Design of Electro-Pneumatic Exoskeleton Robot for Upper Limb Actuation

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Abstract – *Most of tasks in daily activities are performed by upper-limbs. Physically weak persons such us elderly, injured or disabled person need to perform most of the daily activities with the help of exoskeleton robot. Therefore, various kind of exoskeleton robots have been developed in order to assist the physically weak person in their daily life. The current existing researches related to exoskeleton robot need to solve problems that related to suitable materials which is light and strong and also to work on the portable power supply that could power up the system for a long time independently. The proposed of this research project is to develop an electro-pneumatic powered shoulder orthosis for flexion motion only. This electro-pneumatic powered shoulder orthosis is actuated by a pneumatic cylinder which is placed at the backpack. For technical simplicity, this shoulder orthosis used an external power supply unit. Then, performance analysis is carried out in terms of payload test. This shoulder orthosis need to lift up load (1kg, 2kg, 3kg, 4kg and 5kg) on 45º flexion motion. For each load, this shoulder orthosis need to repeat the test for three times. The time for each complete flexion motion is recorded. All the data is recorded in tables and presented in graphs. It is found from the experiments that the time taken for the cylinder to complete the flexion motion is increasing with load. This is because the cylinder needs to overcome the load as well as the gravitational force in order to complete the 45º flexion motion. As for the velocity, it is decreasing with the increasing of load. This is because, as the load increases, the cylinder becomes slower and it takes some time to complete the flexion motion.*

Keywords: *exoskeleton robot, electro-pneumatic, flexion, upper-limbs, orthosis, flexion*

Article History
Received 30 July 2018
Received in revised form 17 January 2018
Accepted 17January 2018

I. Introduction

The average normal person has -50º to 180º of flexion motion. The shoulder motions of the physically weak persons are limited and need to be assisted by exoskeleton robots that have the same flexion motion as the human. If the exoskeleton robot moves excessively, the patient might get hurt.

Weight training can help the physically weak persons through building strength and increasing flexibility. The amount of weight that an average man and woman can lift on 90º flexion motion is 10kg and 7kg respectively. However, the amount of weight that can be lifted by physically weak person on 90º flexion motion is just 30% of that average amount.

The physically weak persons need a good performance exoskeleton robot. Continuous use of exoskeleton robot helps the physically weak person to improve their movement and range ability [1]. However, pneumatic actuators are generally too unpredictable for precise movement. Therefore, the performance of exoskeleton robot that uses pneumatic actuator may vary from time to time. Since the applications of exoskeleton robots are very practical and useful, there are many researchers all over the world have developed the exoskeleteon robots using different methods [1]-[5].

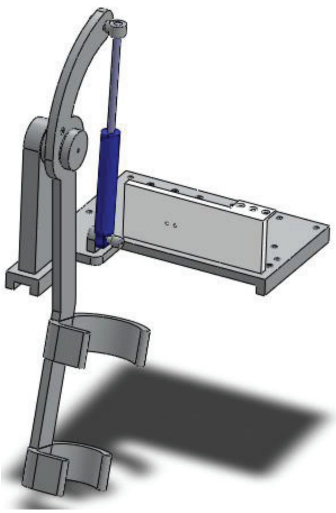
The rest of this paper is arranged as follows; in Section II methodology of the whole project is presented. In Section III, experiment results are presented. Finally, conclusion and future works are discussed in Section IV.

II. Methodology

The methodology of the whole project will be explained in this section. It consists of several sub-sections which are the design of the exoskeleton prototype by using Solidworks, circuit design, microcontroller board application and experiment.

A. Prototype

The mechanical design is focused on the upper-limb shoulder of the exoskeleton robot. This shoulder orthosis is designed by using SolidWorks computer-aided design (CAD). The material used for this design is 6061 aluminium alloy. This material is suitable to withstand human arm weight together with the load used for experiment. The complete design draft of this system is shown in Fig. 1.



(a) SolidWorks environment

(b) The real structure

Fig. 1. The structure of the exoskeleton robot

B. Circuit Design

The simulations of the circuits are done by using Fluidsim and Proteus software. The whole complete circuit system is shown in Fig. 2. As seen in the figure, there are two sensors used for detecting the force labelled as force sensing resistor 1 (FSR 1) and force sensing resistor 2 (FSR 2). K1 and K2 are the 24V relay coils used to integrate the electro-pneumatic to the overall system. The overall system tested in Proteus and Fluidsim environments are shown as in Figs.3 and 4, respectively.

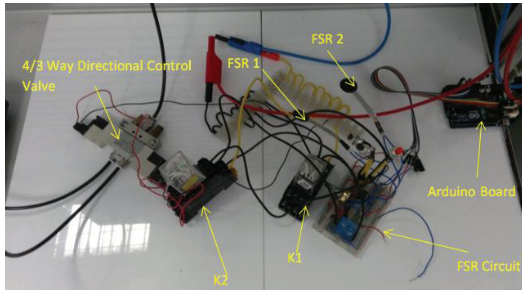


Fig. 2. The real circuit of the overall system

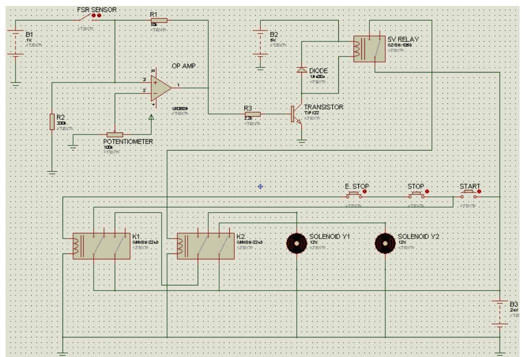


Fig. 3. The overall system tested with Proteus

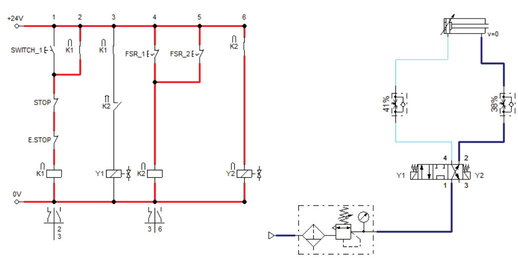


Fig. 4. The overall system tested with Fluidsim

C. Microcontroller Board Application

In this project, Arduino Uno R3 has been used as the brain of the system. It is one of open-source electronics prototyping platform based that easy to use and can receive input from a variety of sensors. In this project, FSR sensor is integrated using Arduino Uno R3 board which then communicates with directional control valve. Arduino Uno R3 used for this project is shown in Fig. 5. This board has been chosen as the platform for this project due to its simplicity in terms of programming language.

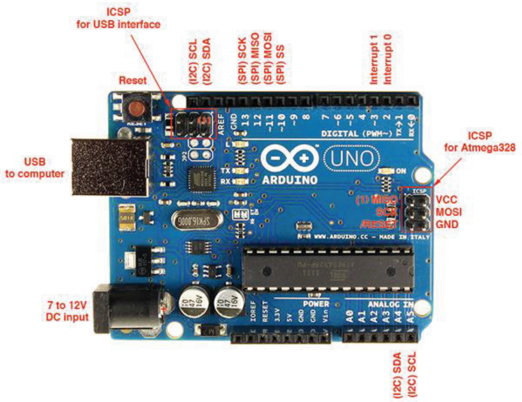


Fig. 5. Arduino Uno R3 board

D. Experiment

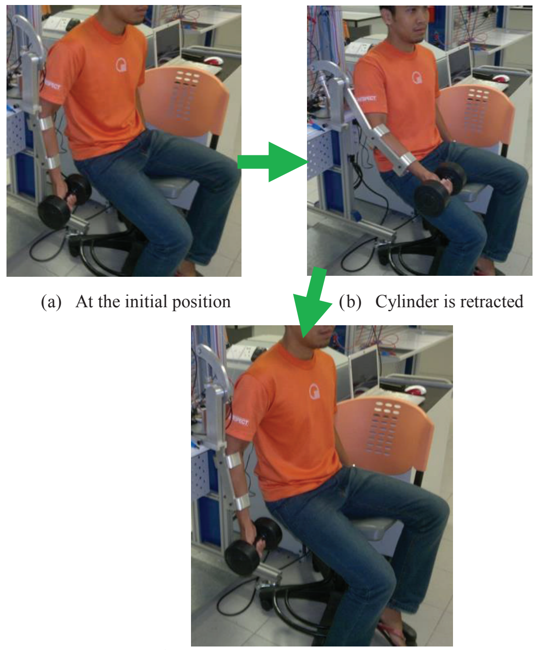
Experiments of the designed exoskeleton are done in order to analyse its performance, ability and robustness. There several possible experiments that can be done in this research study such as payload, repeatability and accuracy test. However, in this research only the payload test is finished completely. The other experiments are left for the future works.

The payload test is carried out to analyse the velocity produced by the system to lift up load in 90^o flexion motion. The equipment used in this experiment is shown in Table I.

TABLE I
EXPERIMENT EQUIPMENT

Item	Apparatus	Quantity
1.	Shoulder orthosis sytem	1
2.	1 kg load	1
3.	2 kg load	1
4.	3 kg load	1
5.	4 kg load	1
6.	5 kg load	1
7.	Stopwatch	1

The experiment setup is shown as in Fig. 6. Figs. 6(a)-(c) are the sequence of the payload test, from the initial position until the end position. At first, a person as subject is needed to wear the shoulder orthosis system. The initial position is shown as in Fig. 6(a). Then, start button is switched on and the load is grasped by the user. When the arm is pressed on the lower arm holder, the FSR sensors are triggered. As the result, the cylinder is retracted as shown in Fig. 6(b). In the moment FSR sensors are detected, timer is started immediately. Note that this process is called flexion motion. When the cylinder is fully retracted, the timer is stopped and the time taken for complete flexion motion is recorded. During this step, the cylinder is returned back to its initial condition as shown in Fig. 6(c). This entire step is repeated three times to get the average value. The whole process is repeated for different load, 1 to 5 kg.



(a) At the initial position
(b) Cylinder is retracted
(c) Cylinder returned to the initial position

Fig. 6. The sequence of the payload experiment

III. Experiment Results

In section, the results obtained from the payload test will be presented. In order to calculate the velocity exoskeleton robot motion during the payload test, the distance travel led by the motion must be determined. The end tip of the exoskeleton robot structure has been chosen for the distance calculation. As for the distance calculation, it must be known that the angle of the motion is 41.62^0, whereas the length of the radius from the joint to the tip of the load is 0.34 m. Therefore, the calculations for the travelled distance of the structure are shown as in Eqs. (1) – (5).

$$Distance = 2\pi r \times \frac{angle}{360^o} \quad (1)$$

$$Distance = 2\pi r \times \frac{41.62^o}{360^o} \quad (2)$$

$$= 2\pi(0.34) \times \frac{41.62^o}{360^o} \quad (3)$$

$$= (2.1362) \times \frac{41.62^o}{360^o} \quad (4)$$

$$= 0.2469m \quad (5)$$

From the experiment procedures done in Section II D, the results are obtained as in Table II.

TABLE II
DATA FOR TIME TAKEN FOR A COMPLETE FLEXION MOTION

Load (kg)	Distance (m)	Time taken			Average
		1st	2nd	3rd	
1	0.2469	1.43	1.91	1.32	1.55
2	0.2469	2.10	2.25	2.28	2.21
3	0.2469	2.32	2.15	2.29	2.25
4	0.2469	2.67	2.45	2.43	2.52
5	0.2469	2.88	2.96	2.81	2.88

As calculated in Eqs. (1)-(5), the travelled distance of one swing motion is 0.2469 m. Furthermore, the velocity can be calculated by using Eq. (6).

$$Velocity, V = \frac{Distance\ Travelled}{Time\ Taken} \quad (6)$$

From Equations (1)-(5), data in Table II and the velocity formula of Equ (6), the velocity of the flexion motion is calculated and arranged as shown in Table III.

TABLE III
VELOCITY FOR A COMPLETE FLEXION MOTION

Load (kg)	Velocity (ms^{-1})			Average
	1st	2nd	3rd	
1	0.1726	0.1292	0.1870	0.1629
2	0.1175	0.1097	0.1082	0.1118
3	0.1064	0.1148	0.1078	0.1096
4	0.0924	0.1007	0.1016	0.0982
5	0.0857	0.0834	0.0878	0.0856

The data obtained in Table II and III are then plotted as shown in Figs. 7 and 8.

It is shown in Fig. 7 that when the loads are increased, the time taken is getting longer. At the load of 5 kg, the time taken is the longest which is 2.88 s. On the other hand, the time taken is the shortest when the load is at minimum value which is 1.55 s for the 1 kg load.

From Fig. 8, it is shown that when the loads are increased, the velocity is decreased. At the load of 5 kg, the velocity taken is the slowest which is 0.0856 ms^{-1}. On the other hand, the time taken is the fastest when the load is at minimum value which is 0.1629 $ms^{-1}$for the 1 kg load.

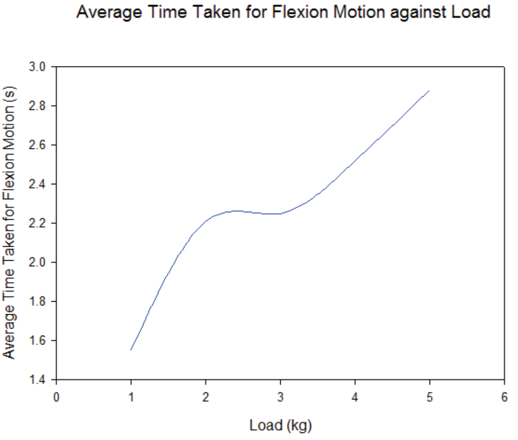


Fig. 7. Average time taken against load

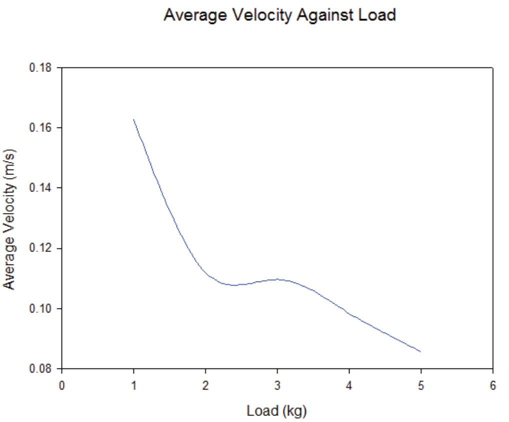


Fig. 8. Average velocity against load

As shown in Figs. 7 and 8, the data is obtained as plotted because when the load is increased, the cylinder needs to overcome the load and the gravitational force acting upon the load. Therefore, the time taken for the cylinder to overcome these forces is longer.

Since the applied pressure is 6 bar during the whole process, therefore, the velocity of the cylinder is constant. However, when another load is added to the system with a different or bigger weight, the velocity of the cylinder becomes different. It becomes slower than its normal velocity.

This velocity is different because the double acting cylinder which initially applied by 6 bar pressure need to overcome a greater downward forces together with the gravitational force. Therefore, the time taken for the cylinder to fully retract is longer than the initial velocity. The initial average time taken for a complete flexion motion of the cylinder without any load is 1.2 s.

IV. Conclusion

In this research project, the main objective which is to develop an electro-pneumatic powered shoulder orthosis for flexion motion is achieved successfully. This is proven from the methodology section as shown in Section II previously. In this research, the structure is focused on shoulder flexion motion only. Furthermore, shoulder orthosis that being developed is powered by electro-pneumatic system where the main actuation system is a double acting pneumatic cylinder.

The other objective of this project is to analyse the performance of the exoskeleton robot in terms of payload test. Payload test is carried out to analyse the velocity of the cylinder produced by the shoulder orthosis system to lift up the load in 45^{o} flexion motion. From this payload test, the time taken for the cylinder to complete the flexion motion is increasing with load. This is because the cylinder needs to overcome the load as well as the gravitational force in order to complete the 45^{o} flexion motion. As for the velocity, it is decreasing with the increasing of load. This is because, as the load increases, the cylinder becomes slower and it takes some time to complete the flexion motion.

In the future we would like to expand the developed system with a complete structure of the whole exoskeleton, upper and lower limbs. Furthermore, it is intended to continue the experiments for the repeatability and accuracy test.

Acknowledgements

The authors wish to acknowledge the Ministry of Education, Malaysia and Universiti Teknikal Malaysia Melaka, for supporting this research financially under Grants PJP/2013/FKE(11C)/S01188.

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