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LINEAR ACTUATOR BASED BIONIC ARM FOR ASSISTING THE LIFTING ACTIONS IN INDUSTRIES AND WAREHOUSES

1. Sumanth P Desai
Department of Mechanical Engineering / KLE Dr.MSSCET, Belagavi, India
** desaisumanth123@gmail.com*
2. Ganesh Suresh Hosur
Department of Mechanical Engineering / KLE Dr.MSSCET, Belagavi, India
** gsph97@gmail.com*
3. Ashraf Ali Pathan
Department of Mechanical Engineering / KLE Dr.MSSCET, Belagavi, India
** ashrafpathan1204@gmail.com*
4. Nilesh Uday Kadam
Department of Mechanical Engineering / KLE Dr.MSSCET, Belagavi, India
** kadamnu03@gmail.com*
5. Abhishek Anant Kulkarni
Department of Mechanical Engineering / KLE Dr.MSSCET, Belagavi, India
** abhishekkulkarni540@gmail.com*

Abstract

A novel approach has been reported in order to reduce the injuries inflicted while performing repeated tasks for a prolonged duration of time. Lifting is a major activity contributing to the injuries. Such injuries are called as Work Related Musculoskeletal Disorders (WMSDs). Most of such work-related injuries are repercussions of frequent, repetitive manoeuvring of items that are not too heavy (fewer than 25 pounds/12.5kg). Hence a prototype of the system comprising of linear actuator (only for the arm) and controlled by Arduino which would assist the user to perform repetitive lifting tasks is developed. This system is found to reduce the force on the biceps, thus reducing the injuries.

Introduction

In India, it is found that about 82% of the respondents suffer from WSMDs. In 2012, it was seen that the tasks that inflicted injury constituted of material handling (30%), repetitive movements (63%) and awkward body postures (46%). In the European Union alone, about 40% of the workers suffer from the back or neck and shoulder pain [1].

An exoskeleton is an anthropomorphic structure, which deals with transmission of force from source to a desired location. The research and development of the exoskeletons has witnessed growth at a rapid pace since the past decade. The robotic exoskeletons are broadly divided into two categories namely; Active exoskeletons and Passive exoskeletons. The main difference between these is Active methods demand a power input that is continuous, while passive methods see the user capacity as their limitation [2].

The model is affiliated to Active Robotic exoskeletons category. The fabricated model is a portable, light-weight structure made out of recyclable material. The operator can wear is with ease all by himself. The power necessary for the lifting is produced by the linear actuator. The exoskeleton is also incorporated with a Thin Film Transistor (TFT) resistive touch display. This enables the interaction of user with the machine through touch. The system also has a feature called self-diagnosis which lets the system know if there is any sensor failure.

This project uses a powerful development board named Arduino whose open source nature enables anyone with fundamental basis in programming to write the features which can greatly support its development.

Underlying Principles

Analytical Model of the Human Arm:

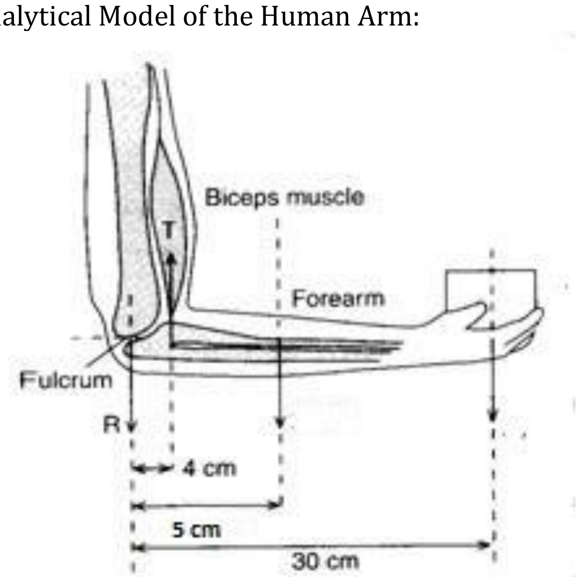

Figure 1: Structure of Human Arm

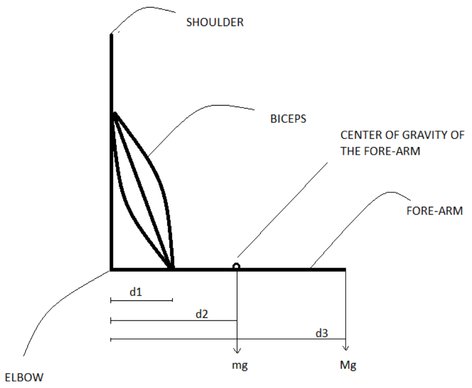

Figure 2: Analytical Diagram of the forces acting [3]

- Terms:
  - d_1 = Distance of the bicep muscles from the elbow.
  - d_2= Distance of the center of gravity of the forearm from the elbow
  - d_3= Distance of the load to be lifted from the elbow
  - m = Mass of the fore arm
  - M = Mass to be lifted
  - g = Acceleration due to gravity
  - F = Force acting on the biceps
  - F_m = Assistive force produced by the motor

- Assumptions
  - $d_2 = \frac{d_3}{2}$ *(Referred from The Physics of Human body)*
  - $d_1 = 4\ cm$ *(Referred from The Physics of Human body)*
  - $d_3 = 30\ cm$ *(Average size of the human fore arm- Referred from The Physics of Human Body)*
  - $g = 10\ m/s^2$
  - $Effect\ of\ the\ triceps\ muscles\ during\ lifting\ is\ neglected.$

- Deducing the equation:

The force 'F' acting on the biceps is as shown in the in the figure 2.

Therefore, balancing the torque on the system:

$$Fd_1 = ((md_2) + (Md_3))g$$

Simplifying the equation to find force on the Biceps muscles:

$$\therefore F = \frac{((md_2) + (Md_3))g}{d_1} \qquad --(1)$$

Now, considering the assistive force 'F_m' provided by the system and assuming it to be acting at a distance of 'd_m' form the elbow:

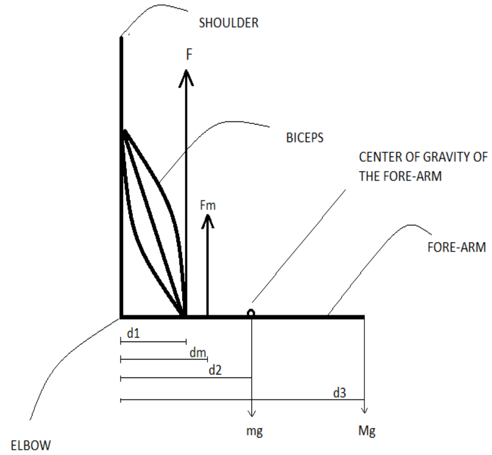

Figure 3: Analytical Diagram of the forces acting considering assisting force

Balancing the torques on the system:

$$Fd_1 + F_m d_m = ((md_2) + (Md_3))g$$

Rewriting the equation as:

$$Fd_1 = \left((md_2) + (Md_3)\right)g - F_m d_m$$

Now, solving to find the force on the biceps:

$$F = \frac{\left((md_2) + (Md_3)\right)g - F_m d_m}{d_1} \qquad --(2)$$

Hence, from the equations (1) and (2), it is seen that the force on the Biceps muscles is reduced by a magnitude of:

$$x = \frac{F_m d_m}{d_1} \qquad - - (3)$$

If,

F_i = Force on the Biceps muscles without assistance

F_o = Force on the Biceps muscles with assistance

Rewriting the equation (3):

$$\therefore x = \frac{T}{d_1} \qquad --(4)$$

Because:

$$T = F_m . d_m$$

$hence,\ F_m = \frac{T}{r}$

$T = Output\ torque\ of\ the\ Motor$

r = Distance between the motor shat and the point where the force is made to act

Methodology

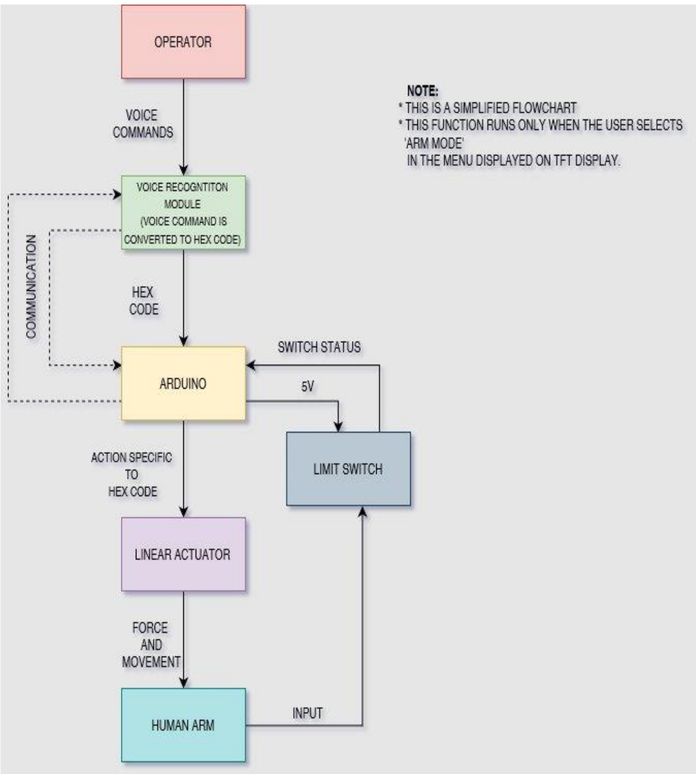

Figure 4: A flow chart of the operations

The above flow chart depicts the interactions of various components of the system with one another after the user selects 'Armed mode' on the thin film transistor screen. The Arduino is involved in all the decision making functions of the system and hence acts as brain. A voice input is given to the Arduino through the Electrohouse Voice- recognition module. Each voice command is converted to a distinctive hexadecimal code which is interpreted by the Arduino. The Arduino is programmed to execute specific functions for different hexadecimal codes. Here external limit switches are used to determine the position of the actuator piston whose interaction with the Arduino is as shown above.

Model

A dummy model was designed to validate the concept and to assure the practicality of the model. The image of the model below is a rendered image of the CAD design. This was done using Autodesk Fusion 360. The component in red is the upper arm while the component in black is the lower arm or the forearm. The component silver which connects the actuator and the forearm is the linear actuator.

Figure 5: Dummy of the concept

In the above figure, the 3d model of the concept is shown. The linear actuator produces a moment about the elbow that lifts the wrist end. The actuator can either be attached at the back of the elbow or ahead of the wrist. Mounting it either ways will bear not much significant effect on the effectiveness of the actuator. The bill of materials required to build the actual model would be as follows:

Table 3: Bill of Materials

Sl. No	Material	Specification	Quantity
1	Plywood Strip	200mmX45mm	2
2	Linear Actuator	900N	1
3	Li-ion Battery	6600mAh(2C)	1
4	Industrial Power Supply	15Volts, 5A	1
5	Buck converter	7-40Volts to 1.2-35Volts	1
6	TFT touch-screen	2.4" Resistive Touch	1
7	Electro house voice recognition module	-	1
8	Push Button	Push-to-On	1
9	Arduino Mega	-	1
10	Velcro straps	-	1.5meters
11	Jumper wires	Male to Male	30
12	Jumper Wires	Male to Female	12

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The user interface is a very major component of the system which enables the user interact to with the system as well as receive the vital information from the system.

Figure 6: Image of the user interface of the system

The user can access four functions through the main menu the functions of which are as follows:

1. Wear Mode: This mode brings the actuator to the position to the position at which the user can wear the exoskeleton with ease.
2. ARM mode: This mode activates the system. The sensor readings will be converted to the movement of the actuator.
3. Diagnostics Mode: This mode checks if the sensors are working.
4. Back: Takes back to the home screen. The purpose of this is to avoid any accidental touch encounter with the contents of the menu.

Figure 7: Image of the Emergency Mode

5. Emergency Mode: Upon arming the system, if the user is in an emergency situation, he can activate the emergency mode which will deactivate the system and trigger an alarm along with a 'HELP" message displayed on the screen as shown in Figure 7.

Effectiveness of the system

Hence selecting a motor with appropriate torque and making its force act at suitable distance from the elbow would result in a system that would reduce the force on the Biceps muscles.

Distances are taken as per assumptions and the values of weights are chosen randomly (within 12 kg)

Table 1: Without assistance

Serial No		Weight in kg	Force on the Biceps in kg
1		Weight of the forearm(1.5kg)	5.625
2		3	28.125
3		5	43.12
4		8	65.625
5		11	88.125

Table 2: With assistance:

$d_m = 15\ cm$

$F_m = 5\ kg$

Serial No.	Weight in kg	Force on the Bicep in kg
1	Weight of the fore arm (1.5)	-10
2	3	12.375
3	5	27.49
4	8	50.00
5	11	72.5

Results and Discussions

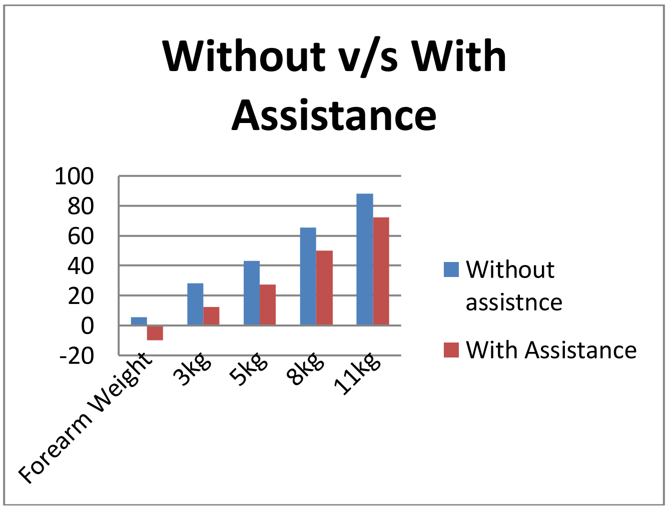

Figure 4: Comparison between forces with and without assistance

The above graph shows the comparison between the force with assistance and without. On the X-axis we have the weight to be lifted and on the Y-axis we have the force on the biceps in kilograms. The columns in blue correspond to the force without assistance and the ones in red correspond to force on the biceps with the system. It can be inferred from the above graph easily that there is a considerable decrease in the amount of force exerted on the biceps. This reduction thus reduces the injuries inflicted to the muscles.

Conclusion

A cost-effective and an easy to use exoskeleton is built which respects the mobility of the arm and does not arrest any of its movements. The system is capable of lifting 15-18kg because most of the injuries occur due to the repeated manoeuvring of the lighter load. Since the Arduino is an open source platform, anyone can write simple programs to add new features. There is also a great scope to create a program for data streaming when this system is used for rehabilitation of the upper arm.

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