as well as providing enough force to carry the weight.

Keywords: *Shoulder girdle, pneumatic cylinder, rotary actuator, directional solenoid valve, wearable controller*

1. INTRODUCTION

The shoulder girdle refers to the structure of the shoulder that is supported by three bones: humerus (the upper arm bone), scapula (the shoulder blade), and clavicle (the collar bone). The bones form four joints held together by a number of muscles and ligaments. Shoulder girdle muscles stabilize scapula so the shoulder joint muscles will have a stable base from which to exert force for moving the humerus. It also contracts to enhance movement of upper extremity when shoulder goes through extreme range of motion and to maintain scapula in relatively static position during shoulder joint actions. Shoulder girdle movements are based on the dynamic movements produced by the scapula. These movements are protraction, retraction, elevation, depression, upward rotation and downward rotation. In protraction and retraction, the scapula moves away and toward the midline. In elevation and depression, the superior border of scapula and the acromion moves in upward and downward direction. And in the upward rotation and downward rotation, the glenoid cavity rotates in upward and downward direction while moving the inferior angle laterally and medially.

In the past years, the actuators used in the shoulder girdle part of most humanoid robots are electric motors, such as the shoulders of musculoskeletal humanoid Kenshiro. The actuation method used in Kenshiro is the planar muscle in which the mechanism is a wire that is winded many times by pulleys and both ends of the wires are rolled up enabling high reduction ratio. The motor used for planar muscle of the Kenshiro is an electric motor. Somehow, Electric motors have some disadvantages such as in humanoid Kojiro. In humanoid Kojiro, even though the electric motor is fit for muscle, it has some problem about power performance and its dynamic movement is difficult because the output is inferior to human.

The proponents also found out that the purpose of the human shoulder girdle is to have high load-carrying capacity with small motion capabilities. The shoulder girdle bears the full load and inertial forces of the arm and the range of motion of the shoulder girdle is significantly smaller than that of shoulder joint. For these reasons, it is necessary to exert great force on the shoulder girdle part. To be able to solve this problem, the proponents came up to an idea of representing the muscles of human shoulder girdle by using pneumatic actuators such as the cylinders and rotary actuators as their main actuators in implementing the 3-dof robotic shoulder girdle. Ever since, pneumatic system is ideal in carrying high-loads which needs a great force to handle. The design of the robotic shoulder girdle is based on human anatomy to do a human-like shoulder girdle.

Although there is no direct application of this study that will benefit a certain individual or group. The design of the robotic shoulder girdle will help improve the existing design of humanoid robots to give more flexible and power on their imitation of the human movement. Robot such as androids will have human like movement if all human movement will be considered. The wearable device for the control of the robotic girdle will help some future applications involving manipulation of the robot. Such applications are tele-operated robotics, robotic avatar, exoskeletal support robotics, virtual reality, and more. With high power capability of this robot, this study can be used as a support system or what we call as service robotics that assist difficult jobs that a human performs.

2. METHODOLOGY

A. Designing of Mechanism and Controller of the Project

The design of the project was based on the skeletal structure and the muscles responsible for each motion of the human shoulder girdle. The proponents applied the pneumatic actuators as their main actuator to the robotic shoulder girdle and their position and orientation were based on the human anatomy of the shoulder girdle. Acquiring the knowledge on how the present muscles and bone in the shoulder girdle (Highered.Mcgraw-hill.com, 2013), the proponents determined the human shoulder girdle anatomy and the position on each present muscle that is responsible for each degree of freedom (elevation and depression, protraction and retraction, and upward and downward rotation), summing up all the pre-information gathered based on computation of materials measurement and the position of parts. The Autodesk Inventor aids the proponents in designing, visualizing and simulating the project before it is built. Based on the materials and measurements obtained and the conceptualized design, the proponents used formula based on mathematical and physics laws. The proponents also computed the pressure needed for every given payload using a free-body diagram. With these, the proponents obtained and verified measurements needed for the materialization of the robot.

For the control mechanism, the proponents used the Festo Fluidsim to design an electro-pneumatic circuit of 5/3 way solenoid valve that can hold or trap volume of air inside the cylinder thus, the proponents can control the length of extension and retraction of the piston rod of the double-acting cylinder. The proponents also used the Fritzing software to design the circuitry that can trigger the on-off switching of the solenoid valve.

For the controller design, the proponents, through researching about the position of joints of the human shoulder girdle, the position and placement of the potentiometer should be parallel to the corresponding joint present.

B. Evaluating the System Response at Different Given Payloads and Angular Displacements

For the evaluation, the proponents would want to know if the robotic shoulder girdle could achieve the position relative to the controller's position in different given payloads and angular displacement at constant pressure. To achieve the objective, the proponents compare the values sent by the two potentiometers from the controller and the prototype that will represent as input sensor and feedback sensor respectively. The proponents monitor the data using the serial monitor of the Arduino IDE. Then, the data will be an input to the Microsoft Excel coming from the movements produced by the robotic shoulder girdle and the controller and represent it as a line graph. This data will be used to evaluate the system response of the prototype with respect to the controller with different given payload and angular displacement.

3. RESULTS AND DISCUSSION

A. Designing of Mechanism and Controller

1. Designing of Mechanical Structure

a.) Representation of Human Shoulder Girdle Bones. Before constructing the design of the robotic shoulder girdle, the proponents acquired all the necessary dimensions. The proponents based the dimensions of the robotic shoulder girdle to the average size of a human shoulder girdle.

Since, the shoulder girdle is supported by three bones: humerus (the upper arm bone), scapula (the shoulder blade), and clavicle (the collar bone), the proponents represented each bone according to its original structure base on the human anatomy as presented in Figure 1.

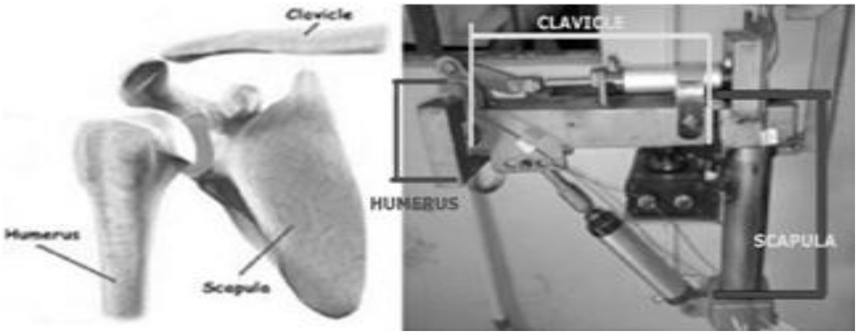

Figure 1. Design Structure of Shoulder Girdle.

b.) Representation of Human Shoulder Girdle Muscles. The muscles involved for the elevation and depression movement is the trapezius muscle. In figure 2, the cylinder 3 represents the trapezius muscle. The muscle involved for the protraction movement is the rhomboid muscle while in the retraction movement, the muscle involved is the pectoralis minor muscle. In figure 3, the cylinder 2 represents the two muscles involved in the protraction and retraction movement. For the upward and downward rotation movement, the muscles involved are the trapezius muscle and the serratus anterior muscle. In figure 4, the cylinder 1 and cylinder 3 represent the trapezius and serratus anterior muscles respectively.

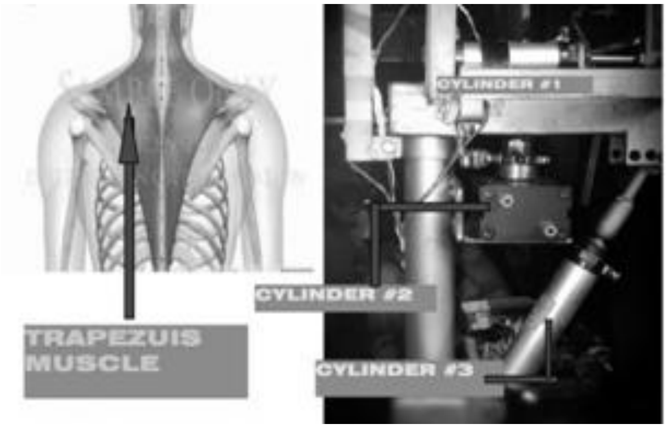

Figure 2. Representation of Trapezius Muscle.

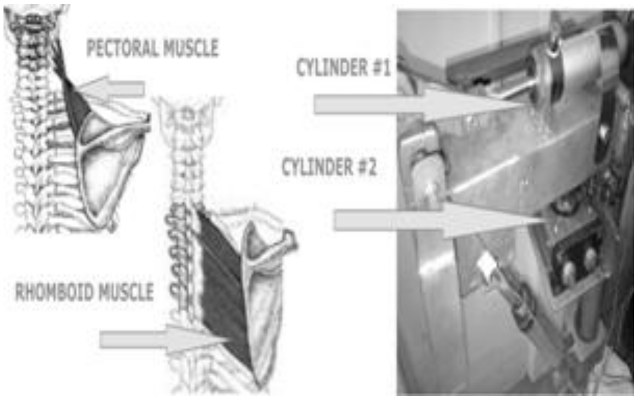

Figure 3. Representation of Rhomboid Muscle and Pectoralis Minor Muscle.

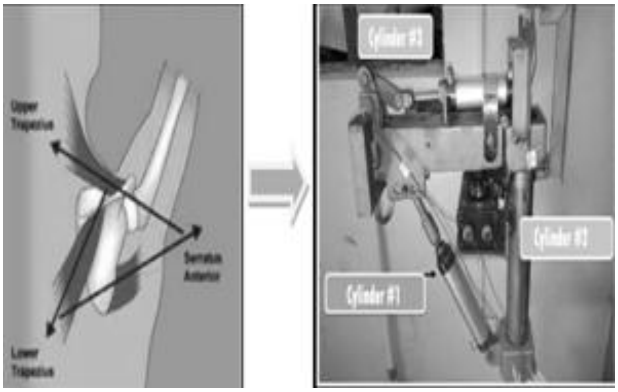

Figure 4. Representations of Trapezius Muscle and Serratus Anterior Muscle.

In getting the force requirement as shown in figure 5, the proponents computed for the pressure needed to carry the maximum given load which is 25kg, given the bore size of the cylinder, and the dimensions of the prototype and force acting on it, and still reached the maximum of its range of motion.

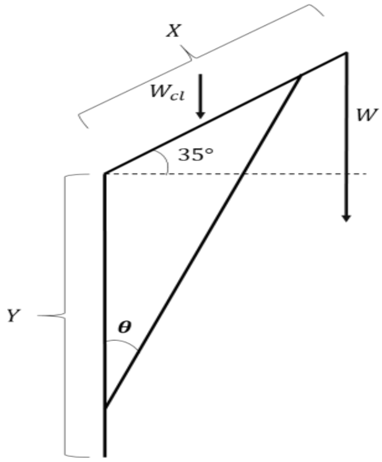

Figure 5. Forces Acting at Elevation Movement.

$$\theta = \frac{\tan^{-1} y + x \sin 35°}{x \cos 35°} \quad [1]$$

$$F = \frac{W + W_{cl} \sin 35°}{\cos \theta} \quad [2]$$

$$p = \frac{4F}{\pi d^2} \quad [3]$$

Where:

y = 30 cm
x = 23 cm
W_{cl} = 78.4 N
d = 0.032

When m = 25kg, p = 130.79psi
m = 20kg, p = 108.69psi
m = 15kg, p = 86.59psi
m = 10kg, p = 64.49psi
m = 5kg, p = 42.39psi

The compressor available can only produce 60 psi.

2. Designing of Control System

Figure 6 shows the control system which is capable to trap volume of air inside the cylinder thus, the proponents can control the length of extension and retraction of the piston rod of the double-acting cylinder to any desired position.

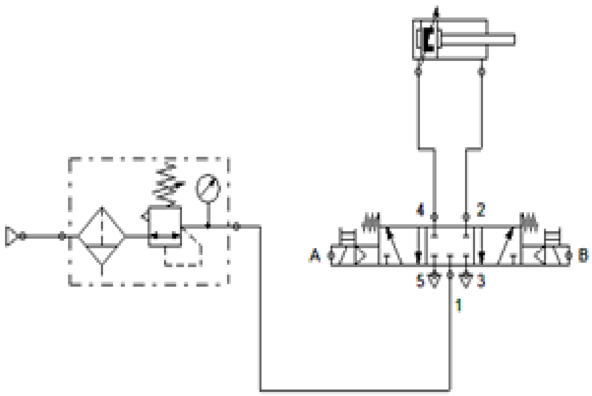

Figure 6. Electro Pneumatic Circuit Design.

The proponents used a 5/3 way directional valve to drive the pneumatic actuator's motion. The valve has a normally closed configuration. Due to this configuration, the valve has the ability to hold air inside the cylinder because it traps the air from escaping the cylinder thus; the proponents can maintain the desired position of the pneumatic actuator to achieve the desired angle of the prototype.

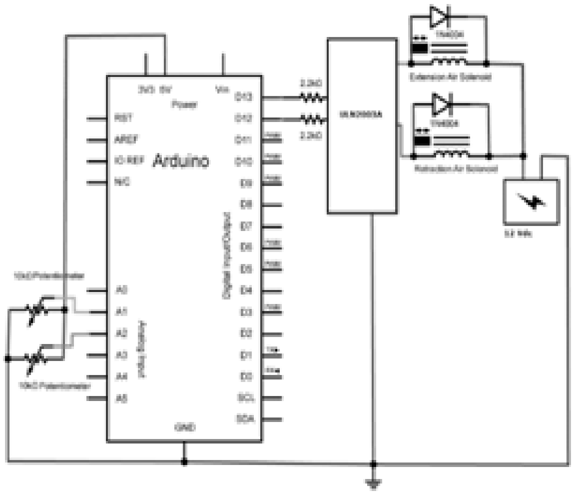

Figure 7. Solenoid Circuit Design.

Figure 7 shows the circuitry of the solenoid of 5/3 way directional solenoid valve. The proponents compared the values sent by the potentiometers from the wearable controller and from the prototype to trigger the on-off switching of the 5/3 way directional solenoid valve.

3. Designing of Wearable Controller

The proponents used potentiometers as sensors for the controller to be used. The potentiometers are located and placed at the controller in their designate position based on the location of joints in accordance to human anatomy of shoulder girdle movements. While figure 8 shows the position of the potentiometers on the controller which was based on human shoulder girdle joints and which also corresponds to the position of the potentiometers placed to the designed prototype.

Figure 8. Robotic Shoulder Girdle Joints: potentiometers for elevation & depression (right), protraction & retraction (left), upward & downward rotation (middle).

The wearable controller is built using potentiometer pre-programmed to control the pneumatic actuator. The potentiometer will send analog signal to the microcontroller that will process and interpret the signal according to the program. Then it will trigger the solenoid and it will translate the given input into motion. Figure 9 shows the design of the wearable controller.

Figure 9. Wearable Controller.

The proponents constructed the design of the wearable controller that will satisfy the motion and also located the exact points as to where the position sensor must be placed on the controller. Figure 10 shows the positioning of the sensor at the wearable controller.

Figure 10. Positioning of Sensors.

B. Evaluating the System Response at Different Given Payload and Angular Displacement

Below are the data gathered coming from the tests and analysis made for system response evaluation of the robotic shoulder girdle with respect to the wearable controller with payload variations of 5kg, 10kg, 15kg, 20kg and 25kg at different angular displacement of 5 degree incremental performing elevation and depression movement.

The potentiometers produced output voltages that correspond to the changing of the angular position of the knob. The proponents used the value of potentiometers as the input sensors and feedback sensors for the controller movement and prototype movement respectively.

The proponents used the Arduino map function to scale the values to the necessary range of motion of shoulder girdle movements. Once the range was set, the proponents use the serial monitor of the Arduino IDE to see the digital values sent by the potentiometers for references and testing purposes. Through serial monitor, it allows the values sent to it to be displayed real-time. The proponents used the values sent by the serial monitor to produce a line graph use in evaluation of response time of the prototype and the controller.

The figures show the relationship between the responses of the robotic shoulder girdle with respect to the wearable controller relative to time. The x-axis denotes the time in seconds, while the y-axis denotes the angle in degrees. The controller angle represents the controlled value of the test and the feedback angle represents the variable value of the test. Both elements start at rest at time 0. The proponents set the pressure to 60psi for load consideration.

Figure 11 shows the response of the elevation and depression movement of the prototype at 5kg. At 0 second, both controller and feedback were at 0 degree. Notice that for every angular displacement, the prototype has an immediate response with respect to the controller but there is a delay because the prototype responds every 0.5 second after the controller starts to elevate and depress from the steady state level.

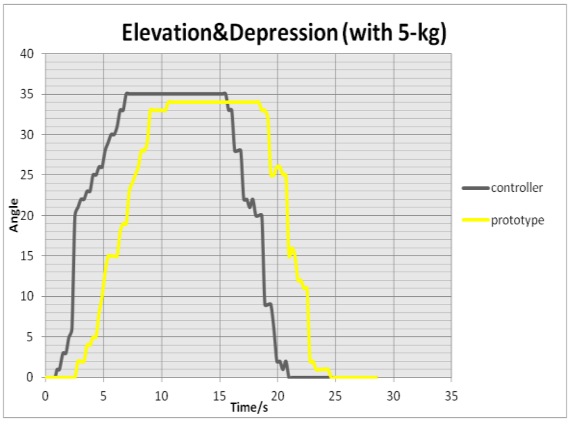

Figure 11 Response Time of Prototype with 5-kg at Maximum Reached Angle

And also, in figure 11, the prototype didn't reach the maximum angle in carrying 5kg which is 35 degrees even though it can sustain the needed pressure to elevate which is 42.39 psi from 60 psi that the proponents use because in computing the needed pressure, the proponents didn't consider the friction and the backlash in the free-body diagram.

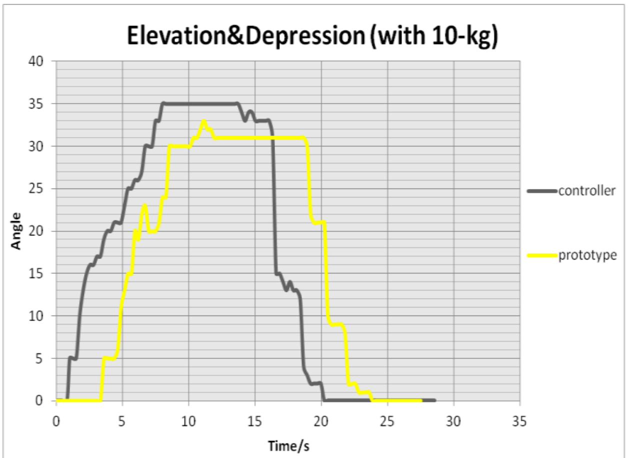

Figure 12. Response Time of Prototype with 10-kg at Maximum Reached Angle

Figure 12 shows the response of the elevation and depression movement of the prototype at 10kg. At 0 second, both controller and feedback were at 0 degree. Notice that for every angular displacement, the prototype with respect to the controller has slower response compared to the response in 5 kg payload because the prototype responds only every 1 second after the controller starts to elevate and depress from the steady state level.

And also, in Figure 12, the prototype only reached almost 31 degrees in carrying 10KG because it can't sustain the needed pressure to elevate in reaching maximum 35 degrees which is 64.49 psi from 60 psi that the proponents used based on the computation of pressure needed.

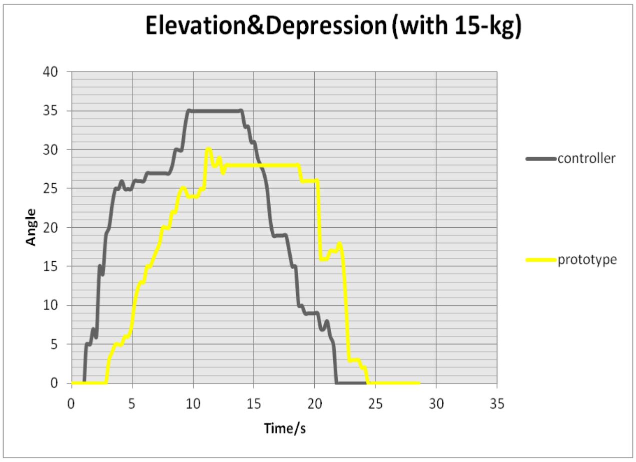

Figure 13. Response Time of Prototype with 15-kg at Maximum Reached Angle

Figure 13 shows the response of the elevation and depression movement of the prototype at 15kg. At 0 second, both controller and feedback were at 0 degree. Notice that for every angular displacement, the prototype with respect to the controller has slower response compared to the response in 10 kg and 5 kg payload because the prototype responds only every 1.5 seconds after the controller starts to elevate and depress from the steady state level.

In Figure 13, the prototype only reached almost 28 degrees in carrying 15kg because it cannot sustain the needed pressure to elevate in reaching maximum 35 degrees which is 86.59 psi from 60 psi that the proponents used base on the computation of pressure needed.

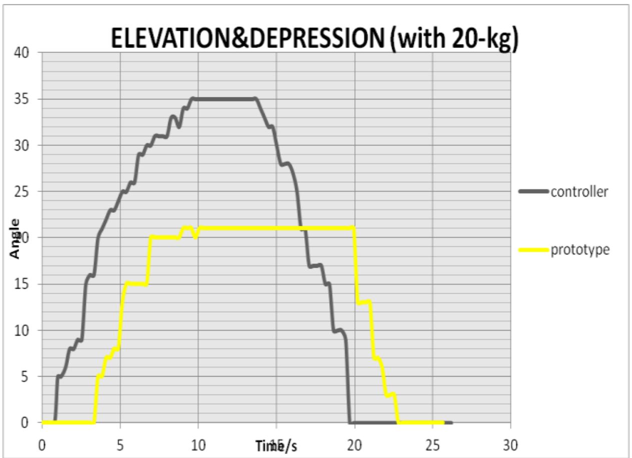

Figure 14. Response Time of Prototype with 20-kg at Maximum Reached Angle

Figure 14 shows the response of the elevation and depression movement of the prototype at 20kg. At 0 second, both controller and feedback were at 0 degree. Notice that for every angular displacement, the prototype with respect to the controller has slower response compare to the response in 3 previous payloads because the prototype responds only every 2 seconds after the controller starts to elevate and depress from the steady state level.

And also, in figure 14, the prototype only reached almost 21 degrees in carrying 20KG because it can't sustain the needed pressure to elevate in reaching maximum 35 degrees which is 108.69 psi from 60 psi that the proponents use base on the computation of pressure needed.

Figure 15. Response Time of Prototype with 25-kg at Maximum Reached Angle

Figure 15 shows the response of the elevation and depression movement of the prototype at maximum 25kg. At 0 second, both controller and feedback were at 0 degrees. Notice that for angular displacements of 5 degree, 10 degree and maximum 15 degree, the prototype with respect to the controller has same response compare to the response in 20 kg payload because the prototype also responds for every 2 seconds after the controller starts to elevate and depress from the steady state level.

And also, in figure 15, the prototype only reached 15 degrees in carrying 15kg because it can't sustain the needed pressure to elevate in reaching maximum 35 degrees which is 130.79 psi from 60 psi that the proponents use base on the computation of pressure needed.

4. CONCLUSIONS

The proponents located the exact points as to where the pneumatic actuators must be placed for the correct mimicry of the human shoulder girdle movement. The orientation and proper positioning of actuators were thoroughly observed in creating a mechanism that resembles the shoulder girdle that was based on the human. The structure of the wearable controller could perform the elevation and depression movement; upward and downward rotation movements; and protraction and retraction movement of the shoulder girdle with a considerable threshold in terms of the accuracy, therefore, it agrees with the concept of mimicking but the controller is not comfortable to be worn by the user and the design is limited to only one person. In the control mechanism, the 5/3 way directional valve is effective in storing air inside the cylinder in positioning purpose on the solenoid valve. Using the 5/3 way directional valve in each cylinder, the mechanism can control the position of the pneumatic actuator to provide and hold the desired movement of elevation and depression; upward and downward rotation; and protraction and retraction.

In angular value assessment, with constant pressure, as the payloads gets heavier, the response of the prototype get slower until reaching the maximum payload. The prototype also reached higher range of angular displacement when it has lighter payloads, as the payload gets heavier the lower the range of angular displacements it reached. All the tests showed stability at the steady state after it reached its max angle. The proponents also noticed that the heavier the payload of the robotic shoulder girdle, the slower it can reach the angular position with respect to the elevation movement produce by the controller but the faster it can reach the zero-degree position in the depression movement. The reason to this was because of the valve that cannot vary the pressure with respect to the load, and there was no sensor to evaluate the weight of the load.

5. RECOMMENDATIONS

The proponents recommended using human like covering to be more realistic in its appearance and make a more comfortable controller and that is not only limited to only one person. And also use a controller sensor that can read the force generated by the muscle or a sensor that can read the mass of the payload and a valve that can vary the pressure to compensate payloads.

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