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# Exoskeleton

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***Abstract:--*** **Exoskeletons are a feature of some of the world's strongest creatures. An Exoskeleton is the stiff covering on the outside of some creatures like the arthropods like scorpions and crustaceans. Having a hard covering on the outside in the form of an exoskeleton is a great defence against external threats. Just like the natural exoskeletons protect some of these animal's soft, inner organs from injury, artificially powered exoskeletons have also been incorporated into human lives to provide an excellent survival strategy. An exoskeleton is the external skeleton that supports and protects an animal's body, in contrast to the internal skeleton (endoskeleton) of, for example, a Human. In usage, some of the larger kinds of exoskeletons are known as "shells". Examples of exoskeleton animals include insects such as grasshoppers and cockroaches, and crustaceans such as crabs and lobsters, snails, clams, tusk shells, chitons and nautilus, are also exoskeletons.**

## I. INTRODUCTION

The earliest exoskeleton-like device was a set of walking, jumping and running assisted apparatus developed in 1890 by a Russian, named Nicholas Yagn. The first true exoskeleton in the sense of being a mobile machine integrated with human movements was co-developed by General Electric and the United States military in the 1960s. The suit was named Hardiman, and made lifting 250 pounds (110 kg) feel like lifting 10 pounds (4.5 kg). Powered by hydraulics and electricity, the suit allowed the wearer to amplify their strength by a factor of 25, so that lifting 25 pounds was as easy as lifting one pound without the suit. A feature dubbed force feedback enabled the wearer to feel the forces and objects being manipulated.

## II. HISTORY

The earliest exoskeleton-like device was a set of walking, jumping and running assisted apparatus developed in 1890 by a Russian named Nicholas Yagn. As a unit, the apparatus used compressed gas bags to store energy that would assist with movements, although it was passive in operation and required human power. In 1917, US inventor Leslie C. Kelley developed what he called a pedomotor, which operated on steam power with artificial ligaments acting in parallel to the wearers movements. With the pedomotor, energy could be generated apart from the user.

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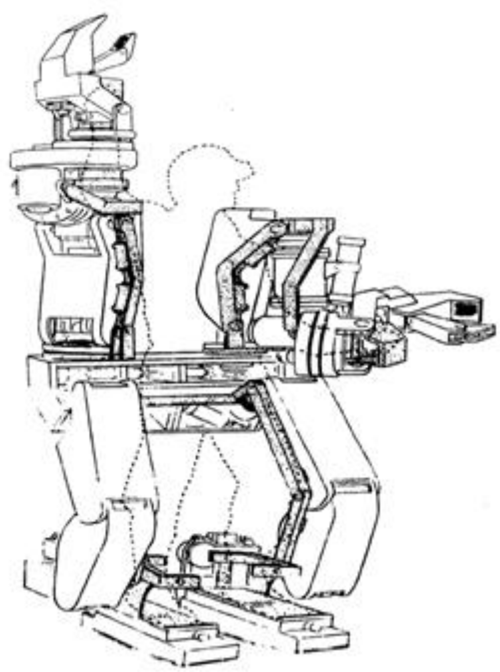

***Fig 1: Exoskeleton***

While the general idea sounded somewhat promising, the actual Hardiman had major limitations. It was impractical due to its 1,500-pound (680 kg) weight. Another issue was the fact it is a slave-master system,

 

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where the operator is in a master suit which is in turn inside the slave suit which responds to the master and takes care of the work load. This multiple physical layer type of operation may work fine, but takes longer than a single physical layer.

When the goal is physical enhancement, response time matters. Its slow walking speed of 2.5 ft. /s further limited practical uses. The project was not successful. Any attempt to use the full exoskeleton resulted in a violent uncontrolled motion, and as a result it was never tested with a human inside. Further research concentrated on one arm. Although it could lift its specified load of 750 pounds (340 kg), it weighed three quarters of a ton, just over twice the lift able load. Without getting all the components to work together the practical uses for the Hardiman project were limited.

## III. NEED FOR EXOSKELETON

- Exoskeletons provide external rigidity and support for the being inside so as to protect them from any harm.
- The same concept is applied to powered exoskeletons to support and magnify the physical abilities of a being.
- They reduce muscle fatigue of the operator and thus increase their working efficiency.
- They use a complex arrangement of structures incorporated with high torsion servos or hydraulics.
- To augment human economy, strength and endurance.
- To overcome human disability and induce performance.
- To save time from using semi heavy machineries.
- To enhance defence capabilities of a country or individuals.
- To enable faster response during disasters and enabling difficult rescue missions.

## IV. COMPONENTS OF EXOSKELETON

- Force multiplying skeletal metal structure with joints and linkages.
- Servos and motors.
- Tactile and proximity sensors.
- Sustainable power source.
- Tensile and compressive force storing devices like hydraulics.
- Actuators.
- On board computer.

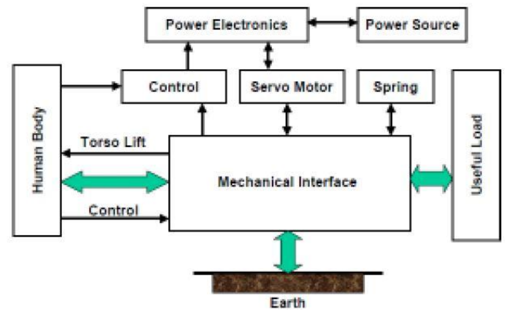


*Fig 2. Block Diagram of components of exoskeleton*

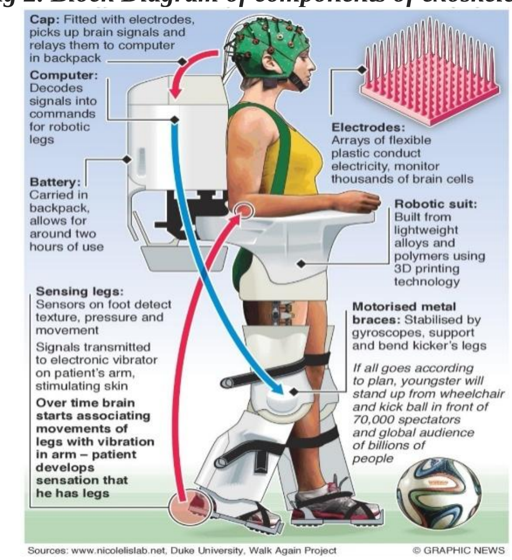


*Fig 3 Scheme of components of exoskeleton*

### *4.1 Materials for Exoskeletons*:

To construct an exoskeleton, engineers will need lightweight materials that can withstand large forces. Materials like steel and aluminum have specific strength of around 100 to 250 kNm/kg while fiberglass is around 1,300 kNm/kg. Carbon fiber offers specific strengths of over 2,400 kNm/kg new technologies, such as carbon nanotube, exceed 40,000 kNm/kg with a tensile strength of 62 GPa. However, much higher strengths might be possible as carbon nanotubes have a theoretical tensile strength of 300 GPa Cyber dyne's HAL uses carbon fiber legs, and many other companies use carbon fiber for their suits.New processes and technologies are focusing on cutting weight while increasing strength and mass production.

### *4.2 Power and Drives:*

To make a viable exoskeleton, engineers need motors or some other actuators that function quickly to prevent interference with the user's natural motions. Hydraulics seems like a good way to gain mechanical advantage. Lockheed Martin, for example, has used them

in its Human Universal Load Carrier suit.Today, hydraulics can provide the desired exosuit's characteristics with opener closed loop control. Using both gives users hard set variables (open loop) and dynamic variables (closed loop) that adjust as needed.
Electric actuators, another good option, offer features such as variable speed and efficient operation. They are also becoming more "intelligent," thanks to the addition of sensors, microprocessors, and software.

Although hydraulics looks like the most common drive for exoskeletons, some designers still use electric actuators. Many engineers use both to better combine synthetic and natural motion. With technology becoming increasingly mobile, battery density has increased over the last decade. In 2007, for example, batteries with an energy density of 600 Wh/L cost about $1,000/kWhr. By 2013, density had gone to 1,400 Wh/L at a cost of $300/kWhr.

The higher a battery's voltage, the shorter its life span tends to be. To sidestep this conundrum, engineershave developed higher capacity electrodes and anodes. They've also devised better chemistries forbatteries. Lithium ion cells, For example, have the highest specific capacity (3,860 mAh/gm). But there aresafety concerns about lithium batteries' charging/discharging cycles. They suffer from thermal runawayand could cause fires. New carbon Nano composites are helping isolate the lithium deposits that build up onthe electrode and cause this instability.

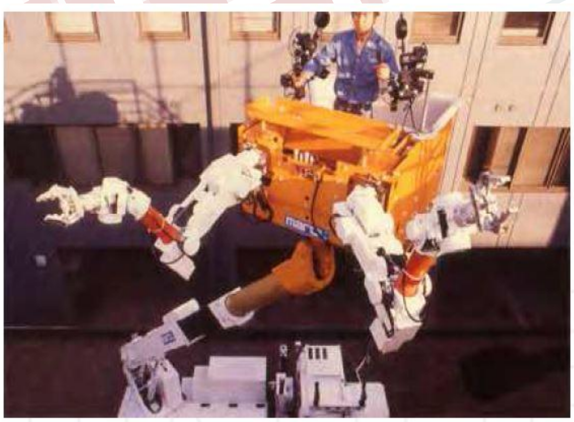

*Fig 4. Power and Drives*

## V. WORKING

- ♣ The user initiates the action by moving the particular body part
- ♣ The sensors detect the movement and send the signal to the on board CPU
- ♣ The CPU processes the data received and verifies it with the validity of other sensors
- ♣ The processed signal is then sent to the actuators that are responsible for moving the desired link
- ♣ The link(s) are moved via different energy storing devices or by hydraulics & pneumatics.
- ♣ The amount of energy used by the user is multiplied by the suit and he/she is able to perform heavy tasks with ease.

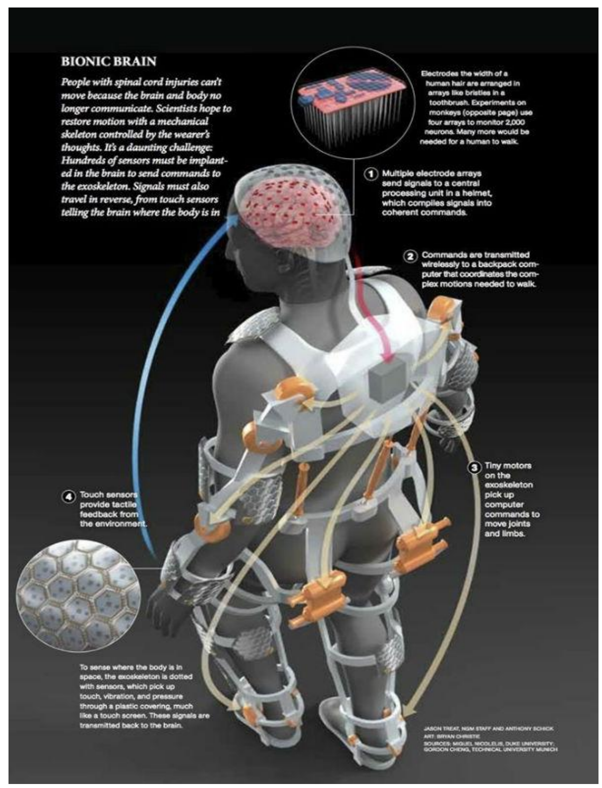


*Fig 5. Working of bionic brain*

## VI. APPLICATIONS

The powered exoskeletons have been tested for years and put into use in several fields, which are as follows:

1. Military
2. Medical
3. Industrial

4. Disaster management

### 6.1 Military & Law Enforcements

- Soldiers often have to hike extended distances while carrying heavy packs and equipment.
- This lightweight exoskeleton takes on some of that weight, reducing the burden on a soldier's body.
- It uses a system of powered cables to provide mechanical assistance, adding carefully timed pulling forces to natural movements so that the user's own muscles expend less energy.

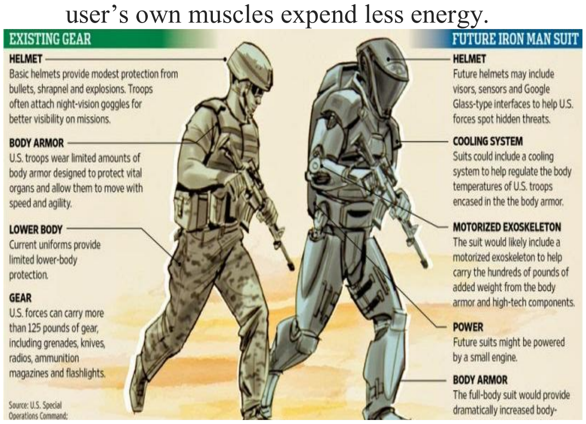


*Fig 6. Brief Military Application*

### 6.2 Disaster Management

These exoskeletons perform agile and heavy duty tasks to prevent or protect human lives in case of natural calamities like earthquake or wild fires.They are specially equipped with specific tools for specific type of disasters. For ex Firefighting EXOS (in pic)

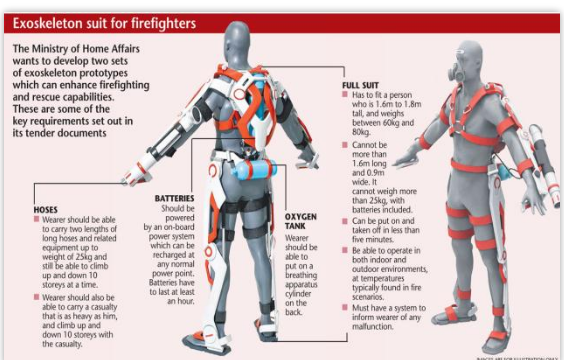


*Fig 7. Brief Disaster management application*

### 6.3 Physical Disability

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. Also training could be more uniform, easier to analyse retrospectively and can be specifically customized for each patient. At this time there are several projects designing training aids for rehabilitation centres (LOPES exoskeleton, Lokomat, ALTACRO, CAPIO and the gait trainer, Hal 5.)

*Fig 8. Medical application*

### 6.4 Construction technology

Up to now, automation and robotic technology has been applied in construction mainly for processing raw materials and production of building parts and building modules. Parts and modules had to be prefabricated in a structured and standardized environment for a safe and robust operation of the robots. In unstructured and not-standardized environments as on the construction site or in service environments, autonomous humanoids or service robots were difficult to operate. However, robot technology advances. Scientists as e.g. T. Hasegawa find ways to structure environments for robots and also cognition and control technology become more advanced. Shimizu Corporation, a big Japanese construction company, cooperates with Yasukawa Electric Corporation, Kawada Industries and the national research institute AIST for introducing Humanoid robots to construction work for more than eight years already. It has already been shown that humanoid robots as HRP-2 can carry a joinery bench together with a construction worker, fit an interior wall, and drive forklifts or diggers. Groups of HRP-2s can cooperate; move over a gradient of around five degrees and compensate for up to two centimetres on uneven surfaces. They can straighten up themselves when they fall over. When carrying a component with a human, they use an adaptive and flexible arm system. An image processing system with a mobile portable control system has been developed to allow location detection. When the robots move over uneven surface, a force sensor in the sole of the foot and a balance sensor in the body register the difference and so, the sole of the foot can adapt to the surface.

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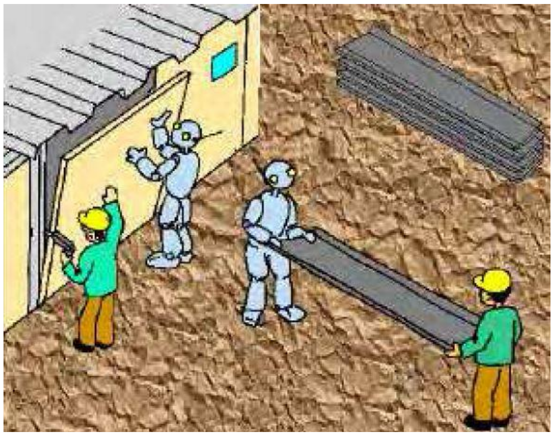

*Fig 9. Constructional Application*

***6.5 Industrial Applications***

They bring new capabilities to managing load and improve endurance and safety in industrial settings.

The lightweight suits are designed to increase in industrial productivity and can prevent common workplace injuries.

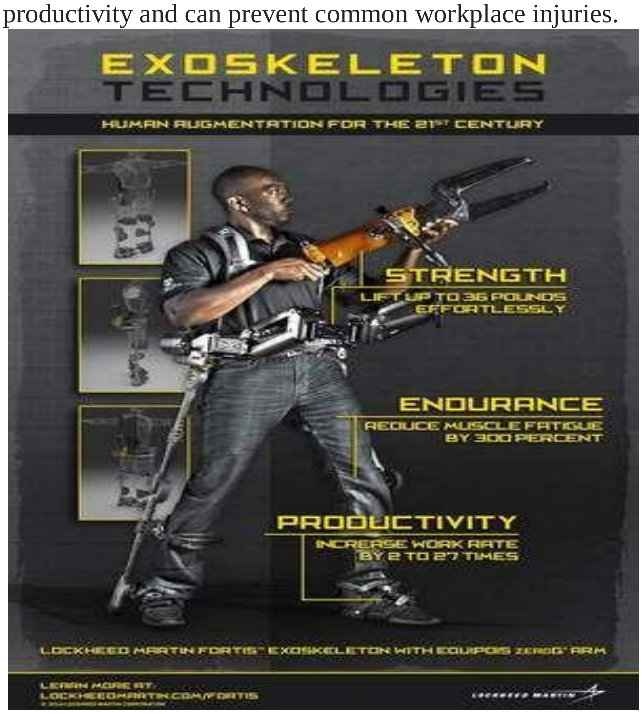


*Fig 10. Industrial application*

## VII. AVAILABLE PROTOTYPES

DARPA DEFENSE ADVANCED RESEARCH PROJECTS AGENCY

***DARPA:***

The Defense Advanced Research Projects. The Defense Advanced Research Projects Agency (DARPA) is an agency of the U.S. Department of Defense responsible for the development of emerging technologies for use by the military. Its purpose was to formulate and execute research and development projects to expand the frontiers of technology and science, with the aim to reach beyond immediate military requirements.

***Cyber dyne HAL 5:***

The Hybrid Assistive Limb (also known as HAL) is a powered exoskeleton suit developed by Japan's Tsukuba University and the robotics company cyber dyne. It has been designed to support and expand the physical capabilities of its users, particularly people with physical disabilities.The first cyborg-type wearable robot allows the wearer to lift 10 times as much as they normally could. HAL 5 is currently in use in Japanese hospitals, and was given global safety certification in 2013.

*FIG 11. Cyberdyne HAL 5.*

Raytheon's Sarcos XOS 2: XOS 2 is a second-generation robotics suit being developed by Raytheon for the US Army 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. ReWalk Personal 6: ReWalk is a commercial bionic walking assistance system that uses powered leg attachments to

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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. Designed in Yokneam, Israel, by Amit Goffer The Bionic Boot: Bionic boots let you run as fast as a CAR: Springy shoes mimic ostrich's gait to let you travel at up to 25 miles per hour. Prototype developed by San Francisco-based inventor Keahi Seymour shoes have springs on the back that imitate Achilles tendon of an ostrich. The springs provide the wearer with more reaction force when running.

*Fig 12. Carbon fiber exoskeleton*


*Fig 13. Steel Composite exoskeleton*

## VIII. DEVELOPMENT- THE RISE OF THE EXOSKELETONS

Trends in sensors, power supplies, batteries, and other technologies are bringing even more potential to the field of developing exoskeletons. Engineers relied heavily on motion control technology to develop the first wearable exoskeleton at Cornell University, the Hardiman1, in 1965. The arms, legs, and feet used electrohydraulic servos, while a hydro mechanical servo controlled the hands. The hydraulics operated off of a 3,000psi pump, letting the person in the suit lift up to 1,500 lb. and walk at 1.7 mph. The suit itself, however, weighed almost 1500 pounds, making it too heavy and complex to warrant further funding.

Since then, sensors, materials, drives, and power supplies have undergone a host of incremental innovations. Companies developing exoskeletons no longer find it difficult to secure funding. Investors recognize that this technology has many potentially profitable applications. These include letting soldiers carry more weight for longer periods of time, aiding senior citizens and others who suffer musculoskeletal injuries, and giving longshoremen and warehouse workers a competitive advantage in the shipping and trucking industries.

### *8.1 Advancing the Sensor:*

The human body constantly senses its surroundings and itself to react properly in a wide variety of environments. A constant exchange of information flows between the sense organs, muscles, and brain. Similarly, exoskeletons require a flow of data between sensors and central processor.

Many types of sensors would be required for such a complex machine, and they would have to be small, efficient, and economical. Fortunately, the trends in sensors are in line with those needs. For example, the Nintendo Wii game controller was introduced with a new accelerometer from ST Microelectronics that was smaller, more sensitive, and demanded less power than previous designs. It was also developed with high volume production in mind. The silicon wafer from which ICs for the accelerometer was increased from 4 inches in diameter to 8 inches, allowing more "chips" to be made at once. The size of each sensor was also reduced with a new micro surfacing process that made it possible for ST Microelectronics to make lots of accelerometers for just a few dollars per sensor. "The Wii controller grabbed the attention of cell phone companies," said Tony Massimini, CTO of Semico Research. "They realized sensors could

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add value while maintaining a competitive production cost."

The digital frontier was beginning to take hold at this time and it was necessary to develop the ability to communicate between digital and analog components. One of the ways that was done was with sensors called MEMS (microelectricalmechanicalsystems). They generally range from 0.02mm to 1.0mm in size, but include electromechanical components ranging from 0.001 to 1.0mm. The development of MEMS has resulted in countless innovations and improvements in sensor technology.

For example, ST's MEMS digital and analog accelerometers can detect up to ±400*g*, and measure 2 x 2 x 1 mm. The Kinetis KL02 from Freescale Semiconductor measures less than 2 x 2 x 0.6 mm, while the VL6180X module from STS measures 4.8 x 2.8 x 1.0 mm is an optical sensor that accurately measure distances up to 10 cm.

| A GENERAL COMPARISON OF ACCELEROMETERS FROM 2004 TO TODAY | | |
|---|---|---|
| Accelerometers | 2004 | Today |
| Size | 5 x 5 x 1.8 mm | 2 x 2 x 1.7 |
| Current | 4000 micro-amps | 100 micro-amps |
| Volt | 5 V | 1.8 V |
| Cost | +$2 per sensor in bulk order | $0.30 per sensor in bulk order |

***Fig 14. Comparison of Accelerometers***

### *8.2 Developments and Markets*

Lockheed Martin says advancements in motion control are driving factors in exoskeleton development, especially improved hydraulics, and electromyographic (EMG) control, which lets patients control electronics by contracting and relaxing specific muscles. Advances in EMG allow the machine to get ahead of the human in the control loop, thereby reducing lag and the associated metabolic cost of tightening and releasing muscles.

The main problem with EMGs is that it can be difficult to translate their analog frequencies to a drive or digital system. A muscle pulse wavers and can even switch polarity. Rectification, pulse width modulation, and algorithms are used to "smooth" these signals.

EMG electrodes have been made more sensitive and capable of detecting faint electric pulses through the skin. This is leading defense contractors to work on controls in which human pilots interact with computersto control aircraft by flexing muscles. This technology has caught the eyes of computer gaming companies.

YEI Technology, for example, recently introduced PrioVR, a fullbody EMG suit. The company's goal is to have it to market for under $400, and an upper body suit for under $270. The equipment could control a video character or an exoskeleton. ReWalk built an exoskeleton that received FDA approval to be sold as the first motorized device that will act as an exoskeleton for people with lower body paralysis due to spinal cord injury. And in 2009, cyber dyne said it would build 400 of its Hybrid Assistive Limb suits per year and license them to hospitals for$2,000/month for rehab. Three years later, 130 medical institutions were using it. There are also severalrobotic companies designing and prototyping exoskeletons that could prevent debilitating muscle injuries,the most common type of on-the-job injury.

In 2011, injuries caused by lifting, pushing, pulling, holding, and carrying costs businesses $14 billion, which was up from $8 billion just two years prior to that in 2009. These injuries and costs are driving the need forexoskeletons that serve as lift assistance devices. Another factor driving demand for exoskeletons is the price of fuel. Although gasoline prices are currently low and going lower, higher prices will likely return. This could lead to more U.S.based shipping lines. To stay competitive, longshoremen wearing exoskeletons could be used to load and unload cargo withoutundue exhaustion or injury.

Shipping and global competition will make exoskeletons necessary, according to Sean Petterson, CEO of Strong Arm Technologies. Many companies, including Strong Arm Technologies, are working on passive andsoft exoskeletons to promote proper posture and form for lifting. With modern materials, some of thesedevices, like Arm Strong Technology's V22, weigh only a few pounds but can lift hundreds. In September 2014, Defense Advanced Research Project Association gave $2.9 million to researchers at Harvard to develop soft exoskeletons that are comfortable enough to be worn under clothing and reduceexhaustion and injury associated with walking long distances carrying up to 100 lb.

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However, costs and design limitations could hamper progress in this area, according to the *Journal of Mechanical and Civil Engineering* published information on associated design restraints, and costs thatmight stand in the way of exoskeleton development. Despite these hurdles, the report notes that with 3Dprinting and rapid prototyping, exoskeletons might soon be a reality.

## IX. CHALLENGES IN DEVELOPMENT

Although the powered exoskeletons have been introduced in our lives to make life easy and efficient, they still lack in certain aspects:

- Insufficient power supply
- Low power to weight ratios
- Weak actuators
- Economic inefficiency

A Sustainable and Portable Battery Pack: Present Non-rechargeable primary cells tend to have more energy density and store it longer than rechargeable secondary cells, but then replacement cells must be transported into the field for use when the primary cells are depleted, of which may be a special and uncommon type. Internal combustion engine power supplies offer high energy output, but they also typically idle, or continue to operate at a low power level sufficient to keep the engine running, when not actively in use which continuously consumes fuel.

Electrochemical fuel cells such as solid oxide fuel cells (SOFC) are also being considered as a power source since they can produce instantaneous energy like batteries and conserve the fuel source when not needed. However they require high temperatures to function; 600 °C is considered a low operating temperature for SOFCs.

Structure and joint mechanisms: Experiments are commonly done using inexpensive and easy to mould materials such as steel and aluminium.However steel is heavy and the powered exoskeleton must work harder to overcome its own weight in order to assist the wearer, reducing efficiency. The Aluminium alloys used are lightweight, but fail through fatigue quickly; it would be unacceptable for the exoskeleton to fail catastrophically in a high-load condition by "folding up" on itself and injuring the wearer.Several human joints such as the hips and shoulders are ball and socket joints, with the Centre of rotation inside the body. It is difficult for an exoskeleton to exactly match the motions of this ball joint using a series of external single-axis hinge points, limiting flexibility of the wearer.

## X. CONCLUSION-THE FUTURE OF EXOS

Mind walker by European Commission – A mind controlled exoskeleton for disabled US government's 2030 initiative -Future Soldier & Super Soldier It is a fantastic time for the field of robotic exoskeletons. Recent advances in actuators, sensors, materials, batteries, and computer processors have given new hope to creating the exoskeletons of yesteryear's science fiction. A better understanding of the physical human-exoskeleton interface is needed to improve the performance of human augmentation devices. A novel exo-interface could significantly increase load-bearing capabilities while reducing migration. Innovations in how we physically couple to the body have the potential for broad applications, and could enable transformative advances in human augmentation technology.

Most of the work related to the development of exoskeletons will likely focus around the following technological issues such as power supply, controls, actuation system, and transmissions. Providing solutions to these problems will help in developing a very efficient but having low-mass exoskeletons. Recent advancements in sensor, actuator, and microprocessor technologies could bring about future exoskeletons, like the one use in ambulatory, that do not require the use of the external balancing aids.

 