Robotics and Control: Theory and Practice
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Lecture – 25
Robotic Exoskeletons: An Introduction

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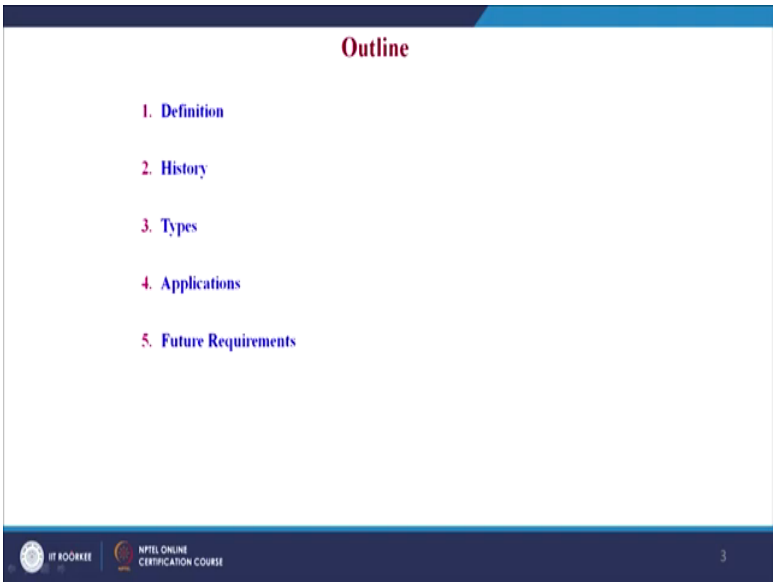

Good afternoon. Today, my topic of my lecture is on Robotic Exoskeletons, an Introduction. The organization of today's lecture will be as follows.

So, first we have the definition of exoskeletons then we move on to the definition of robotic exoskeletons. Then, we come to the historic perspectives of exoskeletons till today and then we see the classification of exoskeletons based on power, mobility and which part of the body is activated. Accordingly, we have classified the exoskeletons, then the application of

exoskeletons and finally, we come to the conclusion involving the future requirements of robotic exoskeletons.

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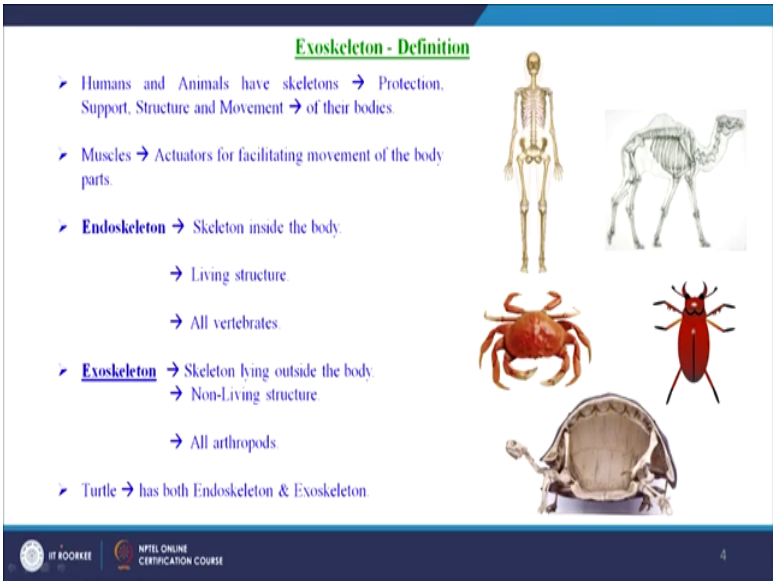

Coming to the exoskeleton definition, what is an exoskeleton? Humans and animals have skeletons for the sake of for the purpose of protection, support, structuring and movement of their body parts. Here the muscles in their bodies acts as actuators for facilitating movement of their body parts. The muscles are connected to the skeletons through tendons and thereby the movement of the skeletons happen.

Now, coming to the definition of endoskeleton, the skeleton part which is present inside the body is called endoskeleton. These endoskeletons are the living structures which grow along with the growth of the body. And, what are all the living beings which have endoskeleton? All vertebrates will have the endoskeleton.

And, now coming to the definition of exoskeleton, the skeleton part which is lying outside the body is called exoskeleton and it is a non-living structure. And, it will not grow along with the body and after some growth it sheds off from the body. And, all arthropods have the exoskeleton as you can see in the schematic.

We have the human being or the animal have the endoskeleton, where the crab and the insect have the exoskeleton alone. Whereas, the turtle is the only living being which has both the endoskeleton and the exoskeleton as you can see in the schematic which is the exoskeleton and we have the endoskeleton the bony structure inside the turtle body.

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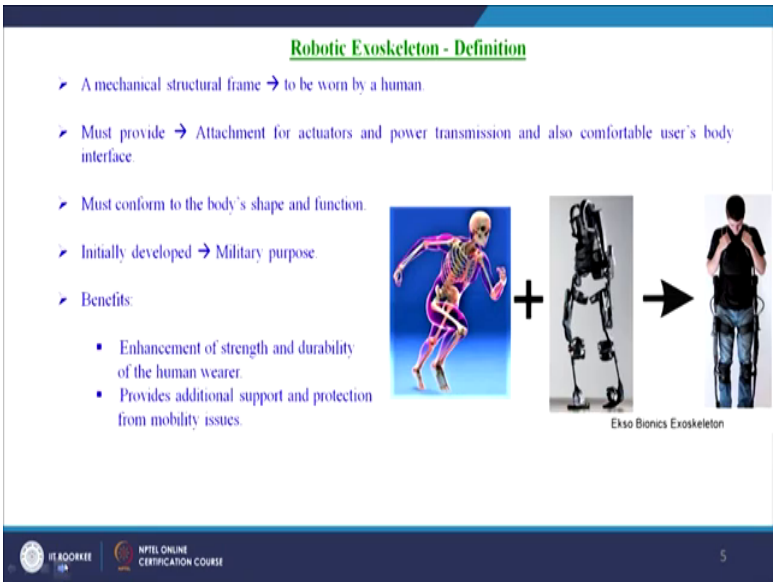

Now, coming to the definition of robotic exoskeleton, it is a mechanical structural frame to be worn by the human being for the sake of protection and support or power augmentation purpose. It must provide the exoskeleton structure must provide the attachment for actuators,

senses and for power transmission and also must be comfortable for the users body interface with the environment. It must conform to the shape of the body and also the function of the human body and the exoskeleton has been first initially developed for the purpose of military applications.

What are the benefits of exoskeleton? It is meant for the enhancement of strength and durability of the human wearer and it also provides additional support and protection from mobility issues. If the human being is not able to walk with the heavy weight the exoskeleton must be worn by this human operator, so that he can easily walk with that heavyweight in an upslope as well or in an uneven terrain as well.

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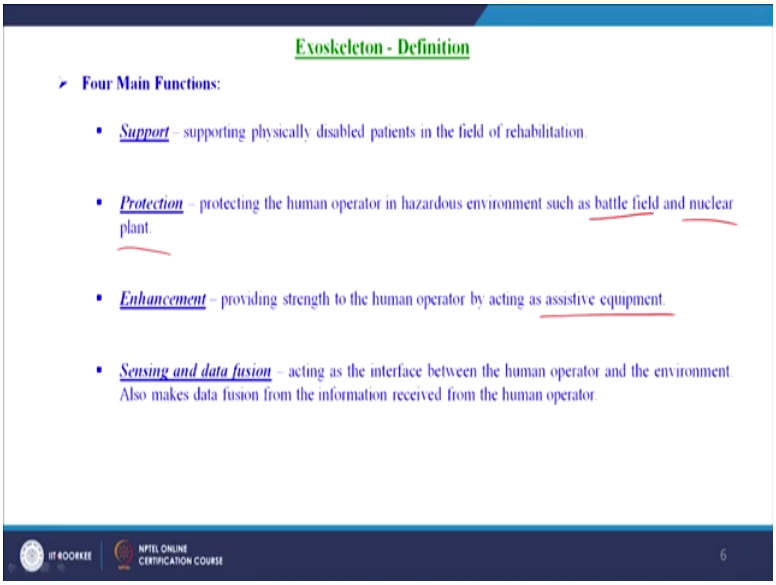

Now, coming to the main four functions of the exoskeleton; the first one being the support, it is supporting the physical physically disabled patients in the field of rehabilitation. In the field

of treatment it is helpful for the supporting purpose. Next comes the protection: protecting the human operator in hazardous environments such as the battlefield or a nuclear power plant.

And, then the enhancement – it is meant for augmenting the human operative strength by acting as an assistive equipment. And, finally, the fourth main function is on sensing and data fusion. It acts as the interface between the human operator and the environment and also makes data fusion from the information received from the human operator.

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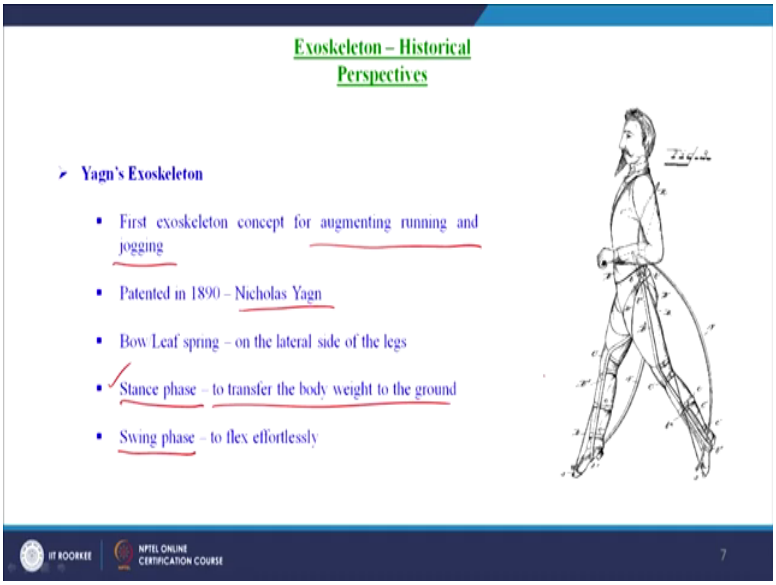

Now, coming to the historical perspectives of the exoskeleton – the first exoskeleton has been patented by Nicholas Yagn in the year 1890, and it was basically the conceptual of exoskeleton. So, this is for augmenting running and jogging. This is basically to bow leaf spring attached on the lateral surfaces or on the lateral sides of the legs two legs, so that in the stands face the exoskeleton spring is helpful to transfer the body weight to the ground.

So, that the user cannot have to weight have to undergo the weight of the body and in the swing face the exoskeleton concept helps to flex effortlessly, that is, in the stance phase it is helpful to transfer the body weight to the ground and in the swing face the swinging leg will be flexed naturally without any effort by this spring based or leaf spring based exoskeleton concept by Yagn.

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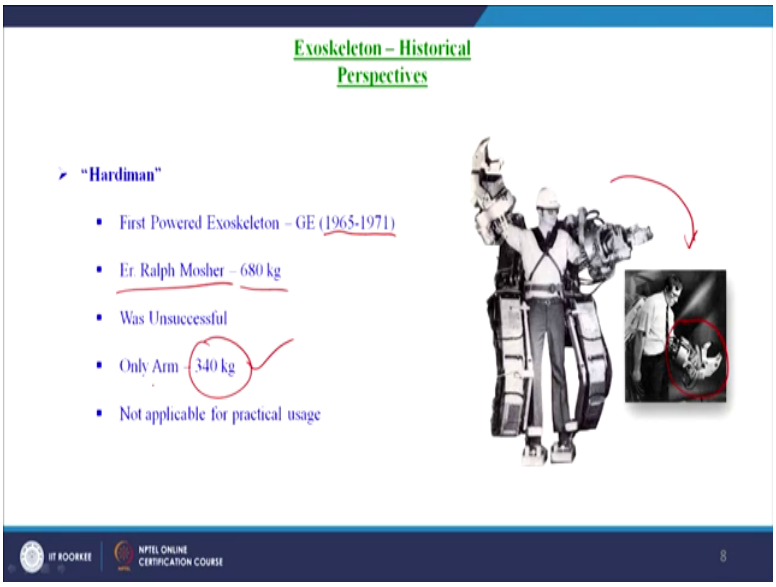

And, the very first practical exoskeleton has been developed by the general electric GE in the year between 1965 to 1971. It is the first powered exoskeleton and it is done by a group of engineers led by the engineer Ralph Mosher with the intention to lift up to 680 kilogram by this exoskeleton, but this task was unsuccessful by this Hardiman exoskeleton and later on they have focused to one arm exoskeleton that could able to successfully lift 340 kilogram,

but the weight of that arm alone is 3 times the weight it was lifting. And, hence this Hardiman exoskeleton was not applicable for practical usage, it has become impractical.

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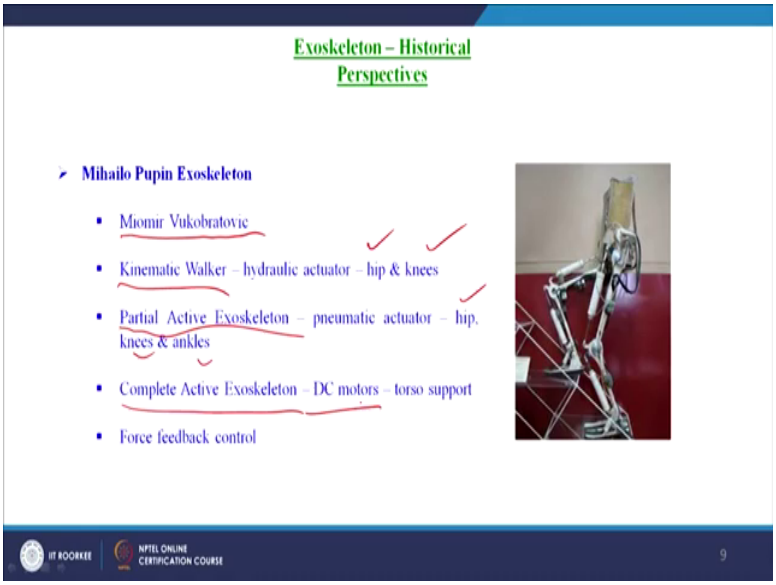

Then, Mihailo Pupin exoskeleton has been developed by Miomir Vukobratovic. I repeat it has been developed by Miomir Vukobratovic and it is basically started as the Kinematic Walker with hydraulic actuator in order to actuate both hip and knees. Later on it has been developed as a partial active exoskeleton with pneumatic actuator so that all the three joints of the legs for example, that is the hip, knees and the ankles are actuated. Finally, from the partial active exoskeleton it has been developed into a complete active exoskeleton so that it can support the torso as well.

And, later on they have changed the pneumatic actuator into DC motors to have a smooth performance and they have attached four sensors three – four sensors on the sole of the foot

of the exoskeleton in order to track the desired or actual or the given force. And, hence force feedback control has been performed in this exoskeleton this that is Mihailo Pupin exoskeleton. This I repeat back and this has been developed in the year 1972 that is Mihailo Pupin exoskeleton has been developed in the year 1972.

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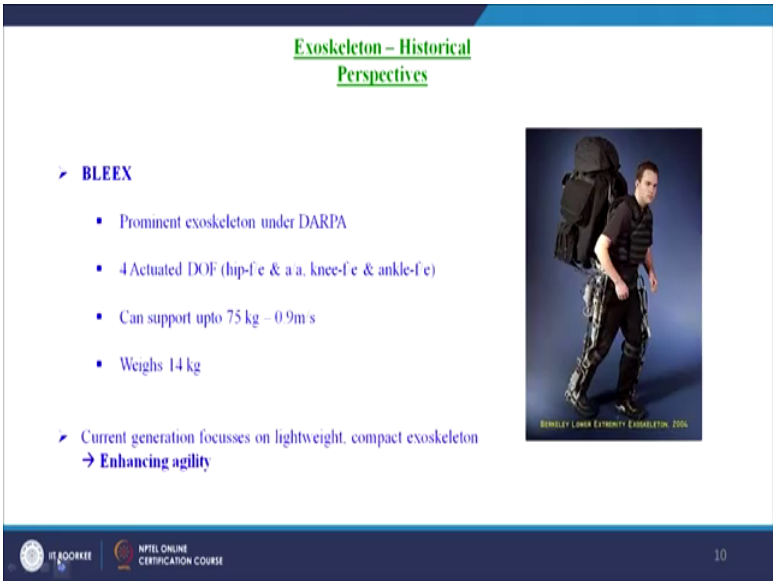

And, now coming to the BLEEX exoskeleton which has been developed in the year 2004 and this is one of the prominent exoskeletons under the DARPA program of the US government. DARPA means the Defense Advanced Research Project Agency of the US government. They have been associated with a couple of universities or institutions in the US, one is Berkeley University UC Berkeley and MIT.

And, this BLEEX which is nothing, but the Berkeley's lake extremity exoskeleton or lower extremity exoskeleton it is basically Berkeley's lower extremity exoskeleton BLEEX and it is

one of the prominent exoskeletons under DARPA program. And, it is a 4 actuated degrees of freedom exoskeleton meant for hip flexion extension and abduction adduction 2 degrees of freedom actuated at the hip joint and 1 degrees of freedom for the knee flexion extension and 1 degrees of freedom actuated at the ankle flexion extension.

And, it can support up to 75 kilogram with the speed of 0.9 meter per second and it weighs the exoskeleton weighs only 14 kilogram and the current generation focuses on lightweight compact exoskeleton in order to enhance agility of the human operator.

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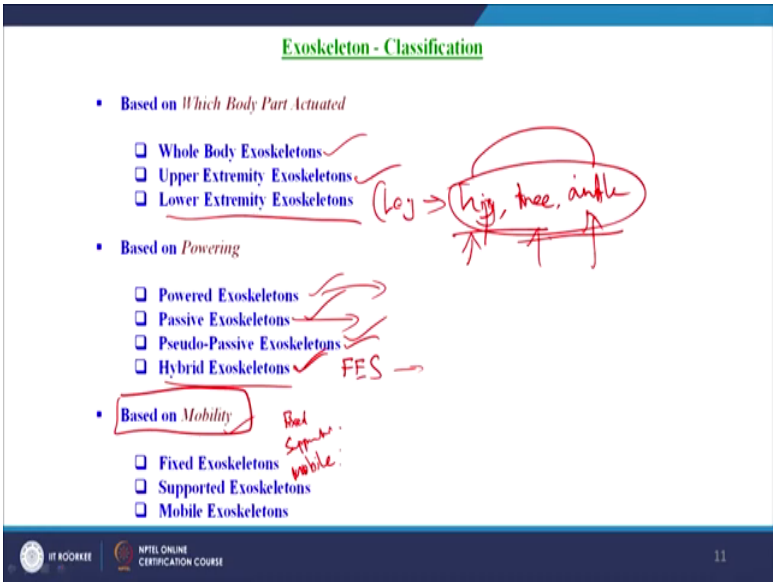

Now, coming to the classification of exoskeleton, first the classification is based on which part of the body is actuated. Accordingly it can be classified further into whole body exoskeleton if the full body is actuated and if the upper body, if the torso the neck and the arm are actuated then it is called upper extremity exoskeleton, and if the leg is actuated then it

is called lower extremity exoskeleton. The leg means it is denoting all the three joints that is hip, knee and the ankle.

So, in the lower extremity exoskeletons the actuation can be for hip and knee or for the knee and the ankle or for the hip and the ankle alone or individually the hip alone or the knee alone or the ankle alone or the combination of all these three joints will be coming under the actuation part of the lower extremity exoskeletons.

Now, the another major classification is on powering of the exoskeleton whether the exoskeleton is powered or not. Accordingly it has been classified into powered exoskeletons, passive exoskeletons, pseudo passive exoskeletons and finally, hybrid exoskeletons. Now, powered exoskeletons generally use batteries or electric cables in order to run the sensors and the actuators they are further broken into or classified further into powered exoskeletons are classified further into static exoskeleton and dynamic exoskeleton.

In the static exoskeletons the actuators are turned on all the times in order to have the function of the exoskeleton in order to maintain it is shapes whereas, in the dynamic exoskeleton the power of the actuators are not on at all the times and it is quite energy efficient exoskeleton. And, coming to the passive exoskeleton it does not require a power source for its operation and they are further classified according to their usage one meant for weight redistribution and the another one for energy capture and the another one for locking the user and the next one will be for acting as a shock absorber.

Now, coming to the pseudo passive exoskeletons – they have the batteries, sensors and the electronics, but are not meant to provide actuation as in the case of powered exoskeletons. So, the pseudo passive exoskeletons will have the batteries, sensors and actuators sorry batteries, sensors and other electronics, but they do not provide actuation.

Now, finally, coming to the hybrid exoskeletons – they do have all the controllers and sensors of a powered exoskeleton, but they use functional electrical stimulation technique of the muscles as actuators. This functional electrical stimulation of the muscles means, it uses the

low electric power pulses in order to artificially generate movement of the limbs that is what getting used in the hybrid exoskeletons.

Then finally, the major classification is on mobility, the exoskeletons classified based on mobility. Definitely it will be one will be they fixed one which is fixed either on the wall or on to the hook part and the another one is supported that is a exoskeleton is attached to a overhead rail and it is supported by a moving frame or it is supported by an adjacent mobile robotics system so that the heavy controller, actuator and sensor part will be kept in the adjacent moving robotic system so that it can provide granted mobility to the exoskeleton wearer.

And, finally, the last subdivision of the mobility based exoskeleton is mobile exoskeleton which allows the user and the extra exoskeleton to move freely around that is all.

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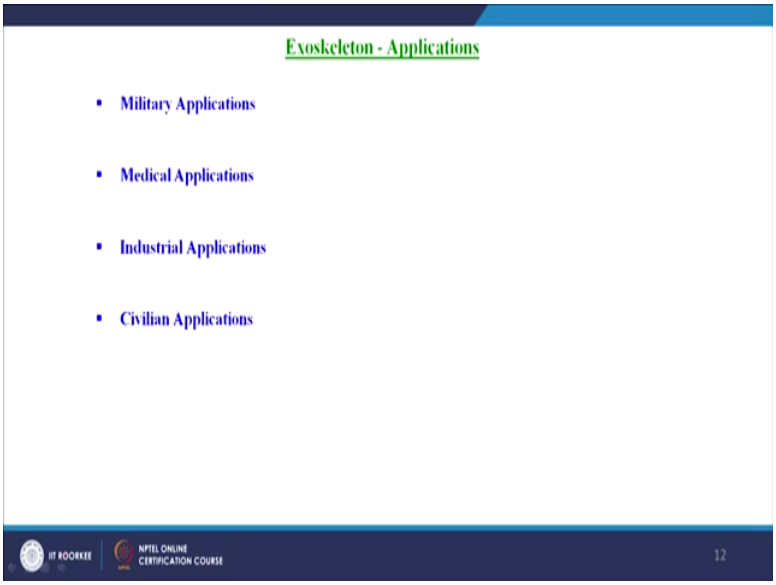

Now, coming to the applications of exoskeleton – the exoskeletons major applications are in the field of military, medical field, industrial field and civilian or consumer application field.

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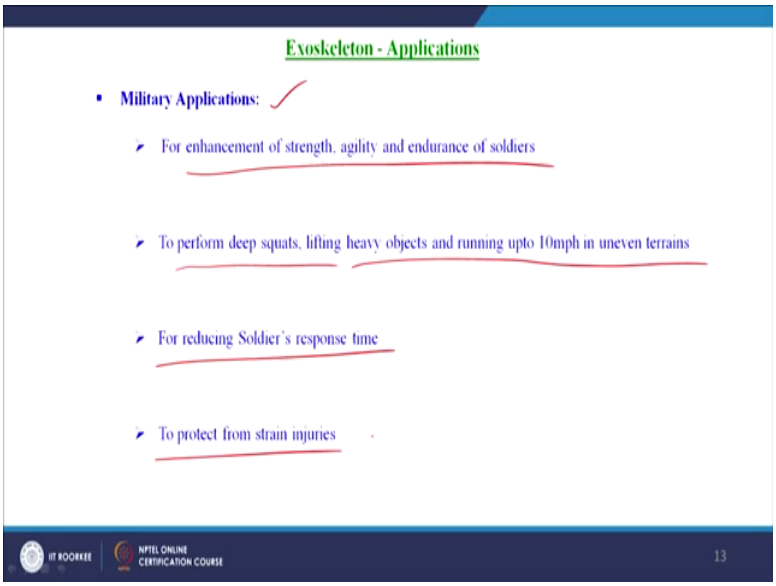

Now, coming to the first application which is the military application they are meant to be useful in the military application in order to enhance the strength, agility and endurance of the soldiers. In order to perform deep squats, lifting heavy objects and running up to 10 miles per hour in uneven upslope terrains and, for reducing soldier's response time and finally, to protect from strain injuries of the soldiers.

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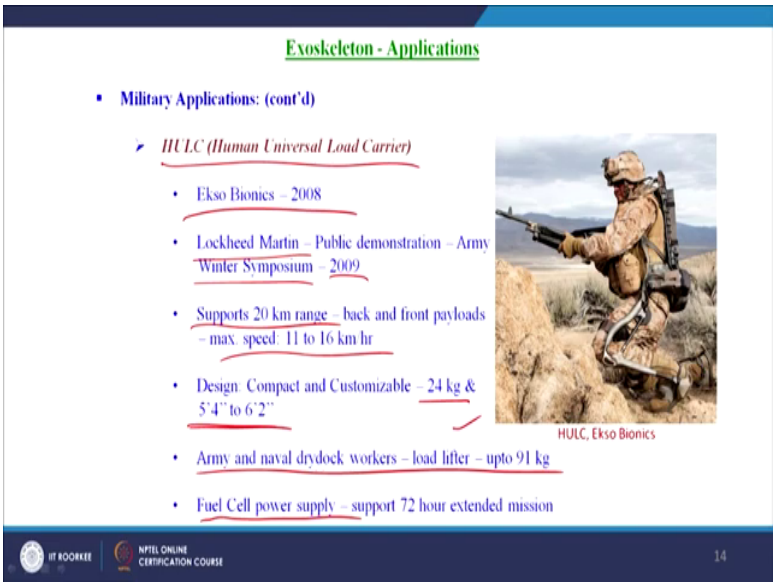

We see the first exoskeleton here under the military applications concept is the HULC that is Human Universal Load Carrier which is developed by Ekso Bionics in the year 2008. In the year 2009, it has been publicly demonstrated by Lockheed Martin in the Army Winter Symposium held in the US. And, this exoskeleton the HULC exoskeleton can support 20 kilometer range and also it suppose the back and front payloads and it provides a maximum speed up to 16 kilometers per hour with the range varying from 11 to 16 kilometer per hour. And, the design is compact and customizable and it weighs up to 24 kg. It weighs roughly 24 kg approximately.

And, it is helpful and it is suitable for the soldiers who are having the heights varying from 5 feet 4 inches to 6 feet 2 inches and it is used as a load lifter for the army and naval dry dock

workers and it can lift up to 91 kilogram roughly 200 pounds and it is powered by a fuel cell and it can support a continual or continuous 72 hour extended mission.

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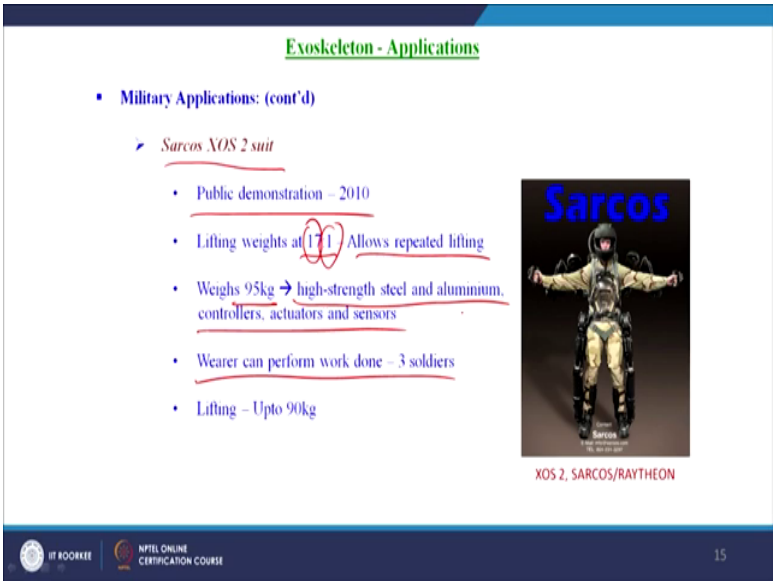

Now, coming to the second exoskeleton under the military application is Sarcos XOS 2 suit. It is a second generation suit of the Sarcos exoskeleton company and it is publicly demonstrated in the year 2010. The operator who is lifting the weight with Sarcos exoskeleton will feel the weight lifted in the ratio of 17 is to 1; that means, the actual weight is 17 times more than the perceived weight and also it allows the repeated lifting.

And, it weighs nearly 95 kilogram and it has high strength steel and aluminum body, controllers and actuators and sensors and electronics associated in the compact system and the wearer can perform the work done which is up to the work done by 3 soldiers. And, the lifting of up to 90 kilogram is possible with this exoskeleton very smoothly and very easily.

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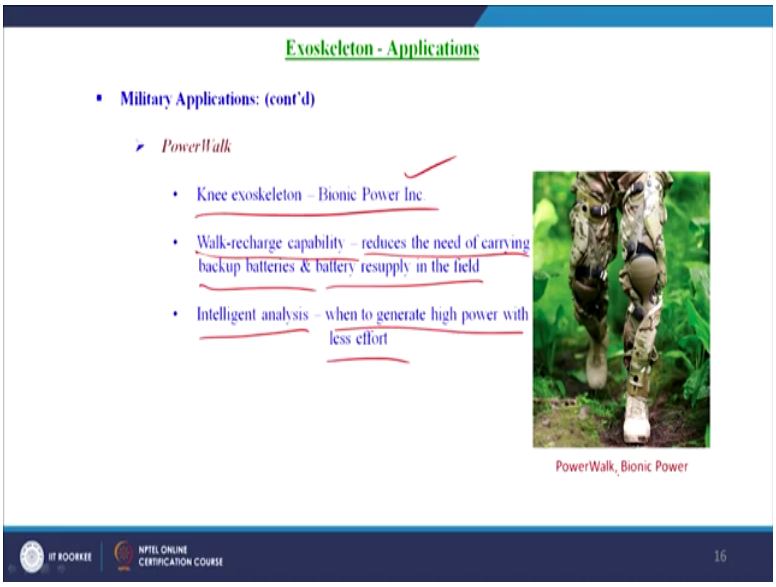

And, now coming to the PowerWalk exoskeleton which is basically focusing on the knee exoskeleton which is here passive exoskeleton and developed by bionic power incorporation and it is here walk recharge capability based exoskeleton; that means, you recharge while walk. And, it reduces the need of carrying backup batteries and battery resupply in the field because those batteries lithium batteries can be recharged by the system itself. And, it has the intelligent analysis to analyze when to generate high power with less effort by this exoskeleton.

And, it has here the working principle has an inboard microprocessor to analyze the various gate or the walking style to determine precisely when to generate maximum power with the least amount of effort. It is average on an average it produces 10 to 12 watt of electricity which over an hour can supply can charge up to 4 smart phones; that means, it is quite

efficient to generate power in a passive manner. We walk thereby we could able to recharge the batteries of the exoskeleton.

And, it has a gearbox in order to increase the speed of the knee rotational speed for efficient power generation and a generated incorporated in the system can convert the mechanical energy into electrical energy. And, this electricity is converted into the electricity for battery charging by a state of the art power conversion circuit, then the soldier whose wearing this exoskeleton can recharge is lithium ion batteries with the electricity converted by the power conversion circuit in the exoskeleton.

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Now, coming to the next application which is the medical application we have several exoskeletons developed in order to assist the elderly people or the patients who lost the control of their motor abilities due to stroke and other disorders. One is phoenix medical

exoskeleton, another one is ARMin, third ported prototype exoskeleton and capio exoskeleton, Ekso-GT exoskeleton and armeo spring arm and hand exoskeleton then we have the ReWalk exoskeleton to discuss about.

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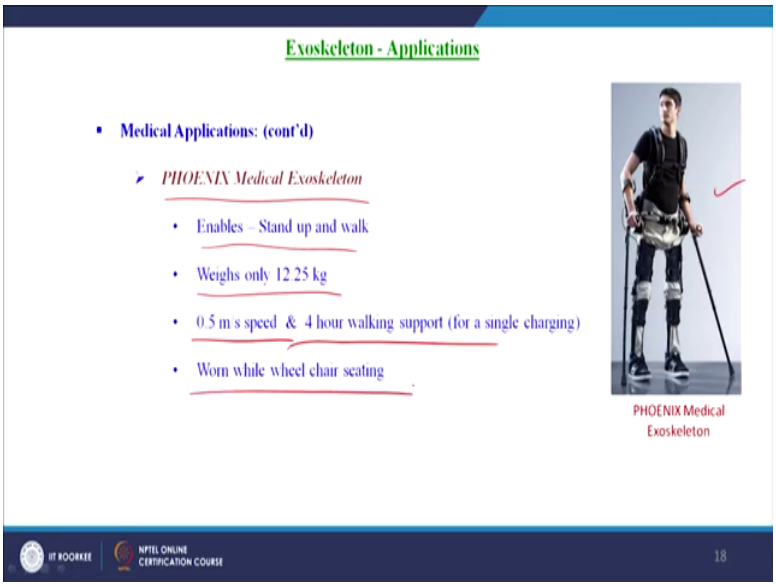

But, precisely we focus in the phoenix medical exoskeleton and the ReWalk exoskeleton. In this lecture, coming to the phoenix exoskeleton this schematic picture is shown here with the bearer and, it weighs only 12.25 kg kilogram. And, it enables the wearer to stand up, walk and have a have an eye to eye contact to the peers. And, it provides 0.5 meter per second speed and 4 hour continuous walking support with one time charging and it can be worn by the patient while he was sitting on the wheelchair itself.

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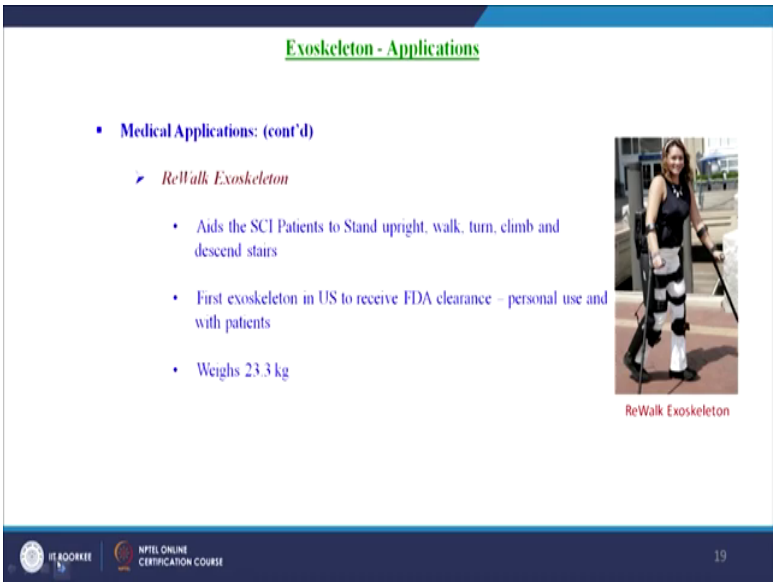

And, we discuss about now the ReWalk exoskeleton. The schematic is shown here and it aids the spinal cord injury patients to stand upright, walk, turn, climb and descend stairs. They can walk down in the steps in the stairs and it is the first exoskeleton in the US to receive FDA clearance for personal use and to be used with patients and it weighs only 23.3 kilogram.

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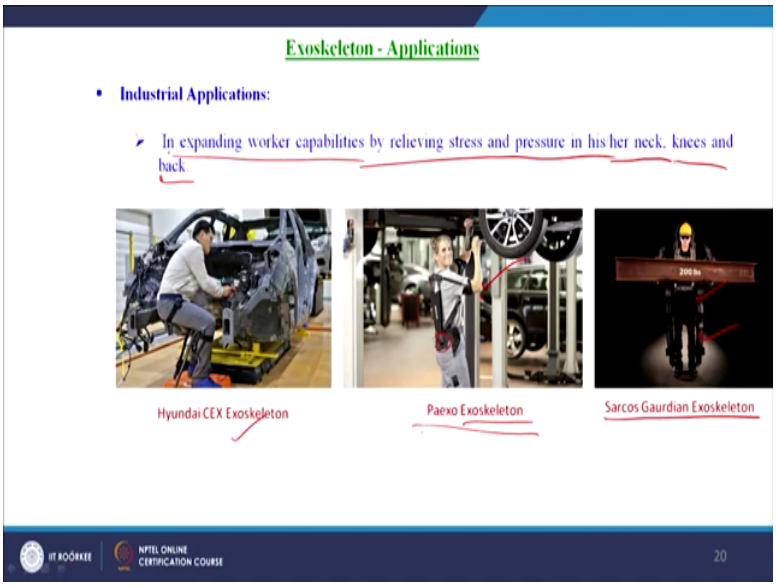

Now, coming to the industrial applications – the exoskeletons are developed for the industry purpose in order to expand workers capabilities by relieving the stress and pressure in his neck, knees and the back. First we see about the Hyundai's chair-less exoskeleton. The Hyundai's chair-less exoskeleton is a one that is weighing only 1.6 kilogram. It decreases the use of waist and lower body muscles by 80 percentage by reducing the thereby reducing the fatigue that results from being in the same position for a long time or sitting in the same position for a long time on the chair. That is why this exoskeleton has been developed and it is only 1.6 kilogram which can withstand the weight of 150 kilogram person.

And, next is the paexo exoskeleton which is weighing less than 2 kilogram and it transfers it is meant for above the shoulder work; that means, the work in order to relieve the stress of the workers who is having raised arm work as can be shown in the schematic so that the weight of the raised arms has been transferred to the hip joint by a mechanical cabling system

technology used in this exoskeleton. So, that it results in much relief of the workers who are having raised arm work.

Then finally, the Sarcos Guardian exoskeleton is a powered exoskeleton which improves the human strength and endurance without affecting the freedom of movement of the operator. It can lift up to 90 kilogram as can be shown in the schematic.

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Finally, the civilian applications there are these exoskeletons are developed in order to assist humans in performing activities of daily living like lifting, walking and performing personal tasks such as writing and opening the knobs etcetera.

The first one is the HAL exoskeleton which is nothing, but the Hybrid Assistive Limb exoskeleton developed by a Japanese company Cyberdyne. And, next we have the Panasonic

exoskeleton; then we have the Walking Assistant Wearable Robot developed by the Hyundai Motor Group of the South Korean company. These are meant to assist the wearers in order to enhance their work towards the activities of daily living.

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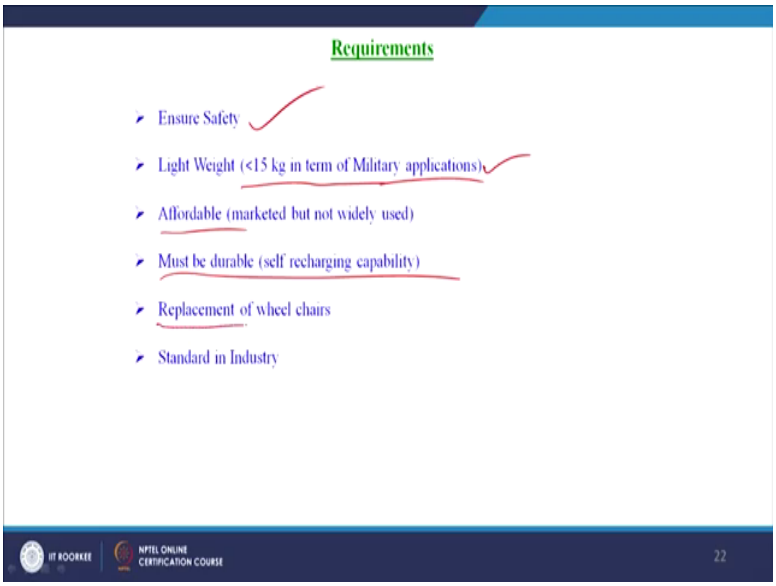

Now, the requirements from this study is that the exoskeleton in the future must be developed in order to ensure safety as a first and foremost requirement. And, it must be light it must be of light weight, nearly less than 15 kilogram in the term of military applications. And, it must be affordable – yes, because most of the exoskeletons are marketed, but are not widely used by the public. Must be durable, but the self recharging capability as in the case of knee exoskeletons and it will be in future the replacement of wheelchairs and will be used as a standard in the industrial usage.

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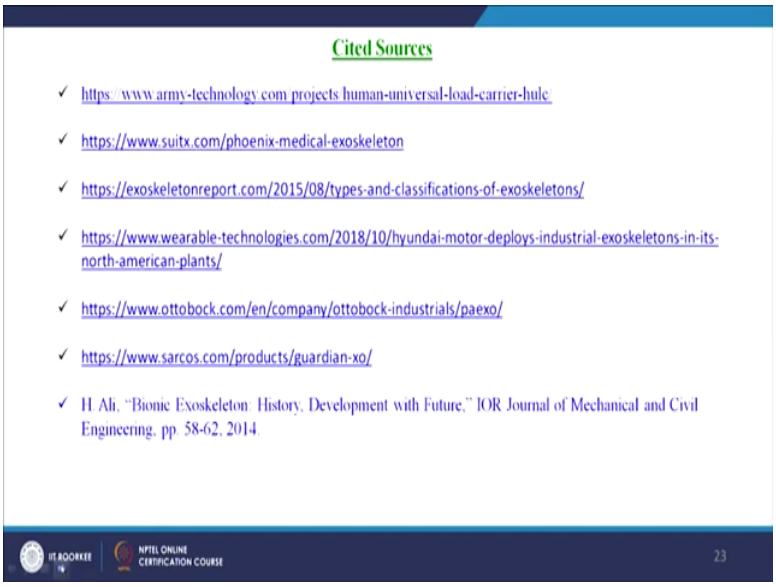

And, these are the cited resources, cited sources which I have utilized in order to present this lecture.

Thank you so much.