Design and analysis of a lower body exoskeleton for rehabilitation

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ABSTRACT: Exoskeleton for rehabilitation has increased in importance due to the aging of the population in this modern society. An exoskeleton is a wearable robot worn by human operators. It is proven that exoskeleton for rehabilitation can be used to recovers from injuries or neurological conditions. In this research, the exoskeleton is operated in a sitting position with knee extension activities. The lower body exoskeleton for rehabilitation will be actuated by a double-acting pneumatic cylinder with Arduino Mega. The lower body exoskeleton consists of only 1-DOF at the knee joint. Testing was done to verify the effectiveness of the exoskeleton for rehabilitation by varying the pressure input against time and measuring the angular speed of the system. Also, additional load to mimic different human weight was also evaluated.

Keywords: *Lower body exoskeleton; Rehabilitation; Physiotherapy*

1. INTRODUCTION

An exoskeleton is an electromechanical system matches the shape and function of the human body. Due to the aging of the population, gait rehabilitation has increased its importance in modern society. The exoskeleton can be used by patient to recover from injuries or neurological conditions [1]. It has been proven that task-orientated repetitive movements can increase the strength of the muscle and coordination of the movement for the patients [2, 3]. It is found that treadmill training can improve gait and lower limb muscle function with locomotor disorders. However, manual rehabilitation exercise is labor-intensive. Because of the low number of therapists, the training duration is limited. In addition, the therapists will suffer back pain, because of the prolong seating posture during theraphy sessions. Therefore, in this research a wearable exoskeleton designed for rehabilitation purposes can greatly help patient to improve their recovery rate and lessen the injuries to the therapists.

2. METHODOLOGY

The prototype of the lower body exoskeleton for rehabilitation consists of two (2) main components, i.e.: pneumatic cylinder actuator and crank -slider mechanism. The prototype design focuses on the lower body, which is the actuation of the knee joint. The exoskeleton material is made from light weight plywood. For the slider and crank mechanism, ball bearing and thrust ball bearing are inserted to the moving parts to reduce friction force. Figure 1 shows the design of the prototype in SolidWorks environment and Figure 2 shows the full prototype. Figure 3 shows the experimental setup consists of pressure gauge, solenoid valve, controller box, 4-channel relay and the exoskeleton. The pressure gauge is used to measure the pressure input whilst the controller box consists of Arduino Mega, which is used to control the extension and retraction of the exoskeleton.

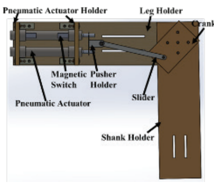


Figure 1 SolidWorks environment

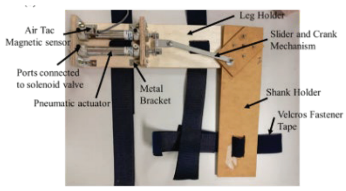


Figure 2 Prototype of the lower body exoskeleton

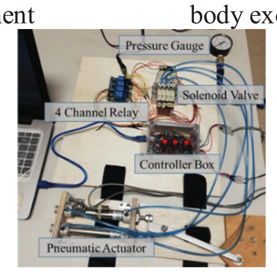
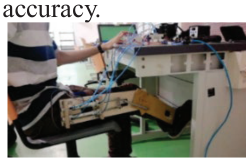


Figure 3 Experiment setup of exoskeleton

3. RESULTS AND DISCUSSION

In this research, the variation of pressure input against time taken for a complete flexion motion is to evaluate the effect of different pressure input in order to complete full flexion motion. The variation of pressure that will be set up are 20psi to 55psi with a 5psi increment. The weight of the user is 63 kg. The percentage of shank and foot to the total body weight is 4.33% and 1.37% respectively for an average male patient, hence the weight of shank and foot is approximately 3.59 kg for a 63 kg male. The time taken for a complete flexion motion is for the shank to complete a full extension of the leg at a sitting position. Also, the variation of the weight of the load is conducted with 0.5kg load variation. Initially, the exoskeleton is at the position as shown in Figure 4(a). Then, the exoskeleton will be activated to extend as shown in Figure 4(b). The extending time and retracting time are recorded and repeated five times to verify it's accuracy.

(a) Initial position



(b) Extended position

Figure 4 Exoskeleton position

Figures 5 and 6 show the pressure (psi) versus average time and linear speed for extending and retracting of the exoskeleton for 0 kg of load. Whilst Figure 7 shows the pressure (psi) versus angular speed for 0.5 kg of load. Equation (1) shows the equation to calculate the linear velocity of the stroke during extending and retracting. To calculate the angular velocity of the crank during extending and retracting, the slider crank is drawn and calculated as shown in Figure 8. V_A is the angular velocity of the crank, whilst V_B is the linear velocity of the pneumatic actuator. Using sine rule, Equation (2) and Equation (3) are derived to calculate the angular speed V_A based on Figure 9. As a conclusion from Figure 5 & 6, the higher the pressure, the higher the average linear speed of stroke during the extending and retracting of pneumatic actuators, hence the higher the average angular speed of the crank during the extending and retracting of pneumatic actuators.

Linear velocity, V_B =

$$\frac{\text{Length of the stroke (m), 0.07m}}{\text{Time required to extend or retract(s)}} \quad (1)$$

$$\frac{V_B}{\sin(58.361°)} = \frac{V_A}{\sin(76.639°)} \quad (2)$$

$$v = r \times w \quad (3)$$

where

v = Linear velocity of pneumatic actuator $(\frac{\text{m}}{\text{s}})$

r = Radius of crank (m)

w = Angular velocity of Crank $(\frac{\text{rad}}{\text{s}})$

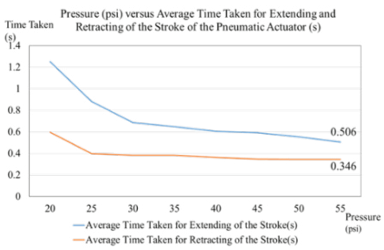


Figure 5 Pressure (psi) versus average time

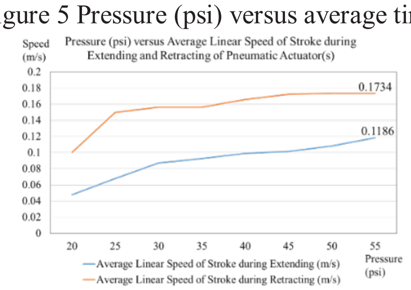


Figure 6 Pressure versus linear speed

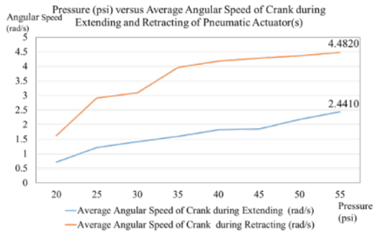


Figure 7 Pressure versus angular speed for 0.5kg load

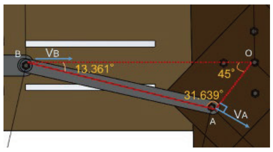


Figure 8 The Length and Angle of the Slider and Crank

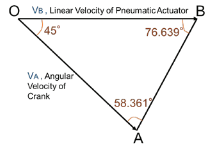


Figure 9 The Velocity Triangle of the Slider and Crank of Exoskeleton

4. CONCLUSION

In conclusion, the variation of pressure input of the pneumatic compressor allows us to determine the time taken for a complete flexion motion. Also, the relationship between the variation of weight of the user and the time taken for a complete flexion motion can be identified. From the result, it can be concluded that the higher the pressure, the shorter the average time taken for extending and retracting of the stroke of the pneumatic actuator. The optimized pressure for the rehabilitation has been recorded for the 0kg and 0.5kg of the load, respectively.

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