Developing A Model of Powered Exoskeleton for Industrial Workers

Supervisor: Dr. Mohammad Mamun, Professor, Dept. of ME, BUET

Conducted By:

Abrar Shahriar Swopnil (S201410051)

Md. Mohi Uddin Khan (S201410103)

Department of Mechanical Engineering

Bangladesh University of Engineering and Technology

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A thesis submitted to the Department of Mechanical Engineering, Bangladesh University of Engineering and Technology in partial fulfillment of the requirements for the degree of Bachelor of Science in Mechanical Engineering.

Supervisor:

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Dr. Mohammad Mamun

Professor

Department of Mechanical Engineering

Bangladesh University of Engineering and Technology

Prepared by:

Abrar Shahriar Swopnil (S201410051)

Md. Mohi Uddin Khan (S201410103)

Bangladesh University of Engineering and Technology

Dhaka-1000, Bangladesh

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Declaration

This is to certify that this thesis or no part of this thesis is submitted elsewhere for any other degree or diploma. Any material produced in this thesis has been properly acknowledged.

Abrar Shahriar Swopnil

Student ID: S201410051

Md. Mohi Uddin Khan

Student ID: S201410103

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Abstract

Metabolic studies have shown that there is a metabolic cost associated with carrying a load (Griffin et al, 2003). Further studies have shown that by applying forward propulsive forces a person can walk with a reduced metabolic rate (Farley & McMahon, 1992 and Gottschall & Kram, 2003). We are designing an powered full body exoskeleton to be used by industrial workers in order to reduce their physical effort in jobs requiring augmented strength. Past exoskeleton endeavors have led to bulky, expensive, invasive, and tethered solutions. The challenge is to build an exoskeleton system that is inexpensive, streamlined. Our solution is unique in that it will be a low-cost, ergonomic device actuated through motor from the value of potentiometer. Augmented strength is applicable to physically intensive occupations, as well as search and rescue operations. Each year, thousands of workers must take leave due to injuries triggered by heavy lifting; with augmented strength, workers could avoid harmful situations and could work tirelessly which would increase their efficiency.

Contents

Chapter 1

1. Introduction

Exoskeleton was first introduced for human in earlier ages at the time of 18th century. From that time exoskeleton was used as for medical purpose. Beginning from that time exoskeleton was playing a special role in medical science. As some of it the doctors used exoskeleton for prosthetics or for the patients or some were used as a helping purpose for walking or standing. After that stage exoskeleton spread throughout for also military purpose or defense. Now in modern industrial era exoskeleton is also used for the workers to simplify their job. It also helps the workers to carry their load properly and more than their limitation. In the area of lower-limb exoskeletons began primarily in the late 1960s, almost in parallel between a number of research groups in the United States and in the former Yugoslavia. These efforts were split between developing technologies to augment the abilities of able-bodied humans, often for military purposes and developing assistive technologies for handicapped persons. Despite the differences in intended use, these two fields face many of the same challenges and constraints, particularly related to portability and interfacing closely to a human operator.

1.1 Primary Concept

The term, exoskeleton comes from the word as a type of skeleton. The skeleton which remains on the outer side of a body is called exoskeleton. We can see exoskeletons only in the outer part of some insects' body. Various types of insects (mainly in arthropods) they contain exoskeleton. Besides turtle and snake can also contain it.

Purpose (According to an insect):

1: To protect the body

2: To create a shield from the outside bad environment

3: To restore some energy for the future

4: In the body transformation process exoskeleton also helps to support the problem

Human body or other type of spine containing creatures contain skeleton in their body. The skeleton takes

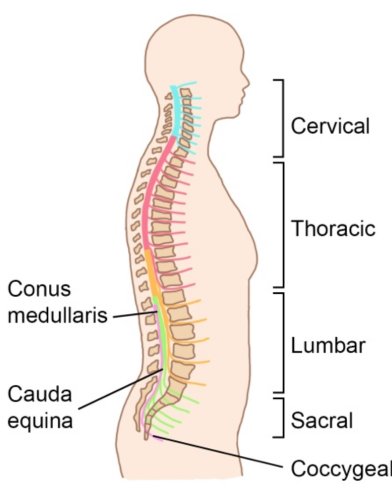


Fig 1.1: Human Spine

the mass of the whole body and also drives muscles. Spine takes a huge portion of weight of the whole body. We stand by giving the half weight of the body to the spinal cord. Our structure of the body is constructed properly by the skeleton. The spinal cord is a long, thin, tubular structure made up of nervous tissue, that extends from the medulla oblongata in the brainstem to the lumbar region of the vertebral column. It encloses the central canal of the spinal cord that contains cerebrospinal fluid.

Besides an inner part of the skeleton protects also some of our body parts like heart, lungs and also some sensitive parts and also prevents any type of outside thrust or sudden force.

According to our project we are developing a model that can change the direction of the force into another direction and also will be able to make the weight light which will increase efficiency of ours at the time of taking a load.

1.2 Exoskeleton Types According to Human Structure

According to the human body an exoskeleton system can be of different types of exoskeleton. The type of an exoskeleton depends on -

1: What body parts are actuated or powered by the wearable device?

- full body
- upper extremities: arms and torso
    - further broken down into specific areas: some exoskeletons can concentrate on the wrist and fingers, while others focus on the shoulder and elbow joints
- lower extremities: legs
    - further broken down into: hip, knee, or ankle only, hip-knee, hip-ankle, knee-ankle or hip-knee-ankle. The motion can also be in more than one plane of rotation

2: Is it powered?

- **Powered exoskeletons** use batteries or electric cable connections to run sensors and actuators
    - Static exoskeletons: the actuators need to be turned on at all times in order for the device to maintain its shape.
    - Dynamic exoskeletons: actuators do not need to be turned on at all times and the device can be many times more energy efficient. This type of exoskeletons is further differentiated by what they are designed to do.
- **Passive exoskeletons** do not have any electrical power source and can be used for:
    - weight re-distribution: springs and locking mechanisms divert the weight of an object around the user and into the ground
    - energy capture: ankle spring-clutch exoskeletons have been shown to improve walking efficiency, while spring-dynamo knee exoskeletons can be used to charge a battery.
    - dampening: some spring or spring-damper passive exoskeletons have been designed as shock absorbers (high-speed skiing – Ski Mojo) or vibration reducers (small high-speed boat – Marine Mojo)
    - locking: some passive exoskeletons are designed to be unobtrusive until they are locked into place, allowing the user to sit or crouch in the same position for a prolonged period of time.
- **Pseudo-passive exoskeletons** have batteries, sensors, and other electronics, but they are not used to provide actuation.
    - The best example of a pseudo-passive exoskeleton is the C-Brace by Ottobock, which uses its electronics to control a variable damper in the knee. The C-Brace alternatively unlocks,

slows down the swing of the leg and locks depending on the position of the leg in the gait cycle as determined by the integrated sensors.

- **Hybrid-exoskeletons** are wearables that have all of the controllers and sensors of a powered exoskeleton but use FES (functional electrical stimulation) of the muscles as actuators.

3: Is it mobile?

- Fixed: the device is tethered, attached to a wall, a bracket or suspended from the air by a fixed hook and harness
- Supported: the exoskeleton is attached to an overhead rail, is supported by a moving frame or in some cases, supported by an adjacent wheeled robot. These configurations allow for the heavy motors, controllers and batteries to be externally supported while still granting mobility to exoskeleton wearer.
- Mobile: the user and exoskeleton can move around freely.

4: How is it controlled (user-machine-interface)?

- Joystick: reserved for exoskeletons that provide 100% of the energy for motion needed by the wearer.
- Buttons or control panels: the exoskeleton is placed in different pre-programmed modes. The control surface does not have to be on the exoskeleton, previous designs have them on a wrist strap, integrated into walking aids such as crutches or held by a supervisor adjacent to the user.
- Mind-controlled: using an electrode skull cap
- Sensors: current exoskeletons designs can have as many as 40 different integrated sensors that monitor rotation, torque, tilt, pressure and can capture nerve signals in the arms and legs
- No control: some passive exoskeletons have no control buttons or switches.

5: How is it built?

- Rigid materials such as metals or carbon fiber.
- Flexible materials in the entire construction (soft exoskeleton or exosuit).

6: Origin?

a. Home built (DIY) – some of the biggest companies today started out in garages
b. Research labs (academia)
c. Commercial companies (industry)
d. Governments – currently only the Chinese government is actively developing an exoskeleton. All other governments may provide grants, but are looking to buy a working model.

1.3 Biomechanics of The Human Spine

The smallest motion unit of the spine is a motion segment consisting of two adjacent vertebrae with the intervertebral disc between them. The connection is based on the articular triad, composed of two symmetrically located zygapophysial (or facet) joints and the intervertebral disc. The possibility of movement within the unit depends on parameters of the triad, ligaments and the shape of articular processes. The movability of the spine as a whole is a sum of movements within each motion segment. There are three planes of movement in the spine: a sagittal plane (flexion and extension in a range of approximately 90°), frontal plane (lateral flexion in the maximum range of approx. 60°) and horizontal plane (turning around vertical axis – approx. 90° in each way). Curvatures of the spine in a sagittal plane are crucial for a distribution of stress in the vertebral column, which entails durability of spinal structures and suppression of dynamic loads. Charriere et al. Determined the correlation between curvatures and durability of the spine – according to the authors, the durability of the spine is proportional to the square of curvature amount "+1". Thereby, human spine consisting of four physiological curvatures is seventeen times more resistant to stress than the straight spine. The spine is a complicated mechanism, differentiated in terms of materials. In one kinematic chain there are stiff bone elements cooperating with discs, supported by ligaments. The vertebrae, similarly to other bones, are composed of outer cortical bone and inner cancellous bone. The cortical bone is more durable and denser, while the cancellous one is less durable, but able to distribute stress better, thanks to its trabecular structure. Mechanical properties of vertebrae form under pressure resulting from performing everyday activities. It should be noted, that either lack of load or overloading can negatively affect the structure of these tissues. The durability of bones (i.e. vertebrae) changes with age. Since birth bone tissue rebuilds itself internally under pressure, strengthening its structure. The best mechanical properties of the bone are observed in people between 25 and 35 years old. With progressing age, the properties weaken, hence the growing susceptibility to injuries. Swedish scientist Alf Nechemson conducted the analysis of pressure changes in lumbar spine both in vivo and in vitro, depending on gender, age, posture, performed activities and degeneration of vertebra's tissue. Results of the research were presented as a correlation between the changes of pressure affecting lumbar intervertebral discs and human posture, with standing position as the reference (100% of pressure), as shown in the Figure.

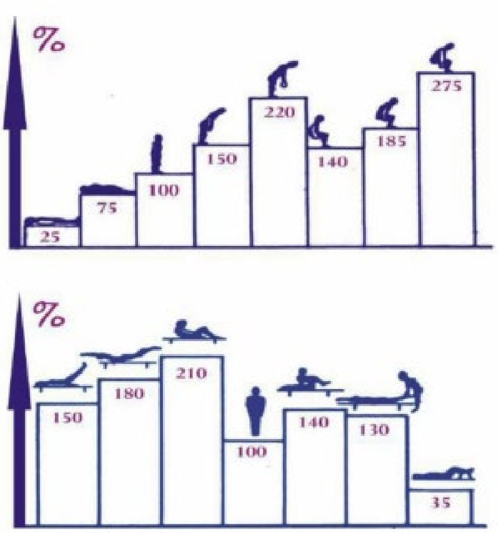


Fig 1.2: The pressure affecting L3-L4 intervertebral discs depending on the body posture

1.4 Biomechanics of Lifting

Lifting models can be -

a) Analytic models:

   1: HAT model of lifting

   2: Cantilever low back model of lifting

   3: Link segment static models

b) Computer models:

   1: 4D WATBAK computer program (University of waterloo)

   2: 3D Static Strength Prediction Program (University of Michigan)

1.4.1 Hat Model of Lifting

1: Upper torso is modeled as a single mass representing the combined mass of the head, arms and trunk

2: Referred to as the “HAT model”

3: Simple to analyze, but of limited accuracy

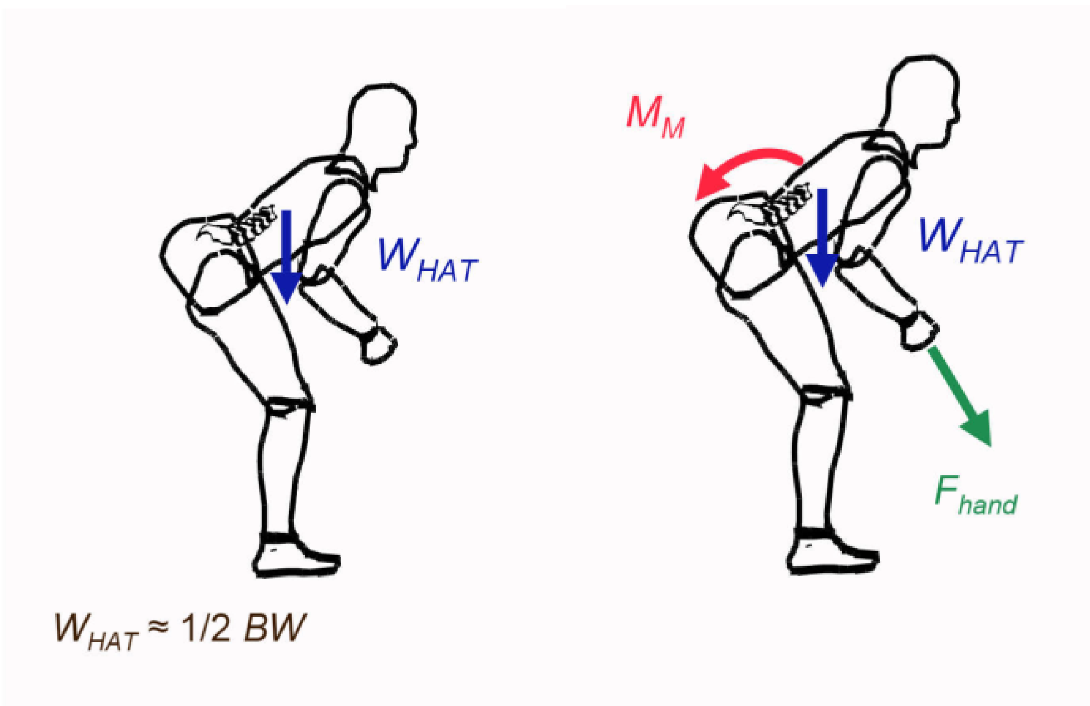


Fig 1.3: Hat Model of Lifting

4: Back muscles must produce a moment (M_m) to counteract moments due to hand force (F_{hand}) and weight of HAT (W_{HAT})

5: Otherwise person would bend or fall forwards

The moment that a force F produces about a fixed point 0 is equal to the force times the perpendicular distance from 0 to the line of action of the force

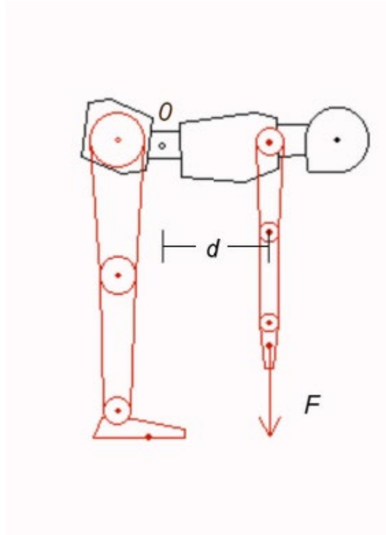


Fig 1.4: Hat Model of Lifting

Mo = F*d

d=" moment arm"

Muscle force can be estimated from muscle moment and moment arm

1: Once the muscle moment (Mm) has been calculated, the muscle force (Fm) can be estimated by dividing Mm by the moment arm of the erector spinae muscle.

2: This force contributes to the resultant joint compressive force

Single Equivalent Muscles:

1: In most joints (other than the spine), more than one muscle or group contributes to Mm

2: In shoulder flexion, there are two prime movers and two assistors

3: In forearm flexion, there are three prime movers

4: We often lump such muscle groups together and refer to the lumped muscle as a "single equivalent muscle"

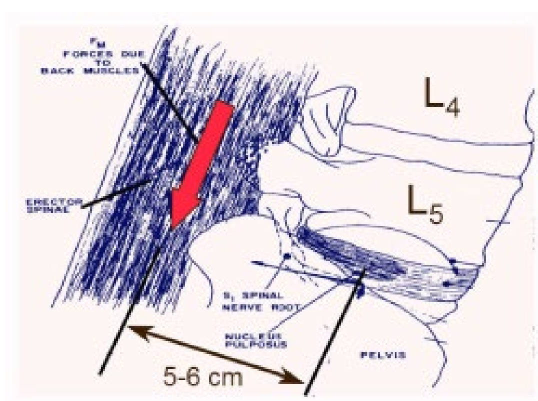


Fig 1.5: Single Equivalent Muscle

1.5 Force Distribution in Spinal Cord

Accurate determination of load distribution among passive and active components of the human trunk in various activities such as sports, exercises or manual materials handling is required for designing performance enhancing devices. In vivo studies have been carried out to estimate spinal muscle forces and internal loads indirectly by measuring intradiscal pressure or load on fixation systems. In these studies, biomechanical models have been used due to the absence of noninvasive techniques.

There are normally 33 vertebrae in a human's vertebral column. The upper 24 are articulating and separated from each other by intervertebral discs. These discs work as shock absorber. Spine cord is supported by ligaments and muscles. The natural shape of the spine creates three balanced curves, lordotic cervical region, kyphotic thoracic region and lordotic lumbar region.

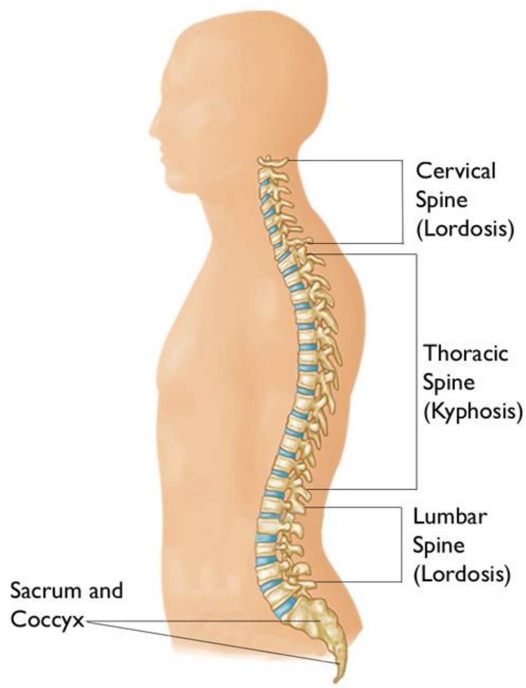


Fig 1.6: Curves in Human Spine in Normal Condition

Many postures can produce a change in the geometry of the spine, but moving from standing up to bending down, and then from bending down to standing up (during these movements the lumbar spine goes from being lordotic to kyphotic to lordotic), and when this is combined with lifting or lowering a load it creates a particular risk for a low back injury.

The back is prone to this strain because of its weight-bearing function and involvement in moving, twisting and bending. Lumbar muscle strain is caused when muscle fibers are abnormally stretched or torn. Lumbar sprain is caused when ligaments, the tough bands of tissue that hold bones together, are torn from their attachments. Both of these can result from a sudden injury or from gradual overuse.

For the average shaped spine, the spine straightened slightly under load. When a person takes load, the spine become more curved then unloaded condition if it has large, mainly lordotic curvature. Spines with smaller lordotic region became straighter under load.

During load-carrying, propulsive, braking and vertical ground reaction forces increase in proportion to increasing load carried. In a study it is found that for a body plus mass increase by 40%, ankle peak plantarflexion torque increased by 38%, knee peak extension torque increased by 98% and hip peak extension torque increased by 47%. The forward inclination of the trunk also increased significantly with load, helping to keep the body plus pack center of mass over the feet. Other adaptations to load included greater knee flexion after impact (which aids in shock absorption), reduced pelvic rotation and increased foot rotation in the sagittal plane.

When the lumbar spine is strained or sprained, the soft tissues become inflamed. This inflammation causes pain and may cause muscle spasms. Lumbar strain or sprain can be very debilitating.

2. Past Works on Powered Exoskeleton

The concept of human exoskeleton is not very new. The first exoskeleton as known so far was made by a Russian technologist named Nicholas Yagin in 1890. It was capable of assisting in walking, jumping and running. It ran by energy of compressed gas bags. However, the power system was passive and it still required human power.

In 1917, invention Leslie C. Kelly developed 'Pedomotor', which could act parallel to wearer's movements. It had artificial ligaments which operated using steam power.

In 1960s, General Electric and the United States Armed Forces co-developed a mobile machine integrated with human movements. This suit was named Hardiman. It can be called the first true exoskeleton. It had a strength amplifying factor of 25. That means it made lifting 110 kilograms feel like lifting 4.5 kilograms. However, the project was not successful overall. It weighed 680 kilograms. Any attempt to use the full exoskeleton resulted in a violent uncontrolled motion, and as a result, the exoskeleton was never turned on with a person inside. Also, it was very slow which limited its practical use.

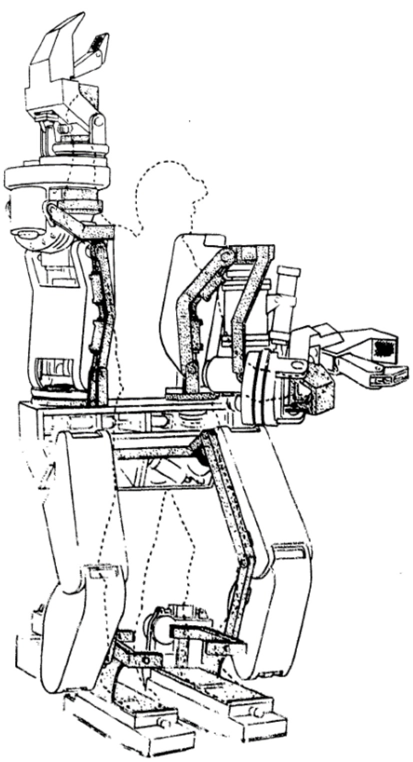


Fig 2.1: Earlier Design of Powered Exoskeleton

In 1969, under the guidance of Prof. Miomir Vukobratović, active exoskeletons and humanoid robots were developed at the Mihajlo Pupin Institute. It had developed legged locomotion. These were predecessors of the modern high-performance humanoid robots.

The present-day active exoskeletons are developed as the systems for enhancing capabilities of the natural human skeletal system. The most successful version of an active exoskeleton for rehabilitation of disabled persons is pneumatically powered and electronically programmed. It was first tested at Belgrade Orthopedic Clinic in 1972. One specimen was delivered to the Central Institute for Traumatology and Orthopedy, Moscow.

Los Alamos Laboratories worked on an exoskeleton project in the 1960s called Project Pitman. In 1986, an exoskeleton prototype called the LIFESUIT was created by Monty Reed, a United States Army Ranger who had broken his back in a parachute accident. In 2001 LIFESUIT One (LSI) was built. In 2003 LS6 was able to record and play back a human gait. In 2005 LS12 was worn in a foot race known as the Saint Patrick's Day Dash in Seattle, Washington. Monty Reed and LIFESUIT XII set the Land Speed Distance Record for walking in robot suits. LS12 completed the 4.8-kilometre race in 90 minutes. The current LIFESUIT prototype 14 can walk 1.6 km on a full charge and lift 92 kg for the wearer.

2.1 Raytheon XOS 2 Exoskeleton

XOS 2 is a second-generation robotics suit being developed by Raytheon for the US Army. The company publicly demonstrated the capabilities of the exoskeleton for the first time at its research facility in Salt Lake City in Utah, in September 2010.

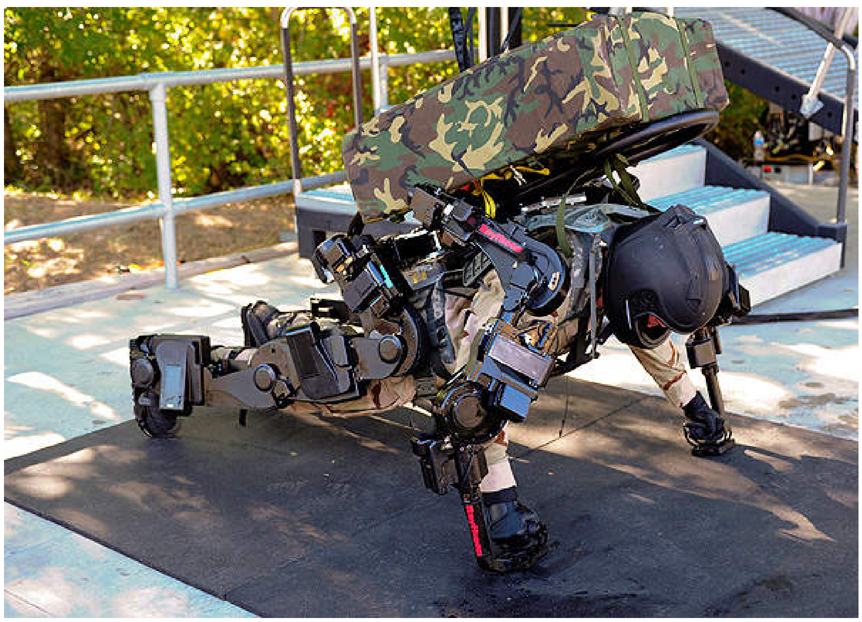


Fig. 2.2: Raytheon XOS 2 Exoskeleton

The wearable robotic suit increases the human strength, agility and endurance capabilities of the soldier inside it. The XOS 2 uses high-pressure hydraulics to allow the wearer to lift heavy objects at a ratio of 17:1 (actual weight to perceived weight). This allows repeated lifting of the load without exhaustion or injury.

2.2 Human Universal Load Carrier

Human Universal Load Carrier, or HULC, is an un-tethered, hydraulic-powered exoskeleton developed by Professor H. Kazerooni and his team at Ekso Bionics. It is intended to help soldiers in combat carry a load of up to 200 pounds at a top speed of 10 miles per hour for extended periods of time.

Fig. 2.3: Human Universal Load Carrier

2.3 Hybrid Assistive Limb

The Hybrid Assistive Limb (also known as HAL) is a powered exoskeleton suit developed by Japan's Tsukuba University and the robotics company Cyberdyne. It is designed to support and expand the physical capabilities of its users, particularly people with physical disabilities. There are two primary versions of the system: HAL 3, which only provides leg function, and HAL 5, which is a full-body exoskeleton for the arms, legs, and torso.

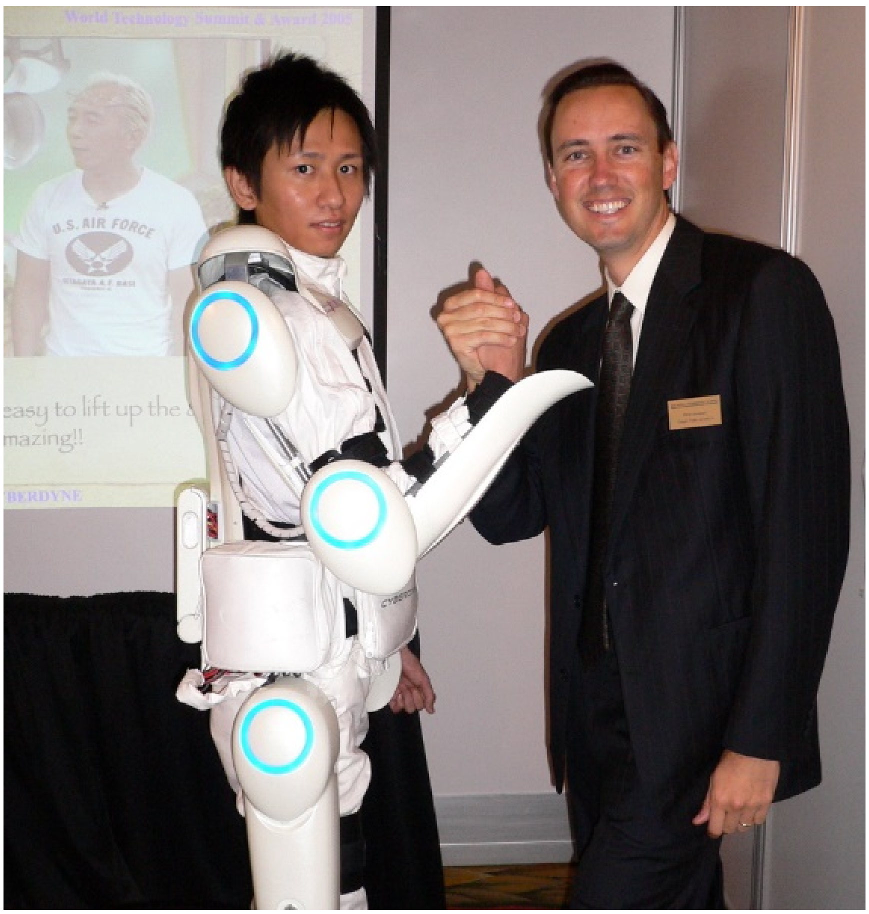


Fig. 2.4: Hybrid Assistive Limb

2.4 ReWalk

ReWalk is a commercial bionic walking assistance system that uses powered leg attachments to enable paraplegics to stand upright, walk and climb stairs. The system is powered by a backpack battery, and is controlled by a simple wrist-mounted remote which detects and enhances the user's movements.

Fig. 2.6: ReWalk

2.5 Ekso (or eLEGS)

In 2010 Berkeley Bionics unveiled eLEGS, which stands for "Exoskeleton Lower Extremity Gait System". eLEGS is another pneumatically powered exoskeleton system, and allows paraplegics to stand and walk with crutches or a walker. The computer interface uses force and motion sensors to monitor the user's gestures and motion, and uses this information to interpret the intent of the user and translate it into action. Users can "put on and take off the device by themselves as well as walk, turn, sit down, and stand up unaided". In 2013 The next generation Ekso GT with smart Variable software was released. It is the only exoskeleton available for rehabilitation institutions that can provide adaptive amounts of power to either side of the patient's body, challenging the patient as they progress through their continuum of care. The suit's patented technology provides the ability to mobilize patients earlier, more frequently and with a greater number of high intensity steps.

Fig. 2.7: Ekso (or eLEGS)

2.6 ExoLite

ExoLite is developed by ExoMED company which enables independent walking without requiring crutches or other means to stabilize. The exoskeleton for legs allows to stand up / crouch, turn around, walk back, stand on one foot, walk the stairs, walk along different, even inclined surfaces.

Fig. 2.8: ExoLite

2.7 Soft Exosuits

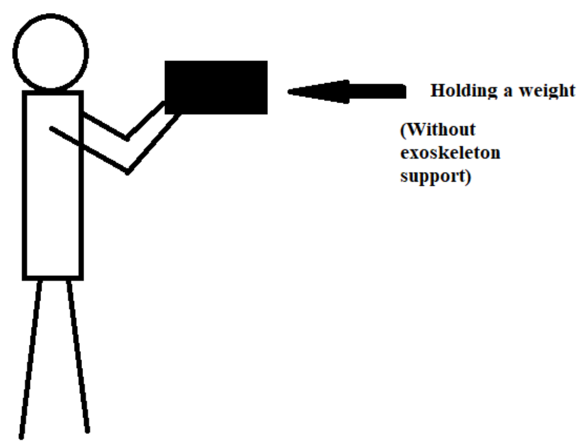
Lightweight Exosuits are a new class of soft robots that combine classical robotic design and control principles with functional apparel to increase the wearer's strength, balance and endurance. It offers a new way to assist the elderly in maintaining or restoring their gait, in rehabilitating children and adults with movement disorders due to Stroke, Multiple Sclerosis and Parkinson's Disease, or to ease the physical burden of soldiers, firefighters, paramedics, farmers, factory workers and others whose jobs require them to carry extremely heavy loads.

3. Conceptual Design

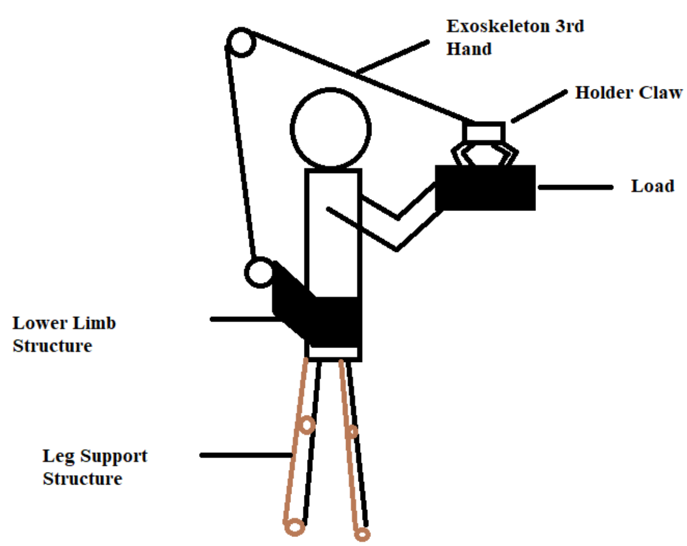
We designed an exoskeleton structure for the workers in the industry or factory. In maximum factory we see that workers do their jobs by holding heavy parts in their hand. That's not easy when the job will be done for a longer period. When we want to make is some type of assembly job such as attaching screws or doing welding in upward position or attaching glue etc. type of jobs then it's hard to hold this job for a longer period. At first it seems to be easy. But as time is passing the heavy object in this situation what we need most is an assistance that will hold the heavy object to carry and also reduce the weight. So that it can help the workers to simplify their job to be done. Our concept for this type of project is that we will create a type of structure that will remain outside of the body and also hold the body structure perfectly. The structure will have an arm that will hold the object which is creating stress to the body of the worker or with which the worker is working for a longer period.

The steps are shown below using figures

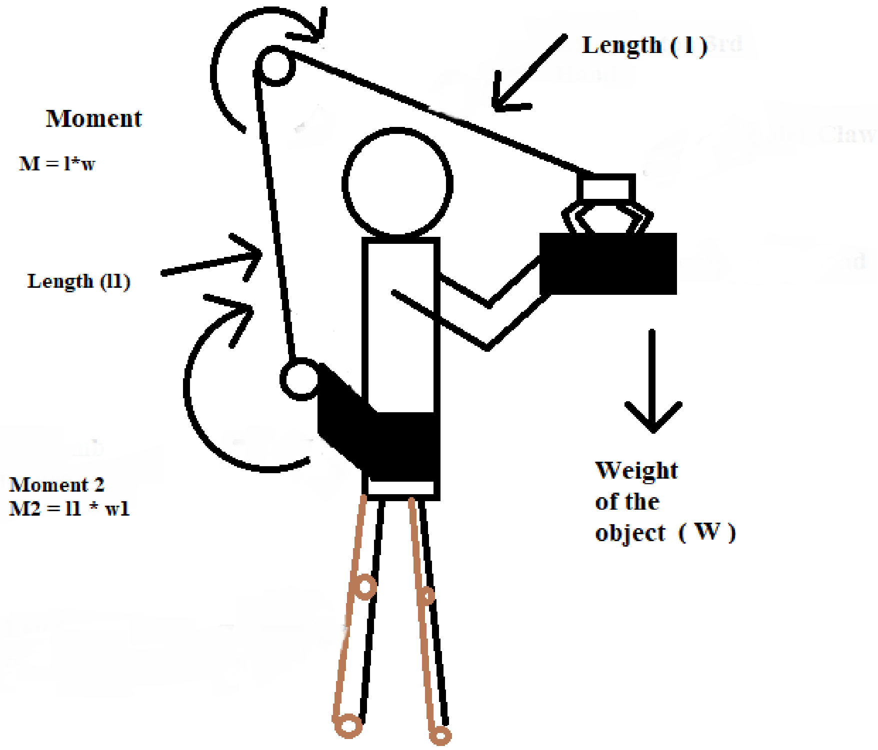
Step 1: Taking load without exoskeleton



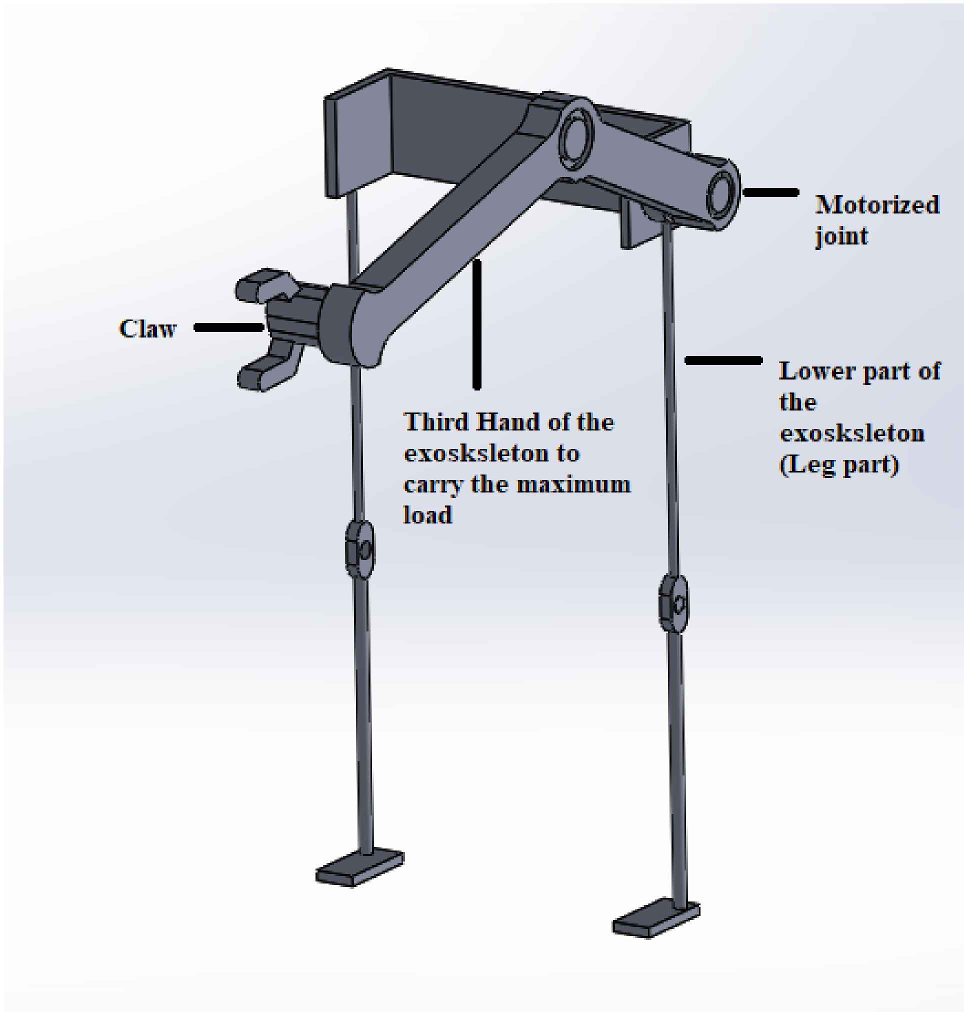
Step 2: Taking load with exoskeleton



Here we see that the load is transferring from the body to the exoskeleton. A third hand or an attached robotic arm with the exoskeleton body is trying to hold the load. As the robotic arm is trying to hold the load the force will or we can say that a huge portion of load is being transferred to the exoskeleton. As the load is reduced that is why we can say that this exoskeleton will reduce the stress to the workers body and also distribute the force to the different parts of the body. From this figure below we see the force distribution in the different parts of the body.



Here is our 3D cad model shown in the figure given below



From the picture we see the 3rd hand and also the leg part in the body frame. There is a control box behind the exoskeleton. The hand can be controlled using the controller. The worker can change the position of the different part of the exoskeleton.

4. Components

Components for this project can be divided into 2 parts:

1: Electrical
2: Mechanical

4.1 Electrical Components

Here working for this project, we have faced many problems. Both electrical and also mechanical. In electrical part we have mainly faced motor controlling time. We see that the motors we have used here is high power dc motor. It requires high current and voltage flow. As also in this project we also need to control the motor in forward and reverse direction. So, motor bridge system is required. We wanted to use L298N motor driver in this project. But accidently our 4 motor drivers failed to draw that much high current. So, they failed actually. Besides high current MOSFETs and high current transistors also were creating problems. So, for this reason we came up with a decision that we will control the motor using relay-based switching system. We will use the 8-relay switch circuit system. At a time 4 relay switch will be dedicated for each motor.

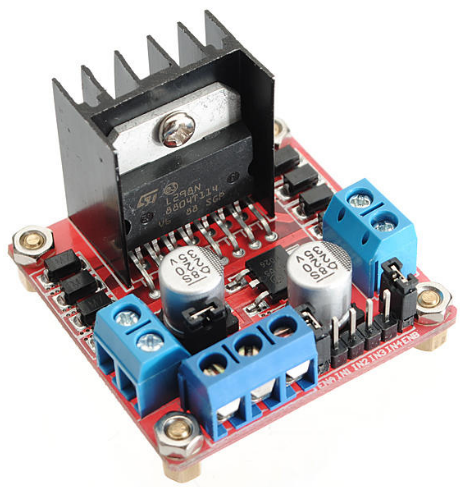


Fig. 4.1: Relay Switch

4.1.1 Relay Switch

Relays are switches those open and close circuits electromechanically or electronically. Relays control one electrical circuit by opening and closing contacts in another circuit. As relay diagrams show, when a relay contact is normally open (NO), there is an open contact when the relay is not energized. When a relay contact is Normally Closed (NC), there is a closed contact when the relay is not energized. In either case, applying electrical current to the contacts will change their state. Relays are generally used to switch smaller currents in a control circuit and do not usually control power consuming devices except for small motors and Solenoids that draw low amps. Nonetheless, relays can "control" larger voltages and amperes by having an amplifying effect because a small voltage applied to a relays coil can result in a large voltage being switched by the contacts. Protective relays can prevent equipment damage by detecting electrical abnormalities, including overcurrent, undercurrent, overloads and reverse currents. In addition, relays are also widely used to switch starting coils, heating elements, pilot lights and audible alarms.

4.1.2 Electromechanical Relay

Basic parts and functions of electromechanical relays include:

1. **Frame:** Heavy-duty frame that contains and supports the parts of the relay.
2. **Coil:** Wire is wound around a metal core. The coil of wire causes an electromagnetic field.
3. **Armature:** A relays moving part. The armature opens and closes the contacts. An attached spring returns the armature to its original position.
4. **Contacts:** The conducting part of the switch that makes (closes) or breaks (opens) a circuit.

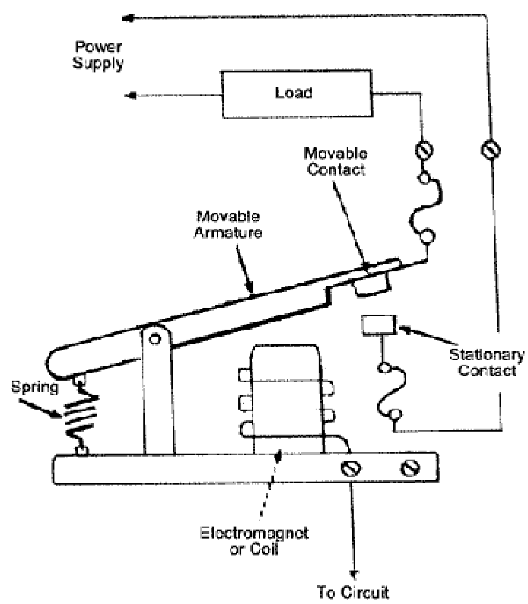


Fig. 4.2: Internal Structure of a Relay Circuit Board

We have used 8 electromechanical relays in our project. The relay circuit board that we have used is from techshopbd. It is a circuit board that contains 10 channel relay switches. The relay board activates using 12-volt power supply. And the relay switch becomes on or off by the 5-volt output from digital port of Arduino. The arduino controls the relay board and also sequentially controls the motor direction according to the command from the operator.

Fig. 4.3: 10 Channel Relay Circuit Board to Control the Motor

4.1.3 Microcontroller Board

Here for the controlling system we used an arduino board. Arduino is an open source microcontroller-based platform. Arduino is an open-source hardware and software company, project and user community that designs and manufactures single board microcontrollers and microcontroller kits for building digital devices and interactive objects that can sense and control both physically and digitally. Its products are licensed under the GNU Lesser General Public License (LGPL) or the GNU General Public License (GPL), permitting the manufacture of Arduino boards and software distribution by anyone. Arduino boards are available commercially in preassembled form or as do-it-yourself (DIY) kits.

4.1.4 Power Source

For the powering of relay switch board and the motor we used two 6-volt lead acid batteries. The relay board works at 12 volts. Or we can also say that the relay board switches activate at 12 volts. Both the 2 motors also work perfectly.

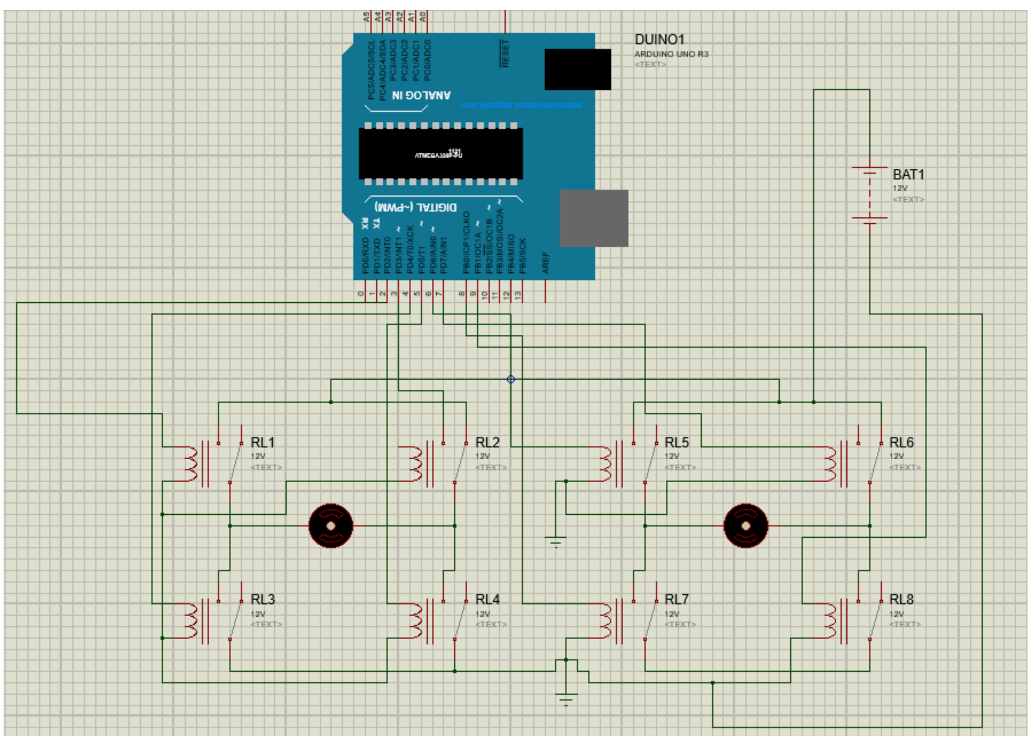
4.1.5.1 Electrical Circuit Design and Implementation

Here under this figure shown below we have designed a circuit using Proteous software. Using this software, we can design any type of circuit system. We designed and simulated the control system. The circuit can be divided into 2 parts-

1: Motor control

2: Taking reading from the sensors

Motor control:



Here from this figure we see that we have used a bridge motor controlling system and 8 output system. In this picture we see an arduino Uno. But actually, we used an arduino mega.

The pin configuration with the motor is given below

Relay 1 – Digital pin number 14

Relay 2 – Digital pin number 2

Relay 3 – Digital pin number 3

Relay 4 – Digital pin number 4

Relay 5 – Digital pin number 6

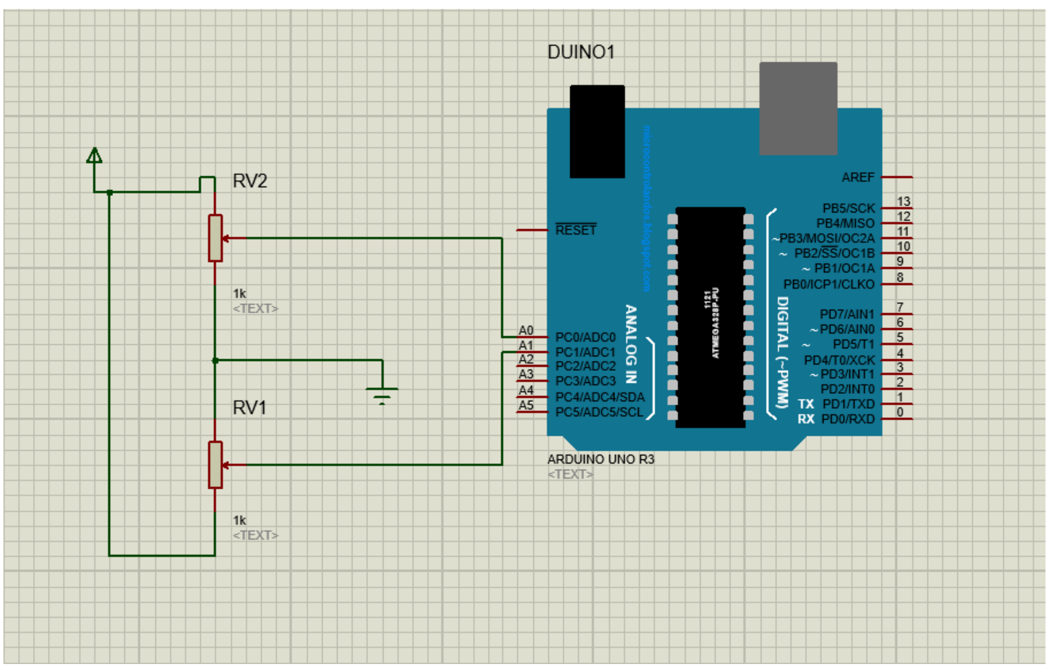
Relay 6 – Digital pin number 7

Relay 7 – Digital pin number 8

Relay 8 – Digital pin number 9

4.1.5.2 Command Control from The Operator

The user will have 2 nobs with him to control the 3rd hand. Both 2 nobs will be dedicated for the 2 motors. Here we have used the 2 potentiometers for the control from the operator. The circuit diagram specifically is given below for the 2 potentiometers.



4.1.5.3 Pin Configuration

Here the 2 sensors will be connected with the 2 analog inputs with the arduino. We know that a potentiometer is a variable resistor. So, for changing the position of the nob the resistance will change. As a result, in arduino analog input we can easily catch the changes.

Pin Connection:

Motor 1 controller potentiometer pin: Analog input 0

Motor 2 controller potentiometer pin: Analog input 1

4.1.5.4 Programming Code

We have used here arduino for controlling. The software is arduino ide. The code will be found in appendix.

4.2 Mechanical Components

Here in the mechanical part we have manufactured the structure from raw metal sheets. We have used some other parts also from the local scrap metal markets. The list of the parts is given below:

1. Metal sheets
2. Scrap metals
3. Pin joints
4. Screws, nut and bolts
5. Belts to attach the structure with the body
6. Ball joint
7. A bag to support the structure
8. Metal shafts
9. Ball joints
10. A box to hold the electric components, and also glue and clamps

Worm Geared Motor:

A worm drive is a gear arrangement in which a worm (a gear in the form of a screw) meshes with a worm gear. A worm drive reduces rotational speed or transmit higher torque. Worm gear drive units transfer motion in 90 degrees. The direction of transmission is not reversible in worm gear when using large reduction ratios. This is due to the greater friction involved between the worm and worm-wheel, and is especially prevalent when a single start (one spiral) worm is used. Worm gear configurations in which the gear cannot drive the worm are called self-locking. Whether a worm and gear are self-locking depends on the lead angle, the pressure angle, and the coefficient of friction.

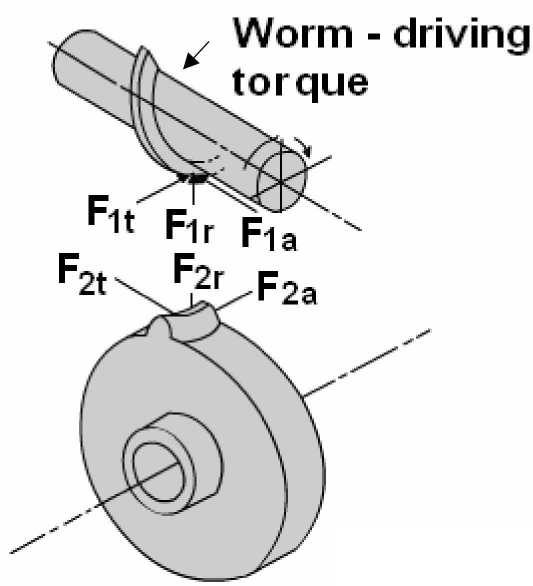


Fig. 4.4: Worm gear force analysis

The tangential, axial, and radial force components acting on a worm and gear are

illustrated in the Fig. For the usual 90° shaft angle, the worm tangential force is equal to the gear axial force and vice versa.

$F1t = F2a$

$F2t = F1a$

The worm and gear radial or separating forces are also equal,

$F1r = F2r$

If the power and speed of either the input or output are known, the tangential force acting on this member can be found from equation,

$F = 1000W/V$

In the Fig. 15.4, the driving member is a clockwise-rotating right-hand worm. The force directions shown can readily be visualized by thinking of the worm as a right-hand screw being turned so as to pull the “nut” (worm gear tooth) towards the “screw head”. Force directions for other combinations of worm hand and direction of rotation can be similarly visualized.

The operation of worm gear motors can be broken down into two stages. Essentially, an electric motor provides the power to rotate the worm or screw gear. As the worm gear turns, it also turns the main gear, allowing for motion and torque to be produced.

The first part of worm gear motors is the worm gear itself. This consists of a shaft with threading that spirals itself on the shaft. This worm gear is set into the splines of another gear. The rotational speed of the worm gear would in turn rotate the gear it is attached to. The second part of the motor, as the name suggests, is the motor. The motor is attached to the worm gear, turning it at different speeds depending upon the amount of torque produced by the main gear.

There are a number of reasons why worm gear motors work better than a standard gear motor. These are as follows:

- Reduction Ratio. With worm gear motors, the reduction ratio is quite huge. This means that a small turn of the worm gear can turn the main gear quite a distance. This can allow the user to either decrease speed and at the same time increase torque. The reduction ratio produced by worm gear motors is comparable to several stages of reduction in regular gears.
- Reverse Power. The strength of the worm gear motors lies is in its limitation in reversing power. Thus, the gear always moves in just one direction. This simplifies the whole set up without need for a backstop. In a standard gear set up, reversing the power would require a backstop, requiring more components in the machine.

Worm gear motors work by using a worm gear attached to a motor to move the main gear. This set up is ideal for a machine requiring a massive reduction ratio, meaning more torque for less speed. Secondly, the simplicity of the set up avoids the need for unnecessary gears in its operation.

5. Final Manufacturing

It took a huge time for us to do the modeling from the theory of mechanics and also develop a model from the theory. After the development of the model we have made the whole powered exoskeleton. We have followed some steps to do the final manufacturing process.

5.1 Manufacturing of the Legs

Manufacturing of the legs was the first part in our full manufacturing process. As the leg part will contain the whole structure so for it this part should be strong enough to contain the load. We have used stainless steel shaft. The leg can also be called a load carrying column.

We have to create a joint with both upper part and lower part of the column. Here for the structure of the legs first we have connected with the 2 joints using welding process.

Pin joints: A revolute joint (also called pin joint or hinge joint) is a one-degree-of-freedom kinematic pair used in mechanisms. Revolute joints provide single-axis rotation function used in many places such as door hinges, folding mechanisms, and other uni-axial rotation devices. (They do not allow translation, or sliding linear motion)

Universal joints: A universal joint (universal coupling, U-joint, Cardan joint, Spicer or Hardy Spicer joint, or Hooke's joint) is a joint or coupling connecting rigid rods whose axes are inclined to each other, and is commonly used in shafts that transmit rotary motion. It consists of a pair of hinges located close together, oriented at 90° to each other, connected by a cross shaft. The universal joint is not a constant-velocity joint.

Fig. 5.1: Lower Part of Exoskeleton

We have used universal joints in our project. For some condition we used this. As universal joints are more flexible.

Ball socket joint: At the starting of the leg we have used a ball socket joint. In our skeleton the starting point of the leg and the body is also formed with ball socket joint. There are some reasons for us to use this ball socket joint.

Modern medium and heavy-duty ball and socket joints may use the ball housing itself as the half socket formed around the neck of the ball pin. The other half socket which bears against the ball end of the ball pin is generally made from oil impregnated sintered iron, another type designed for automatic chassis lubrication, an induction hardened pressed steel half socket, is employed. Both cases are spring loaded to ensure positive contact with the ball at all times. A helical (slot) groove machined across the shoulder of the ball ensures that the housing half socket and ball top face is always adequately lubricated and at the same time provides a bypass passage to prevent pressurization within the joint.

Ball and socket joints for light and medium duty. To reduce the risk of binding or seizure and to improve the smooth movement of the ball when it swivels, particularly if the dust cover is damaged and the joint becomes dry, non-metallic sockets are preferable. These may be made from molded nylon and for some applications the nylon may be impregnated with Molybdenum Disulphide. Polyurethane and Teflon have also been utilized as a socket material to some extent. With the nylon sockets the ball pin throat half socket and the retainer cap is a press fit in the bore of the housing end float. The coil spring accommodates initial settling of the nylon and subsequent wear and the retainer cap is held in position by spinning over a blip on the housing. To prevent the spring loaded half socket from rotating with the ball, two shallow tongues on the insert half socket engage with slots in the floating half socket. These ball joints are suitable for light and medium duty and for normal road working conditions have an exceptionally longer service life.

5.2 Manufacturing of Foot

We have used a metal plate for the manufacturing process.

5.3 Manufacturing of the 3rd Hand

The 3rd hand that we used here was a motor-based system. Previously we have explained about the motor system. We have added a shaft to make the structure of the hand and also used screws and nut and bolt system for the attachment with the lower part exoskeleton.

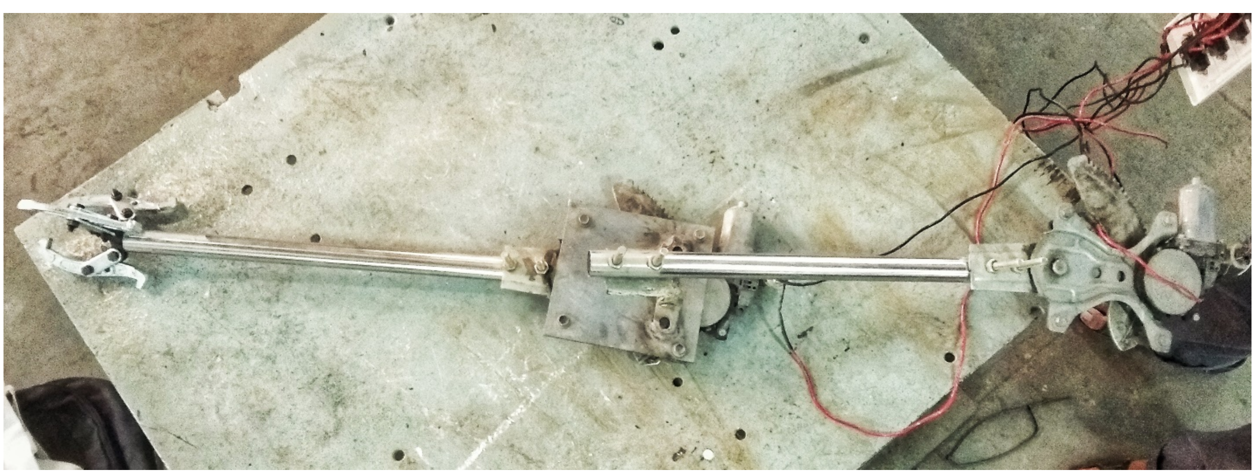


Fig. 5.2: Upper Part of Exoskeleton

6. Results

The integration of human and robot into a single system offers remarkable opportunities for a new generation of assistive technology. Despite the recent prominence of upper limb exoskeletons in assistive applications, the human arm kinematics and dynamics are usually described in single or multiple arm movements that are not associated with any concrete activity of daily living. Moreover, the design of an exoskeleton, which is physically linked to the human body, must have a workspace that matches as close as possible with the workspace of the human body, while at the same time avoid singular configurations of the exoskeleton within the human workspace. The aims of the research reported in this manuscript are to study the kinematics and the dynamics of the human arm during daily activities in a free and unconstrained environment, to study the manipulability of a 7-degree-of-freedom powered exoskeleton arm given the kinematics and the dynamics of the human arm in ADLs. Kinematic data of the upper limb were acquired with a motion capture system while performing 24 daily activities from six subjects. Kinematic and dynamic analyses may provide a fundamental basis towards the development of assistive technologies for the human arm. With the help of our project we are finally able to give the user extra strength which will allow him or her to pick and move objects which are beyond his capable limit.

7. Limitation and Future Development

Even though we have succeeded in transferring the load to ground, our project has some limitations. Those are –

a) The exoskeleton is quite heavy. This is because of using comparatively mild steel in components. This limitation can be overcome by using lighter materials like carbon fiber.
b) Response from the motors are quite delayed. This caused because of imprecise calculation of time required by the arduino to measure the value of potentiometer voltage. By running some iterations and using better microcontroller this situation can be overcome.
c) Various sensors for measuring heart rate, temperature etc. of the worker can be added to the system. This will help to monitor worker's health condition in check. It can give a warning prior to any health condition the worker may face.
d) The design of our exoskeleton isn't much user-friendly because we used spare parts from the local market. If custom made parts can be used in the structure, it will be more user-friendly.

8. Conclusion

Powered exoskeletons are becoming more and more impactful in industries and medical science. The exoskeleton technology has been wide-spreading in the industrial and manufacturing framework over the last decades. Workers are heavily exposed to physical workload due to lifting tasks, repetitive movements, and non-ergonomic postures. Wearable powered exoskeleton has the potential to lower the physical effort of workers and to decrease the occurrence of back pain and injuries. It will also provide more ease, comfort, longer working time and continuous repetitive working compared to manual handling, holding and lifting. However, there are a large number of technological challenges to build an exoskeleton that is capable of quick movements. Power sources with sufficient energy density isn't very common. The skeleton material is heavy which reduces efficiency. Flexibility of the human anatomy is another issue. It is tough for exoskeleton to exactly match human motions with the existing ball joint and hinge points. If these issues are solved, powered exoskeletons can contribute to the evolution of industrial work environment and lead to a better energetics and control.

9. Reference

[1] Aaron M. Dollar, Hugh Herr, "Design of a Quasi-Passive Knee Exoskeleton to Assist Running," 2008 IEEE/RSJ International Conference on Intelligent Robots and Systems, 14 October 2008

[2] Kazuo Kiguchi, Koya Iwami, Makoto Yasuda, Keigo Watanabe, Toshio Fukuda, "An Exoskeletal Robot for Human Shoulder Joint Motion Assist", DOI:10.1109/TMECH.2003.809168, 2003

[3] Mathew C. Ryder, "A Continuous Rotary Actuation Mechanism for A Powered Hip Exoskeleton.", Masters Theses, 22nd January, 2015

[4] Matthew M. Williamson, "Series Elastic Actuators," 1995

10. Appendix

Arduino Code for Controlling Exoskeleton:

```
int recent1,recent2;
int rl1=14;
int rl2=2;
int rl3=3;
int rl4=4;
int rl5=6;
int rl6=7;
int rl7=8;
int rl8=9;
int pot1=A0;
int pot2=A1;
void setup ()
{
 Serial.begin (9600);
 pinMode (pot1,INPUT);
 pinMode (pot2,INPUT);
 pinMode (rl1,OUTPUT);
 pinMode (rl2,OUTPUT);
 pinMode (rl3,OUTPUT);
 pinMode (rl4,OUTPUT);
 pinMode (rl5,OUTPUT);
 pinMode (rl6,OUTPUT);
 pinMode (rl7,OUTPUT);
 pinMode (rl8,OUTPUT);
}
void loop ()
{
 int val1=analogRead(pot1);
 int val2=analogRead(pot2);
 //Serial.println (val1);
 Serial.print ("Difference = ");
 Serial.print (val1-recent1);
 Serial.print (" Value1 = ");
 Serial.print (val1);
 Serial.print (" Recent1 = ");
 Serial.println (recent1);
 Serial.println ();
 if (abs(val1-recent1)>=5)
 {
 if (val1>recent1)
 {
  Serial.println ("bingo");
  digitalWrite (rl1,HIGH);
  digitalWrite (rl4,HIGH);
  digitalWrite (rl2,LOW);
  digitalWrite (rl3,LOW);
 }
```

```
else if (val1<recent1)
{
  digitalWrite (rl2,HIGH);
  digitalWrite (rl3,HIGH);
  digitalWrite (rl1,LOW);
  digitalWrite (rl4,LOW);
}
}
 else
{
  digitalWrite (rl2,LOW);
  digitalWrite (rl3,LOW);
  digitalWrite (rl1,LOW);
  digitalWrite (rl4,LOW);
}
///// for sensor 2
Serial.print ("Difference = ");
Serial.print (val2-recent2);
Serial.print (" Value2 = ");
Serial.print (val2);
Serial.print (" Recent2 = ");
Serial.println (recent2);
Serial.println ();
 if (abs(val2-recent2)>=5)
{
if (val2>recent2)
{
  Serial.println ("bingo");
  digitalWrite (rl5,HIGH);
  digitalWrite (rl8,HIGH);
  digitalWrite (rl6,LOW);
  digitalWrite (rl7,LOW);
}
else if (val2<recent2)
{
  digitalWrite (rl6,HIGH);
  digitalWrite (rl7,HIGH);
  digitalWrite (rl5,LOW);
  digitalWrite (rl8,LOW);
}
}
 else
{
  digitalWrite (rl5,LOW);
  digitalWrite (rl6,LOW);
  digitalWrite (rl7,LOW);
  digitalWrite (rl8,LOW);
}
recent1=val1;
recent2=val2;
delay (500);}
```