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Design and fabrication of Pneumatic Exoskeleton

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Abstract

Pneumatic exoskeleton suit is a fully functional wearable robot that moves in sync with the operator's motion with 3 DOFs. The user will no longer feel any fatigue in carrying heavy loads for long time periods. Recyclable, light and enduring materials are used in this project in order to fulfil safety and environmental concerns. Pneumatic cylinders are integrated with the human anatomy with metal frames to provide absolute synchronization with ordinary human motion. Biceps, triceps, legs and deltoids are assisted by the device and limited according to their allowable angles of motion. The mechanical suit can specifically be used in physiotherapeutic treatment and to aid people with difficulties in mobility and also in the heavy industry.
Keywords: Pneumatic Exoskeleton, Pneumatic Actuator, DOF, Design and Fabrication.

1.Introduction

Pneumatic exoskeletonalso known as powered exoskeleton, exoskeleton suit, exoframe, or exosuit, is a mobile machine consisting primarily of an outer framework worn by a person, and a powered system of pneumatic artificial muscles (fluidic muscles) that delivers at least part of the energy for limb movement. The user will no longer feel any fatigue in carrying heavy loads for long periods of time. Recyclable, light and enduring materials are used in this project in order to fulfil safety and environmental concerns. The main function of the exoskeleton suit is to assist the wearer by boosting their strength, endurance and durability. They are commonly designed for military use, to help soldiers in carrying heavy loads. In civilian areas, similar exoskeletons could be used to help fire fighters and other rescue workers to survive in dangerous environments. The medical field is another prime area for the exoskeleton technology, where it can be used for enhanced precision during surgery or as an assist and for nurses to move heavy patients.

In a production industry, about 15 to 20% of total production cost is used formaterial handling. Currently using material handling equipment's are, conveyors, cranes,forklifts, automatic guided vehicles (AGV's), etc. But, handling of medium weights (0-100kg) especially in small floor area is not economical by these equipment's. This can beeliminated by providing a mechanical suit worn by an operator. The user will no longerfeel any fatigue in carrying heavy loads (up to 100 Kg) for long periods of time. The mainfunction of the exoskeleton suit is to assist the wearer by boosting their strength, enduranceand the durability. For example, if a person can lift a load of 5kg by free hand, he caneasily lift 50kg by wearing this mechanical suit and feels like lifting 5kg. Thus allowingthe wearer his strength to amplify. They are commonly designed for military use, to helpsoldiers carry heavy loads both in and out of combat. In civilian areas, similar exoskeletonscould be used to help fire fighters and other rescue workers survive dangerousenvironments.

The medical field is another prime area for the exoskeleton technology, where itcan be used for enhanced precision during surgery or as an assist to allow nurses to moveheavy patients. For people who are severely injured but not completely paralyzed, there'severy reason to believe that they will have the opportunity to use these types ofinterventions to further improve their level of function. They're likely to improve evenmore. We need to expand the clinical toolbox available for people with spinal cord injuryand other diseases. It will be difficult to get people with complete paralysis to walkcompletely independently, but even if they don't accomplish that, the fact they can assistthemselves in walking will greatly improve their overall health and quality of life.

Moving to the technical part, the exoskeleton suit structure is made mainly from a combination of steel and aluminium. The power system is delivered through a set of pneumatic cylinders.

1.1. Exoskeleton structure

Designing an exoskeleton device for functional training of lower limbs is a very challenging task. From an engineering perspective, the designs must be flexible to allow both upper and lower body motions, once a subject is in the exoskeleton, since walking involves synergy between upper and lower body motions. It must be also a light weight, easy wearable and must guarantee comfort and safety. From a neuro-motor perspective, an exoskeleton must be adjustable to anatomical parameters of a subject.

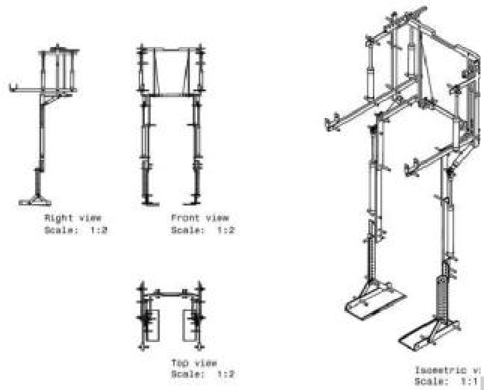

Fig.1. Suit structure

The suit structure is very simple and exposes of an forearm cover, biceps and triceps cover many parts of the human body. It consist, back and shoulders cover, leg cover, joints, etc.

The technology of exoskeletons or mechanical suit is divided into two parts, lowerextremity exoskeletons and upper extremity exoskeletons. The reason behind separatingthe two parts is that people can envision great applications for either part. Also, thetechnology of exoskeleton and human power augmentation is still in its early stage. Therefore, further research is required to ensure that both the upper and lower extremitiesfunction well independently before having an attempt to integrate them.

Upper frame work

This includes metal frame work (links) for the movement of hands of the operatorand the corresponding actuation system (pneumatic cylinders).

Lower frame work

This includes metal frame work (links) for the movement of legs of the operatorand the corresponding actuation system (pneumatic cylinders).

2.Design Considerations

2.1 Leg cover structure

Leg cover structure consists of two pneumatic cylinders for each leg. Both are attached to the metal frame via nuts and bolts. The frame is designed in a way that enables size variability relative to the operator.

Fig.2.Leg cover structure

2.2Back and shoulder cover structure

The back design was made with high focus on minimizing weight. It has a 'Y'shape & has extensions on top which rest on the shoulders. Lower end is mounted inbearings via a metal tube. Small holes are machined on the lower end to adjust the heightrelative to the operator.

2.3Joints

The first joint in the suit is the one connecting the forearm and the biceps cover orframe. The motion in this at this joint is limited due to the fixed angle the forearm canmove. This joint will provide momentum and thrust while lifting of the load. Hence,minimizing friction at this joint is of great importance. Nuts and bolts are used to providethis joint. Similar joint is used for the leg assembly. The second joint is the one thatrepresents the shoulder, connecting the biceps part with the upper shoulder one. Structurewise, the design does not include any physical connection between them due to the varietyof the motion degrees at that joint (shoulder). Usually, a ball joint or universal joint is used.

2.4 Hand cover structure

The forearm cover is designed in a way that enables size variability. Two cylindersare attached to the frames of the hand cover structure. Both are of same diameter andstroke length, but the movement is opposite in direction.

Fig.3.Hand cover structure

3. Exoskeleton components

3.1 Pneumatic cylinders

Pneumatic cylinders are widely used for many reasons. They're durable, clean,affordable, and fairly easy to install and maintain. They move loads in a variety of ways:pushing, pulling, lifting, lowering, and rotating. And they can handle widely varyingpayloads. While not ultra-precise in terms of positioning capabilities they are, nonetheless,accurate enough for countless applications.

Although there are many types of cylinders, their construction is fairly similar fromone to another. Basically, a cylinder is a sealed tube. It contains a rod, attached to a pistonthat extends through an opening at one end. Compressed air enters through a port at oneend of the cylinder, causing the piston rod to move. At the other end, a second port lets airescape. Understanding the basics helps to show how different applications affect thecylinder and piston rod.

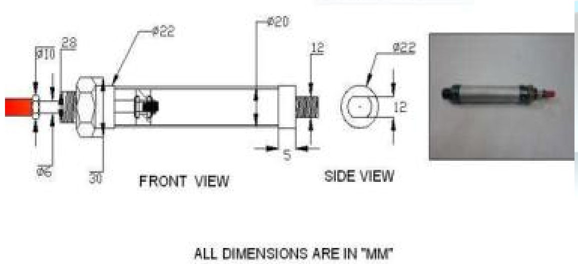

Fig.4. Double acting cylinder

3.2Solenoid valves

A solenoid valve is an electromechanically operated valve. The valve is controlledby an electric current through a solenoid: in the case of a two-port valve the flow isswitched on or off; in the case of a three-port valve, the outflow is switched between thetwo outlet ports. Multiple solenoid valves can be placed together on a manifold.

Solenoid valves are the most frequently used control elements in fluidics. Their tasks are toshut off, release, dose, distribute or mix fluids. They are found in many application areas.Solenoids offer fast and safe switching, high reliability, long service life, good mediumcompatibility of the materials used, low control power and compact design.

Fig.5.Solenoid valve with exhaust silencer

3.3 Compressor

An air compressor is a device that converts power (using an electric motor, dieselor gasoline engine, etc.) into potential energy stored in pressurized air (i.e., compressedair). By one of several methods, an air compressor forces more and more air into a storagetank, increasing the pressure. When tank pressure reaches its upper limit the air compressorshuts off. The compressed air, then, is held in the tank until called into use. The energycontained in the compressed air can be used for a variety of applications, utilizing thekinetic energy of the air as it is released and the tank depressurizes. When tank pressurereaches its lower limit, the air compressor turns on again and re-pressurizes the tank. Aircompressors are available in many configurations and will operate over a very wide rangeof flow rates and pressures. During the compression process, the temperature increases asthe pressure increases. The amount of compression power also increases as the temperatureincreases. Compressors are staged thereby reducing the temperature rise and improving thecompression efficiency. The temperature of the air leaving each stage is cooled prior toentering the next stage. This cooling process is called intercooling. Volumetric efficiencyalso increases with multi-stage compression since the pressure ratio over the first stage willbe decreased. [3] discussed about an eye blinking sensor. Nowadays heart attack patients are increasing day by day."Though it is tough to save the heart attack patients, we can increase the statistics of saving the life of patients & the life of others whom they are responsible for. The main design of this project is to track the heart attack of patients who are suffering from any attacks during driving and send them a medical need & thereby to stop the vehicle to ensure that the persons along them are safe from accident. Here, an eye blinking sensor is used to sense the blinking of the eye. spO2 sensor checks the pulse rate of the patient. Both are connected to micro controller.If eye blinking gets stopped then the signal is sent to the controller to make an alarm through the buffer. If spO2 sensor senses a variation in pulse or low oxygen content in blood, it may results in heart failure and therefore the controller stops the motor of the vehicle. Then Tarang F4 transmitter is used to send the vehicle number & the mobile number of the patient to a nearest medical station within 25

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km for medical aid. The pulse rate monitored via LCD .The Tarang F4 receiver receives the signal and passes through controller and the number gets displayed in the LCD screen and an alarm is produced through a buzzer as soon the signal is received.

3.4 Hoses

Hoses used in this pneumatic system are made up of polyurethane. The diameter ofthe tube selected is 6mm and these hose can withstand at a maximum pressure level of $10x10^5 N/m^2$.

3.5Connectors

3.5.1 Cylinder & valve connectors

In our system there are two type of connectors used. One is the Hose connector and the other is the reducer. Hose connectors normally comprise an adopt hose nipple and cap nut. These types of connectors are made up of brass (or) aluminium (or) hardenedpneumatic steel. One hose take the output of the directional Control (Solenoid) valve andthey are attached to one end of the cylinder by means of connectors.

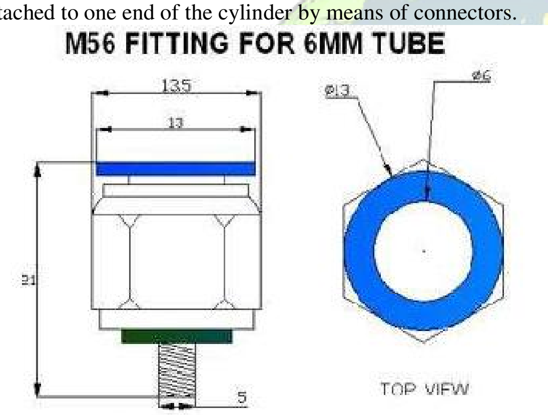

Fig.6. Connectors

3.5.2 T joint connectors

T joint connectors in pneumatic systems are used for splitting input air supply linein to two lines. For example, if we required to activate two cylinders simultaneously with asingle air supply line, we use a T joint connector.

Fig.7. T joint connector

3.6 Speed control devices

Rapid motion of the piston inside the cylinder causes corresponding rapid motion ofthe links or, frames since the cylinders are attached to them. This rapid motion beyond theoperator's capability may cause damages or injuries to the operator since he is inside thesuit.Controlling the mass flow rate of air leaving the cylinder; this is done by using anexhaust silencer or exhaust flow control valve fitted to the exhaust ports of 5/2solenoid valve. This is the most accurate method of speed controlling.

Fig.8. Exhaust silencer

4.Principle of working

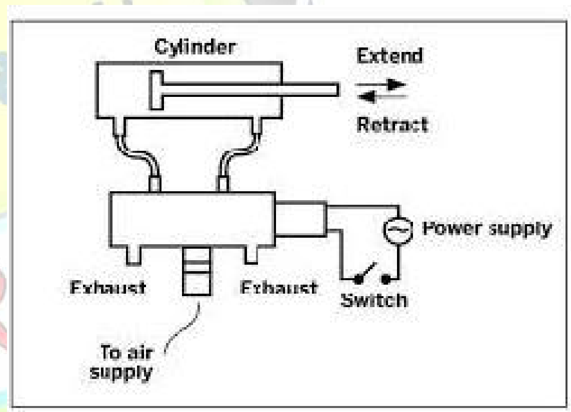

Fig.9. Principle of working

Pneumatic cylinders are attached to the metal frames or links for the movement ofoperators body (hands and legs), and are actuated by the supply of compressed air from compressor via a solenoid valve. The solenoid valve can be controlled either manually or electrically for actuation of cylinder. For manual operation, a push button is provided on the valve. For electrical operation, valve is connected to an external power source and circuit either DC or AC depending upon the type of solenoid valve used. Usually a 5/2 230V AC solenoid valve(spring return) and 20mm diameter 200mm stroke double acting pneumatic cylinder is used. The two outlet ports of the solenoid valve are connected to the two ends of double acting cylinder. Initially port 1 will be in opened condition.

Compressed air is entered in to the one side of the piston-cylinder and the piston moves outward. When the push button is pressed, port 1 is closed and port 2 is opened. Air enters in to the backside of the piston and it will move inward direction. The movement of piston rod causes corresponding movements of the links in which the cylinders are connected.

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5. Fabrication

5.1 Design of hand cover structure

The forearm cover is designed in a way that enables size variability. Two cylinders are attached to the frames of the hand cover structure via nuts and bolts. Both are of same diameter (20mm) and stroke length (200mm), but the movement is opposite in direction. Straps are attached to the hand frame for strapping the suit to operator's hand. Top end of universal joint is welded to the extensions of 'Y' frame that enables the angular movement of hand frame.

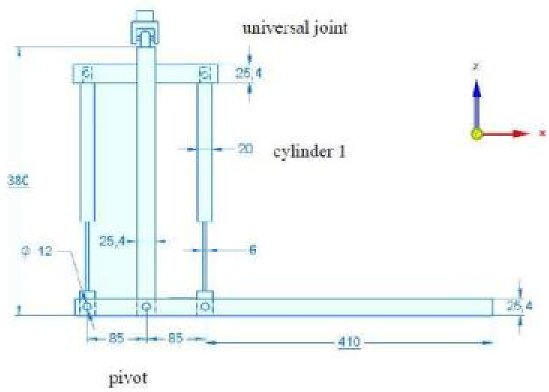

Fig.10.Dimensions of hand cover structure

5.1.1 Calculation of load

It consists of two cylinders in each arm, both are of same diameter and strokelength, but direction of motion is opposite. When compressed air is supplied to the cylinders, cylinder 1 will move upwards while cylinder 2 moves downwards causing the suit arm to move upwards about the pivot 'O'. Thus lifting the weight attached at the end of arm. The length of arm varies relative to the operator. The amount of load that can be lift by the mechanical suit arm for a given size is determined by the following way;

Let,

Inner diameter of pneumatic cylinder,

d =20mm (2cm)

Maximum intensity of pressure applied,

P_{max} = 10kg/cm²

= 10× 9.81 = 98.1 N/ cm²

= (say 100 N/ cm²)

Cross sectional area of cylinder, A = (Π/4)*d²

= (Π /4)*2²= 3.14cm²

We know that pressure acting on each cylinder,

P=Pressure force/cross sectional area of cylinder.

P =F/A

Therefore, Pressure force,

F =P*A =100*3.14 =314N

This force is acting upwards on cylinder 1(F1) and downwards on cylinder 2(F2) as shown in figure 10.

F1=F2=F

To determine the load (W), take moment about the pivot 'O'.

F1×0 .085+F2 ×0.085=W (0.41+0.085)

314×0.085+314×0.085=W× (.41+0.085)

W=107.83 N

=11 kg.

This is the weight that can be lifted with single hand. So a weight of 22 kg can be lifted with both the hands.

For the smooth and safe operation, usually the pneumatic systems are operated with a working pressure of 5-8kg/cm². i.e.,from the above calculations, if the maximum intensity of pressure applied to the system is 8kg/cm², then the maximum load that the suit can lift will be 17.25kg.

The lifting capacity (load, w) of mechanical suit arm can be increased byincreasing the cylinder diameter, distance of cylinders from the pivot'O' (OA& OB) and reducing the arm length (BC).

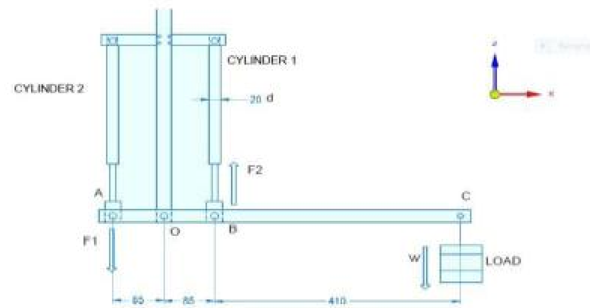

Fig.11.Calculation of load

5.2 Design of leg cover structure

Leg cover structure consists of two pneumatic cylinders for each leg. Both are attached to the metal frame via nuts and bolts. The frame is designed in a way that enables size variability relative to the operator.Foot pedals or, foot plates are connected to the lower end of leg cover structure, so that the operator can keep his foot inside the suit. Also the entire weight of suit is transferred to the ground and the operator does not feel any load.

Fig.12.Leg cover structure

5.3 Design of back cover structure

Fig.13.Back cover structure

The back design is made with high focus on minimizing weight. It has a 'Y' shape & has extensions on top which rest on the shoulders. Lower end is mounted in bearings, so that the upper frame work can swivel in accordance with upper body movement of operator.Upper end of universal joint or, ball joint of hand frame structure is welded to the outer side of extensions that leads to the angular (almost 360 degree) movement of hand frame. Two ball bearings of 20mm inner diameter and 45mm outside diameter are used for this purpose. Outer surface of bearing is welded to the metal frame of waist structure as shown in fig 16A G I tube of 22mm outside diameter having drilled holes is press fitted in to the bearing. Similarly holes of same diameter are machined on the lower end of 'Y' frame so as to adjust the height relative to the operator. Provision for attaching leg cover structure is also made on the waist frame. Various dimensions of back cover structure including waist structure and Y frame are shown in fig 13 and fig 14 respectively.

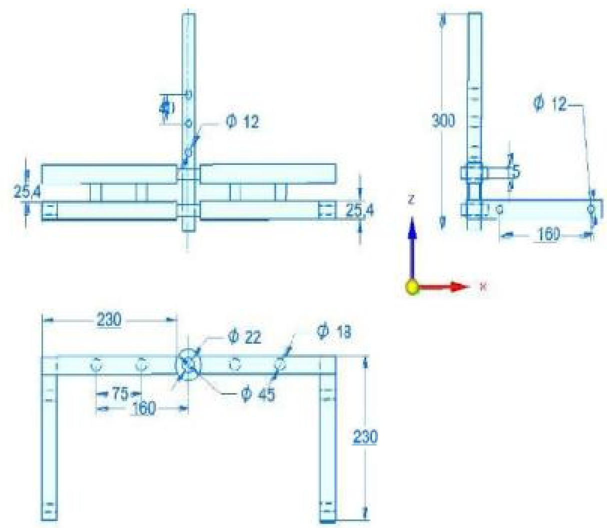

Fig.14.Dimensions of waist structure

6.Results

Maximum intensity of pressure applied to the system = 8kg/cm²

- Theoretical load, w=17.25kg
- Actual load, w=15kg

The actual value of the load that the mechanical suit can lift is less than the theoretical value due to following reasons;

1. Frictional losses

These are mechanical losses, emerges from friction between piston cylinder interface, friction at the joints and friction between air and inner surface of tube.

2. Air leakage

100% leak proofing is not possible for any pneumatic system. There will be some air leakages at the connectors, joints, etc., leads to the reduction in intensity of pressure or simply pressure drop.

3. Variation of cross sectional area in upward and downward stroke. Due to the presence of piston rod, the actual cross sectional area of piston subjected to high pressure air in upward stroke will be less as compared to the downward stroke.

F_r=P (πr_1^{2-} πr_2^2) =P $\pi(r_1^2$-$r_2^{2)}$.
Where:
F_r- Resultant force
r_1- Radius of the piston = 10mm
r_2- Radius of the piston rod =3mm
I.e. Fr = 80× [π/4x (22 – 0.62)] =228.70 N
Total weight of the suit is found to be 15.5 kg.

7 Applications

7.1 Material handling in industries.

Mechanical suit can be used for carrying heavy loads/goods in industries. The suit allowed the wearer to amplify their strength by certain factor, so that lifting heavy weights will be as easy as lifting very small weight without the suit.

Fig.16. Material handling

7.2 Pneumatic walking assist

The exoskeleton arm can specifically be used in physiotherapeutic treatment(physical therapy) and to aid those who have difficulties in mobility Exoskeletons could also be applied in the area of rehabilitation of stroke or spinal cord injury patients. Such exoskeletons are sometimes also called Step Rehabilitation Robots. An exoskeleton could reduce the number of therapists needed by allowing even the most impaired patient to be trained by one therapist, whereas several are currently needed. Alsotraining could be more uniform, easier to analyze retrospectively and can be specifically customized for each patient.

7.3 Military applications

There are an increasing amount of applications for an exoskeleton, such as decreased fatigue and increased productivity whilst unloading supplies or enabling a soldier to carry heavy objects (80–300 kg) while running or climbing stairs. Not only could a soldier potentially carry moreweight, they could presumably wield heavier armor and weapons while lowering their metabolic rate or maintaining the same rate with more carry capacity. Some models use a hydraulic system controlled by an on-board computer. They could be powered by an internal combustion engine, batteries or potentially fuel cells.

7.4 Civilian

In civilian areas, exoskeletons could be used to help firefighters and other rescue workers survive dangerous environments.

8.Conclusions

Operation space limitation is one of the main problems associated with this mechanical suit. Because the compressor is mounted on the floor, outside the suit. Eventhough an air-tank can be fitted on the suit, complete integration of the suit is very difficult. Additionally, new series elastic actuators and other deformable actuators are being proposed for mechanical suit. They are called "Fluidic Muscles" or fluidic tubes. They use pressurized gas to produce mechanical motion. When a fluidic tube is filled with compressed air, its diameter increases and at the same time length is shortened. This behavior acts as a linear actuator and can deliver motion to two joints connected together more efficiently than other pneumatic actuators. Future depends on developing new technologies to remedy certain problems in mechanical suit like power source, structural materials, control actuation, biomechanics. The actuation sub system encompasses all of the parts which transmit power and strength to the user. The engineers move to progressively more expensive and strong but lightweight materials such as titanium, and use more complex component construction methods, such as moulded carbon-fibre plates for the construction of suit material. In advanced mechanical suits, actuation is done by electronic servomotors and controlling is made by the use of sensors. Operators input is determined by force sensing resistors (FSR) attached to the operator's skin. These measuring resistors along with other information such as the joint angles are used to determine the input torques required for various joints. The powered suit detects muscle myoelectric signals from the skin surface by sensors and sent to a computer that translates the nerve signals into signals of its own for controlling the electric motors of the exoskeleton.

References

[1]Wiley: Wearable Robots: Bio-mechatronic Exoskeletons - José L. Pons. Eu.wiley.com. 2001-12-04. Retrieved 2016-02-20.

[2] Robotic Exoskeletons from Cyberdyne Could Help Workers Clean upFukushimaNuclear Mess - Scientific American Blog Network".Blogs.scientificamerican.com.2011-11-09. Retrieved 2016-02-20.

[3] Christo Ananth, S.Shafiqa Shalaysha, M.Vaishnavi, J.Sasi Rabiyathul Sabena, A.P.L.Sangeetha, M.Santhi, "Realtime Monitoring Of Cardiac Patients At Distance Using Tarang Communication", International Journal of Innovative Research in Engineering & Science (IJIRES), Volume 9, Issue 3,September 2014,pp-15-20

[4] The Future of Exoskeletons: Lighter Loads, Limbs and More - Scientific American. Sciam.com. 2007-09-21. Retrieved 2016-02-20

[5] Pneumatic Fluidic muscles based Exoskeleton Suit; Abdulla Almomani, Faisal Miqdadi, Mustafa Hassanin, Mustafa Samy, and Mohammed Awadallah, IEEE, 2013

[6] http://www.pneumatics.be (pneumatic cylinder details)

[7] http://fpef.org/ (solenoid details)

[8] Machine design data handbook (volume 2), by Dr. K. Lingaiah, Professor B.R.Narayana Iyengar.