Robotics and Control: Theory and Practice
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Lecture – 26
Introduction to Robotic Hand Exoskeleton

Good afternoon. Today, the topic of my presentation will be on Hand Exoskeletons a brief review.

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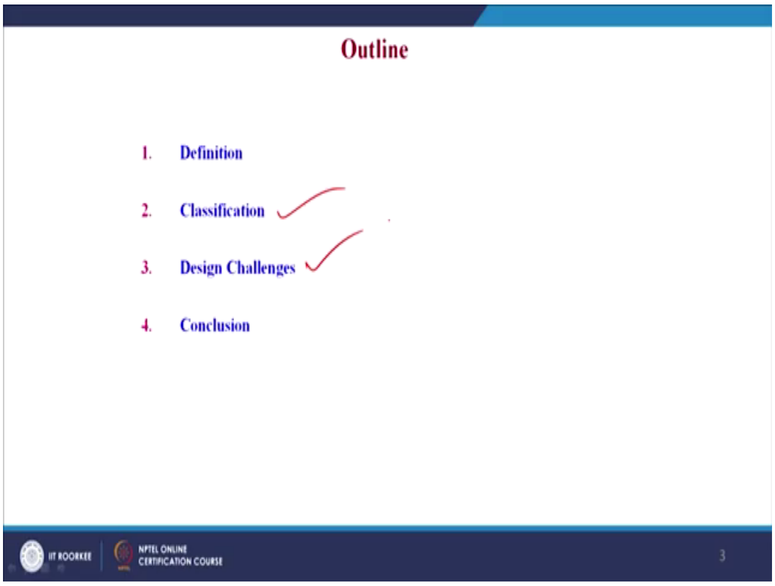

The organization of today's lecture will be as follows. First, we have the definition of hand exoskeletons. Then we see the state of the art and that too especially classification of the hand exoskeletons based on the power transmission method. And, then we come to the design challenges in developing a new exoskeleton which will be a novel one and then finally, we conclude our lecture.

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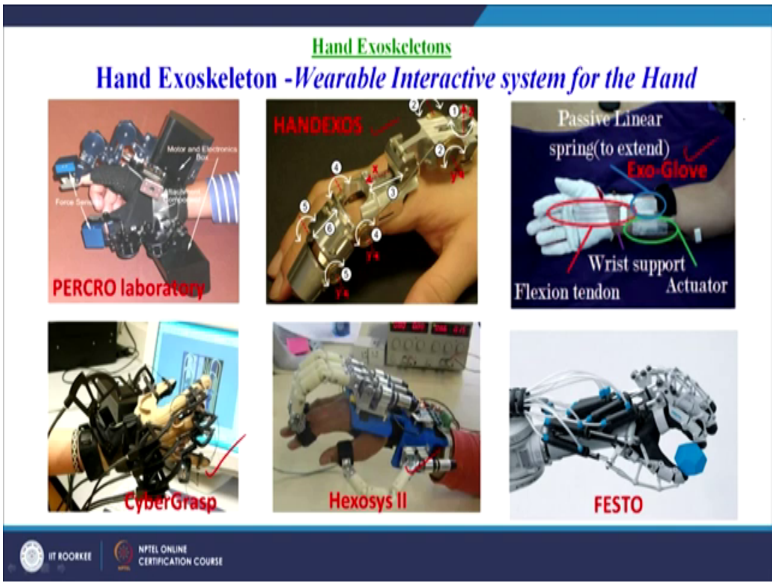

Coming to the definition, what is in hand exoskeleton? Hand exoskeleton is a variable interactive system for the hand. So, it is worn by the patients or the elderly people to assist themselves. There are various hand exoskeletons developed in order to help the elderly people as well as the stroke patients who have lost the control of the hand. For example: you can see here the exoskeletons such as hand exos, hexosys prototype 2, cyber grasp and the exo glove or the famous exoskeletons for the hand.

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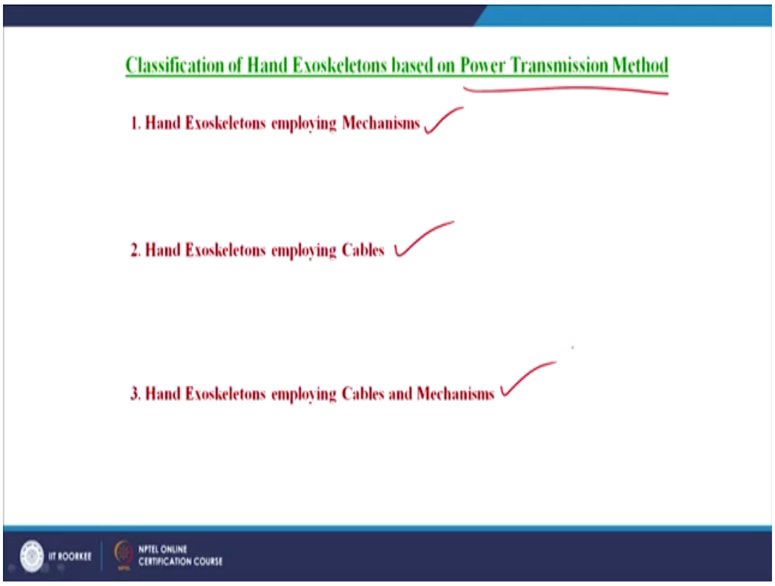

Now, coming to the classification of hand exoskeletons based on power transmission method. There are various ways we can classify the hand exoskeletons. One will be the design and the other will be controlled and the other one will be the sensors used. There are several ways we can classify the exoskeletons in order to review them.

The method which I have chosen here in this lecture is on the classification based precisely on the power transmission method, how the force is getting transferred to the fingers on what design methodology. So, based on the power transmission method, I have classified the exoskeletons for the hand into 3 types. The first one is the hand exoskeletons employing mechanisms; that means, the frames or the mechanisms 4 per mechanisms 6 per mechanisms without cables.

And, the second type is classification of the hand exoskeletons employing only cables. And, the third one is the classification of hand exoskeletons having both cables and mechanisms. The mechanisms is the one which also includes the linkages.

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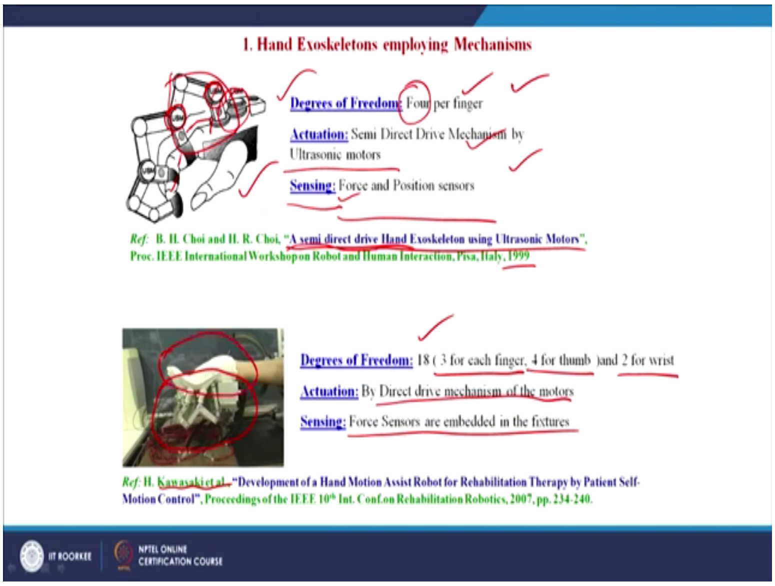

Coming to the first category which is the classification of exoskeletons, hand exoskeletons employing mechanisms. We first start with the design that is the direct drive hand exoskeleton developed by Choi and H R Choi which is entitled by the paper: A semi direct drive Hand Exoskeleton using Ultrasonic Motors. Why it is called semi direct drive? Because, they have used a 6 per mechanism such that excluding the 4 link lengths of the mechanism to link lengths forming the fifth and sixth will be from the human finger and that is why it is called semi direct drive hand exoskeleton.

The direct drive hand exoskeleton generally have the actuators lying on the hand part itself. Here in this design they have utilized the smallest possible ultrasonic motors which are having high power to weight ratios. And, I have categorized in such a way that main focus is on the number of degrees of freedom and the actuation and the sensing involved in the exoskeletons based on this classifications that is mechanisms and the other one using cables only; then the exoskeletons using both cables as well as the mechanisms.

So, in this case of the exoskeleton developed by Choi et al; so, what is the degrees of freedom, how many degrees of freedom that is giving? So, for each finger there are 4 degrees of freedom possible by this exoskeleton. As you can see all flexion extension of the M C P P I P and the D I P joints could be produced by this exoskeleton. And also the abduction adduction of the M C P joint will also be produced by this exoskeleton and hence 4 degrees of freedom for each finger.

And, the actuation is done by the ultrasonic actuators which is having as I mentioned high power to weight ratio. And, the sensing is done by force and position sensors and they have modeled this exoskeleton with the forward and inverse kinematics analysis along with the force analysis with both simulation as well as the experimentation of this proposed exoskeleton. This has been modeled in the year 1999 then in the year 2007 Kawasaki et al have developed a direct drive exoskeleton which is providing 18 degrees of freedom that is 3 for each finger 4 for thumb and 2 for wrist.

The actuation by this exoskeleton developed by Kawasaki is done by the direct drive mechanism of the DC motors. They have employed for the sensing 4 sensors have been utilized for the sensors along with the angle sensors. And, the only thing here is it is quite heavy. So, that it lies down and above that the hand part is placed.

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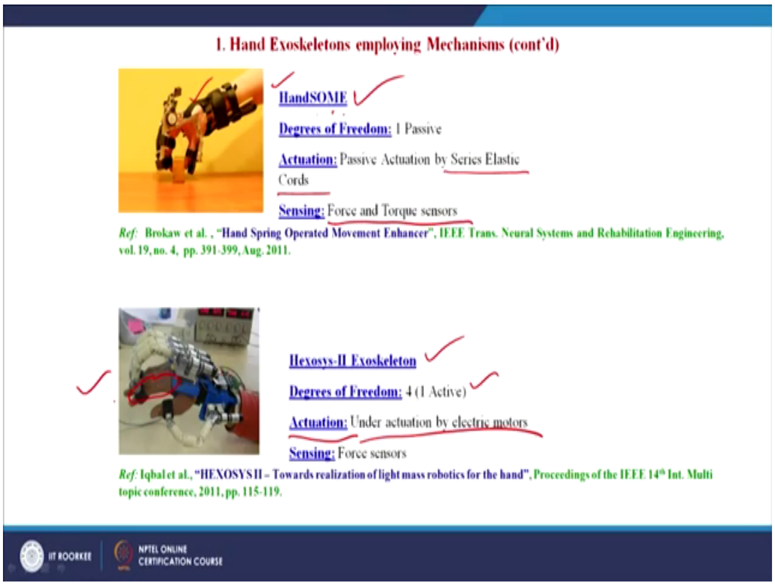

Coming to the next model proposed by Brokaw et al. They have developed the hand exoskeleton termed as handSOME which is the hand exoskeleton with spring operated movement enhancer that is why hand spring operated movement enhancer that is definitely a spring is attached there and it has 1 degrees of freedom which is quite passive.

What this exoskeleton does is; to extend to the fullest of the stroke patients who have lost the control of the hand that is for the elderly or the patients who lost the control of the hand, it is always closed. And, that closed or fluxed completely fluxed hand part of the patient is extended completely by this exoskeleton by a passive actuator which is a spring. And, they have used series elastic cords to have the passive actuation.

And, the sensors utilized or force and torque sensors being utilized. And coming to the next hand exoskeleton developed by Iqbal which is called hand which is Hexosys 2 that is hexosys prototype 2 exoskeleton is the one shown here. They have already proposed the hexosys 1 prototype, but we are seeing here that wants to one which is the hexosys 2 prototype of the hand exoskeleton.

It has degrees of freedom 4 totally 1 for each finger and it has the actuation that is under actuation by the electric motors. Because, of all the combined flexion extension of the three joints of each digit is done by a single motor and hence it is coming under the category under actuation, the sensors used here are 4 sensors.

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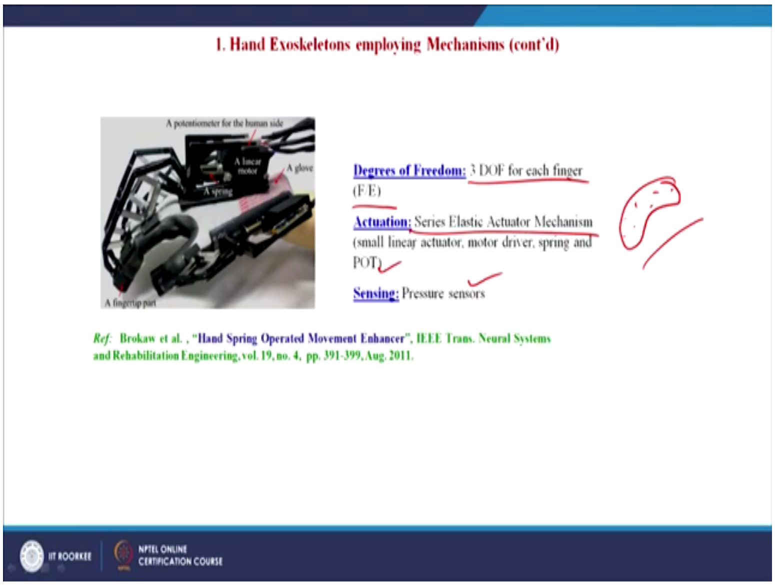

Now, coming to the fifth type that is the latest model which has been developed is the one which is the hand exoskeleton which has 3 degrees of freedom for each finger using only mechanism. They have used a mechanism with your series elastic actuator such that both grasping as well as the manipulation can be done by this exoskeleton. Because of this series elastic actuation each finger will have a work volume.

Each finger will have a work volume, because if they have used only the actuator linear actuator then they will not be getting a work volume rather they will be getting a straight line trajectory or curved trajectory instead of a work volume. And, the sensing is done by pressure sensors and the series elastic actuator as I mentioned will have a small linear actuator, the motor driver which is customized by them and the spring and a potentiometer for the angle feedback.

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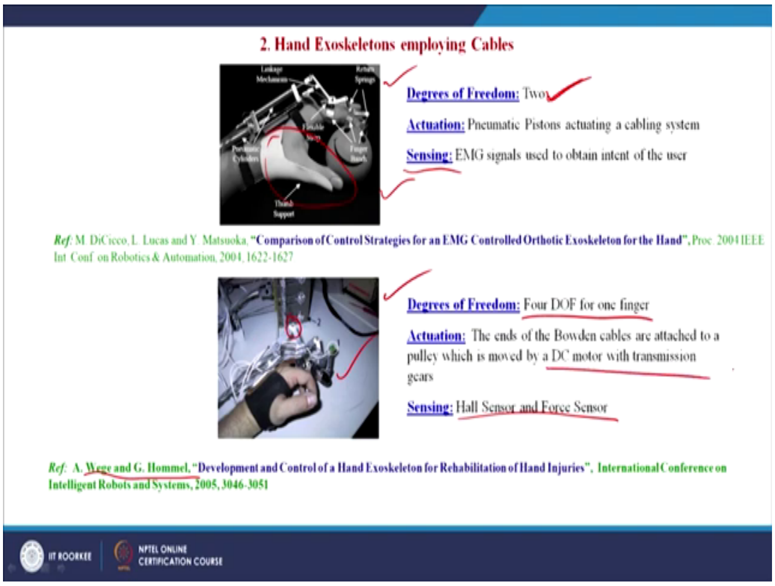

Now, coming to the second category of hand exoskeletons that is first done by Di Cicco et al and this is the one has been developed in the Carnegie Mellon University. And, this exoskeleton is a one which is actuated by pneumatic pistons via a cabling system and it has 2 degrees of freedom providing the natural flexion extension of the index finger with the thumb support that is the thumb is fixed here, they have targeted only the index finger first.

So, that natural finger flexion extension motion of the index finger can be obtained by this exoskeleton through pneumatic actuation. And, they have used 2 actuators that is 2 pneumatic actuators for having this motion of the index finger and the sensing is done through EMG signals in order to obtain the subjects intention or the patience or the wearer's intention through EMG signal recording. And, then coming to the exoskeleton designed are developed by Wege and Hommel. Both position control and force control have been done by Wege and Hommel in this exoskeleton development one.

It is basically a cable driven exoskeleton which is the Bowden cable which has the capability to both flex and extend the cables. And, then it has degrees of freedom; that is 4 degrees of freedom per finger and hence the actuation part is very big here very huge one for this developed exoskeleton. And, the sensing is done by both Hall sensors and force sensors, Hall sensor is meant for the bend sensor to get the bend angle of the mechanism and the force sensor is to have or to get the feedback force from the exoskeleton applying on the finger. And, the actuation is done by the DC motor through Bowden cabling systems.

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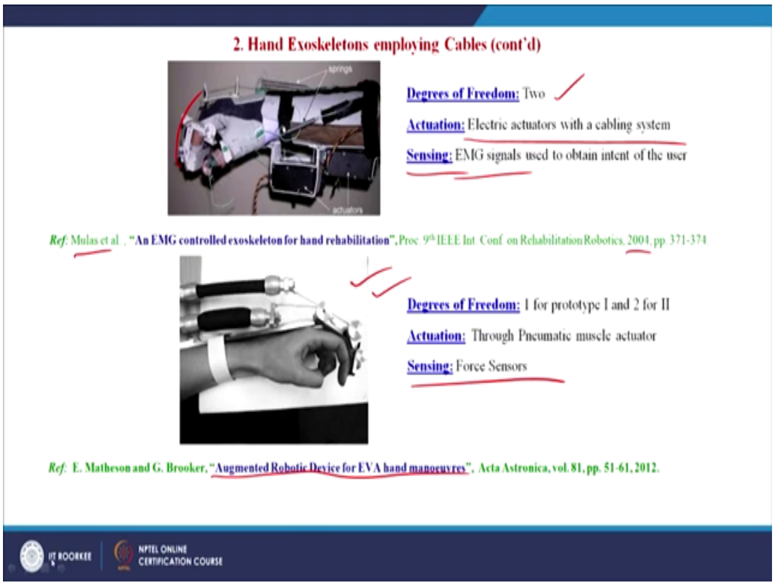

Now, coming to the exoskeleton developed by Mulas et al in the year 2004. It has a degrees of freedom 2 just 1 degrees of freedom for the flexion and extension case and the other one for the MCP and PIP joints. And, this is basically the closure opening and closing of these 2 systems one is for the thumb another one is for the combined collective 4 fingers. The actuation is done by electric DC motors with the cabling system and here the sensing of the system is the EMG signals to obtain of course, the subjects intention.

Now, coming to the exoskeleton designed and developed by Matheson and Brooker which is basically entitled under the paper which is augmented robotic device for EVA hand maneuvers. It has a degrees of freedom 1 for the prototype 1 and 2 for the prototype 2. This is a prototype 2 we are not showing the prototype 1 here. So, this prototype has 2 degrees of freedom and the actuation is through pneumatic muscle actuator which is the artificial actuators muscle actuators and the sensing we have the they have the force sensors to sense the force applied on the fingers.

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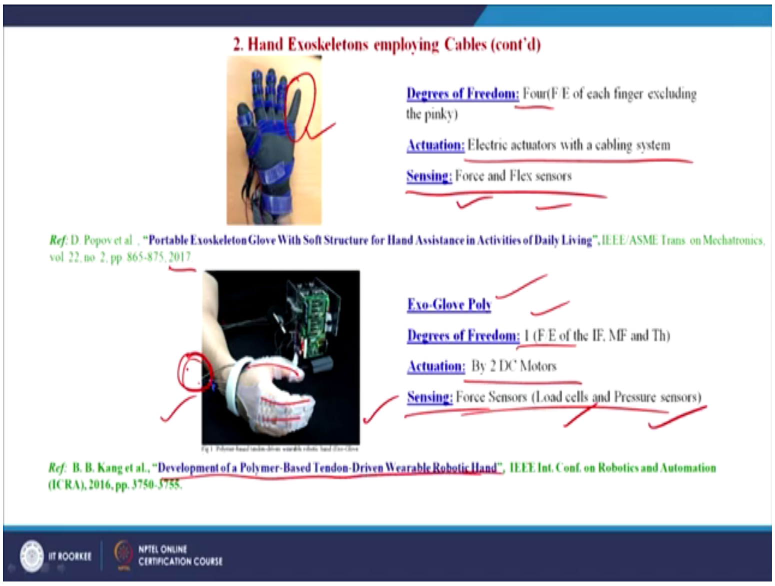

Then in continuation to the hand exoskeletons employing cables; we have the another exoskeleton which is recently developed in 2017 by Popov et al which is a portable exoskeleton in order to perform activities of daily living such as grasping and object manipulation. So, it has a degrees of freedom it is basically a glove type and it is basically has 4 degrees of freedom excluding the little finger here.

So, they have the four digits considered in this exoskeleton design. So, it has four degrees of freedom. So, that flexion extension of each digit except the pinky is considered in this design. And, the actuation is by electric actuators with their cabling system and the sensing they have used both force and flex sensors. For this exoskeleton and now coming to the another one which is quite skin to the patient that is the exoskeleton is not shown as an external device.

It is almost merged with the hand itself; that means, the exoskeleton here the hand exoskeleton is here happening or behaving as here next to skin to the patient's hand. It is called exo glove poly and it has degrees of freedom 1 that is flexion extension of the index finger middle finger and the thumb. That is they have done collectively for the thumb index and middle finger fluxing here that is extending here they have the activity here.

So, that through that the cables are pulled in the dorsal side. So, that extension happens and they have the actuator system pulling the cable passing through the palmer side to these three digits, but these schematic shows only the cables passing through the dorsal side. So, that the actuation is done through the cabling pulling. So, that extension happens. Similarly, they have the actuator pulling the cables attached to these three thumb index and middle finger pulled for flexion motion.

So, thus the degrees of freedom is 1 here for this overall entire hand exoskeleton and it is actuated by 2 DC motors one for flexion and the another one for the extension placed in the dorsal and palmer sides of the hand. And the sensing it used force sensors both load cells as well as pressure sensors. And, it is proposed by B B Kang et al in the year 2016 and it is entitled under the paper development of a polymer based a tendon driven wearable robotic exoskeleton or robotic hand.

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In continuation to the hand exoskeletons employing cables; we have the one which is proposed by Nyez et al. And, this is the exoskeleton which has a degrees of freedom 4 that is accept the thumb actuating the four other fingers index finger middle finger ring finger and the pinky for natural flexion extension of each finger. And, the actuation is done by linear actuators D C linear actuators.

And the sensing, we have position and 4 sensors in this exoskeleton developed one and this is also acting almost closed the hand part that is almost close to the hand. So, that it also behaves like a next skin to the user and then we come to the X-glove which is proposed by Kristen M Triandol Triandafilou a repeat this is proposed to by Kristen M Triandafilou. He has proposed this exoskeleton which is called x glove and it has degrees of freedom five that is each digit has flexion extension combinedly.

And, actuation is done by 5 DC linear actuators one for each as shown in the schematic, the sensing it has position sensors astronomers research work has been done by Professor Camper in this regarding the control of the exoskeleton for the stroke patients.

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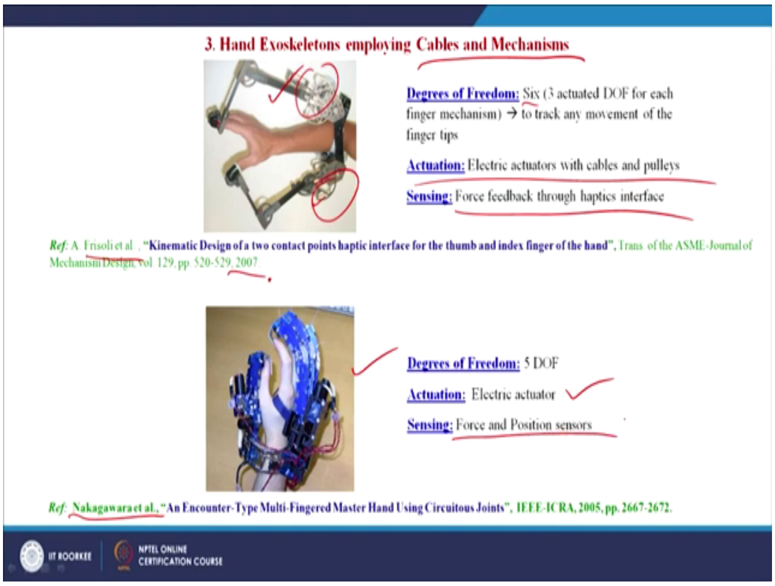

Now, coming to the third and the final classification of exoskeletons implying both the cables as well as the mechanisms; first is the model proposed to by Frisoli et al in the year 2007. So, here you can see that the degrees of freedom for this exoskeleton proposed is 6 degrees of freedom to track any movement of the fingertips, 3 for the index finger and 3 motors for the thumb.

So, that this mechanism can track any trajectory traced by these two fingertips and the actuation is done by the electric actuators with cables and pulleys. The sensing is done with the force feedback through haptics interface. Now, we come to the exoskeleton which is using circuits joint is the one proposed by Nakagawara et al and it has 5 degrees of freedom.

Each finger one degrees of freedom providing the extension and flexion of this each digit and the actuator is the electric DC actuator and the sensors utilized to here or force and position sensors.

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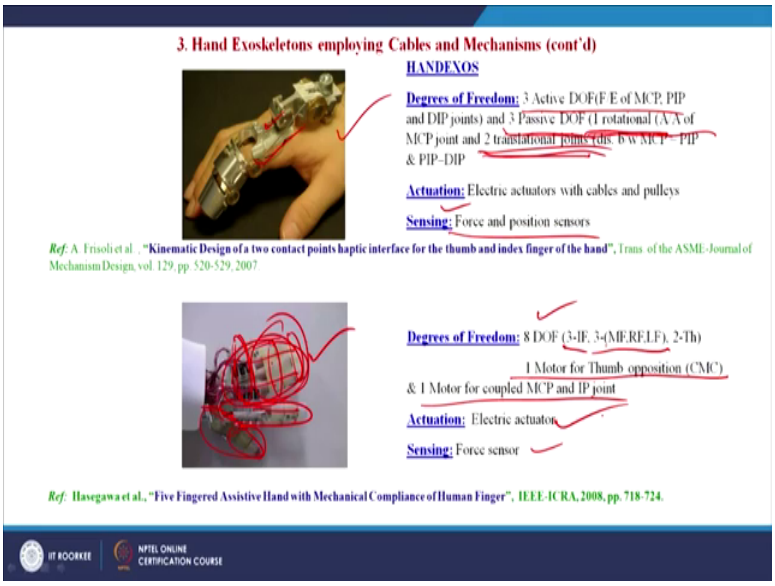

Then we have the hand exos proposed by the author I could not remember. So, this author has proposed this hand exos exoskeleton which has degrees of freedom 3 that is active 3 degrees of freedom that is for flexion extension of the MCP joint P I P joint and the DIP joint and 3 passive degrees of freedom. That is, 1 rotational degrees of freedom that is passive 1 rotational and 2 translational rotational translational degrees of freedom.

So, the rotational joint one rotational joint is meant for the abduction adduction of the MCP joint and the 2 translational joints are meant for having the distance varied between the MCP joint and the PIP joint and the PIP joint and the DIP joint; so, that this exoskeleton can be applicable to various hand sizes. That is why these three passive degrees of freedom are used mainly the 2 translational joints providing the distance between the joints that is a PIP DIP and P I P MCP can be varied.

So, that this exoskeleton can be used by the patients with various hand sizes; now the actuation is electric actuators with cables and pulleys with this mechanism and sensors are both position and force sensors. Finally, we have the exoskeleton which is having the degrees of freedom 8; 3 for the index finger and 3 for the collection of these 3 fingers that is a pinky ring finger and the middle finger and then 2 degrees of freedom for the thumb.

Here precisely one motor is used for the thumb opposition that is in the CMC joint and one motor for the coupled MCP and IP joint for the thumb. Because, the index finger and this motor this collectively these fingers have the motors respectively that is 3 and 3 for them because flexion extension of the CMC for of the MCP PIP and DIP.

So, 3 motors for this combination and 3 motors for the index fingers MCP PIP and DIP joint and 2 motors for the thumb; so, one for the thumb opposition at the CMC joint and one for the coupled MCP and IP joints flexion extension. Then the actuation of course, is done by the electric actuators which is DC motors and the sensing here is also 4 sensors.

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In continuation with the exoskeleton see employing cables and mechanisms. This is the exoskeleton proposed to by Agarwal et al and it has been published in the I J or journal in the year 2015 and this is the exoskeleton which has 2 degrees of freedom this is here shown only for the index finger. It has 2 degrees of freedom one for the flexion extension of the MCP joint and the other degrees of freedom other motor is for the collective or the coupled motion of the PIP and the DIP joint.

Because, it is biologically these two joints distal joint and the proximal interphalangeal joint both are coupled by the ratio that is theta DIP equal to 2 by 3 theta PIP. By this biological relationship they have performed the collective or coupled actuation with one DC motor for the coupled P I P and DIP. Next, we have the cyber glove; which is having 5 degrees of freedom which is a highly commercial exoskeleton, which is highly versatile and actuation is done by electric actuator it has force feedback through haptic interface.

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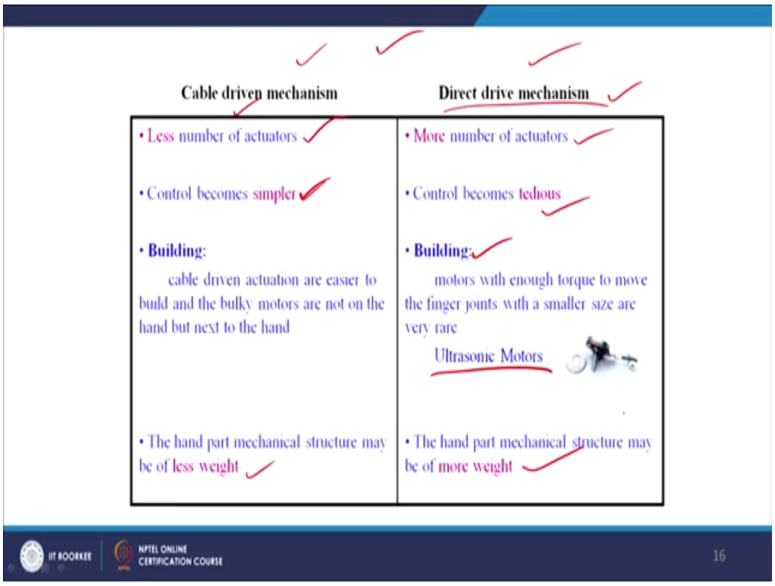

Now, coming to the quick cable the difference or the comparison between the cable driven mechanism and the direct drive mechanism; I see all know that the cable driven mechanism will have lightweight exoskeleton in the hand part. Because, the actuation part will be lying in the forearm or away from the hand part, whereas the direct drive mechanisms will have the actually sitting on the exoskeleton on the hand part itself. And, hence the system with the direct drive mechanism will be bulkier in size and heavier in weight.

And, the less number of actuators will be used in cable driven mechanism, whereas it is more in the case of direct drive mechanisms. And, the control becomes simpler because of the less number of motors the control is simpler in the case of direct drive mechanism and the control is tedious in the case of the in the case of direct drive mechanism. It is tedious and it is simpler in the case of cable driven mechanisms.

And the building the cable driven actuation is easier to build and the bulky motors are not on the hand part whereas, it is next to the hand part, whereas the motors with high torque and the smaller size is quite difficult to get for the development of direct drive mechanisms. But, the one possibility one solution is to use ultrasonic motors. The hand part mechanical structure may be of less weight, but this will be more weight in the case of direct drive mechanisms.

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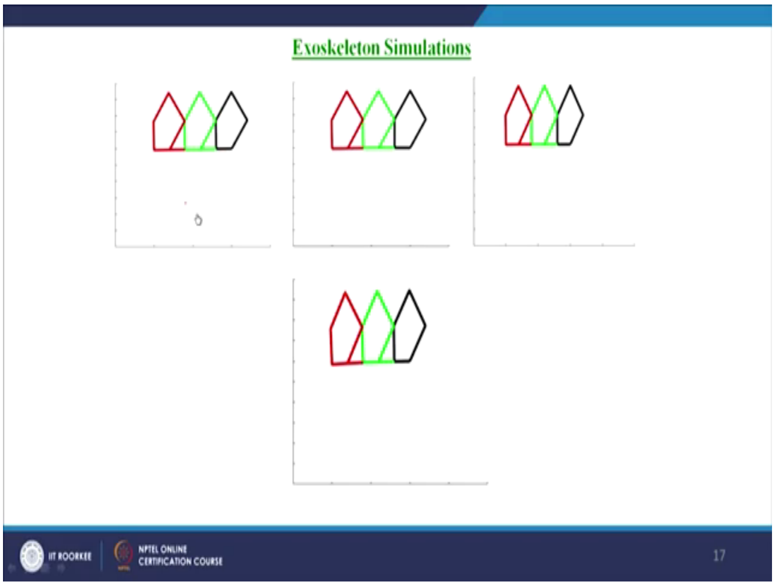

Now, coming to the few simulations which we have done while the study of this literature review of these exoskeletons. So, this is the design which I have developed using pyelogram mechanisms. You can see that this is the simulation showing the proxy that is the MCP joint that is see metacarpal phalangeal joint MCP join the first joint each one this is for the distal phalanx this one is for the middle phalanx.

And, this pyelogram is for the proximal phalanx and this is the simulation showing the MCP joint of this designed exoskeleton and this one is showing the P IP joints simulation and this one showing only the distal joint motion of this exoskeleton. And, this shows the collective P I P D I P and the MCB joint simulation in fluxing the hand part or the finger.

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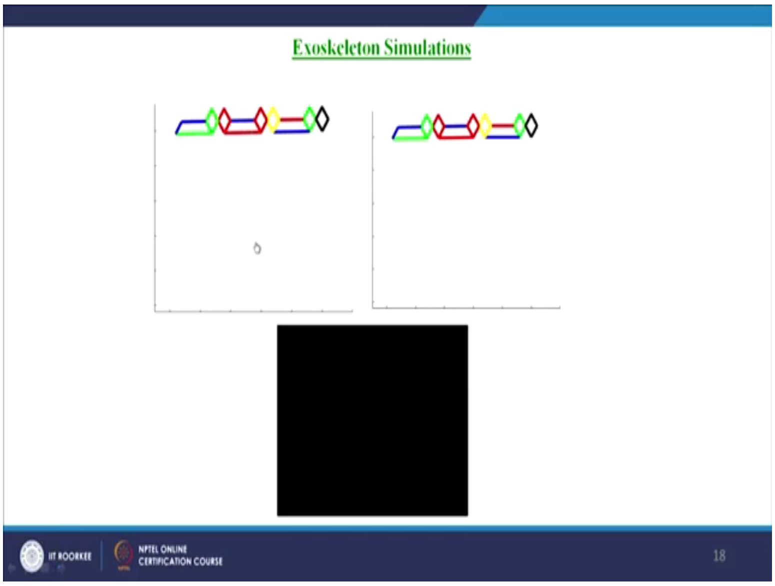

Now, coming to the other idea which is having double pyelogram design the simulation showing only the MCP joint flexion shown here and this one shows the PIP joint flexion of this exoskeleton.

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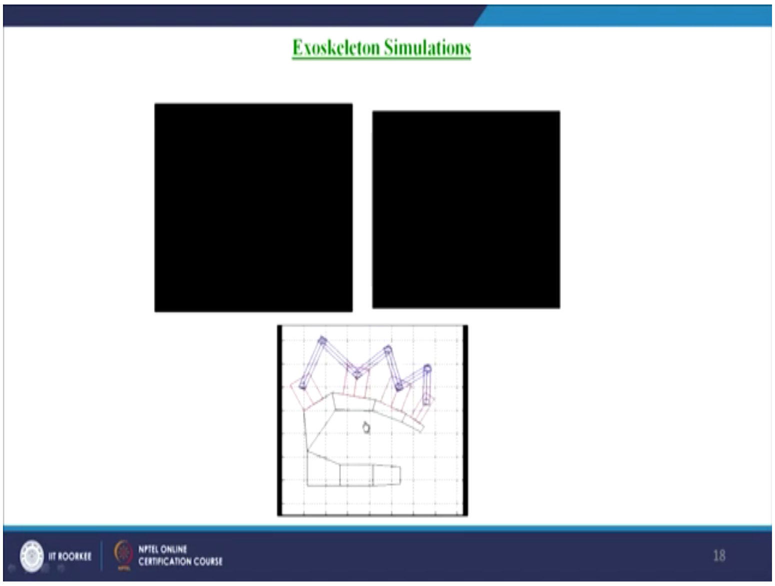

We also have developed a model based on the design by Choi et al as I shown this is the one which is the one having 6 per mechanism involving two links from the human.

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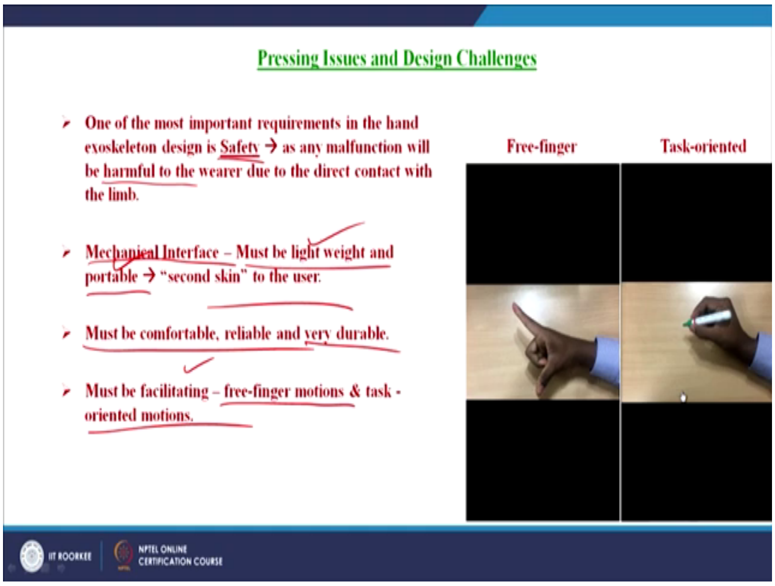

Now, coming to the pressing issues and design challenges; so, one of the most important requirement in the development of hand exoskeleton is safety. One of the most important requirement is safety, because the developed exoskeleton link must not move in another direction must not divert its motion, whereas it must coincide with the motion of the finger limbs or finger phalanx or else. It may cause harm to the wearer's hand. And the second one is the mechanical interface must be lightweight and portable must be the second skin to the user as I mentioned earlier it must be the second skin to the user.

And, hence it must be lightweight and highly compact and must be comfortable reliable and very durable must be facilitating both free finger motions and task oriented motions. What is a free finger motion? There is a one there is a free finger motion the exoskeleton development must be both must be facilitating both free finger motion and task oriented motion, this is a free finger motion.

So, the fingers can be flexed very freely and this is the task oriented as you can see that the object is getting translated in order to perform a writing task with a pen that is task oriented. So, both free finger as well as task oriented motion must be performed by the developed exoskeleton hand exoskeleton.

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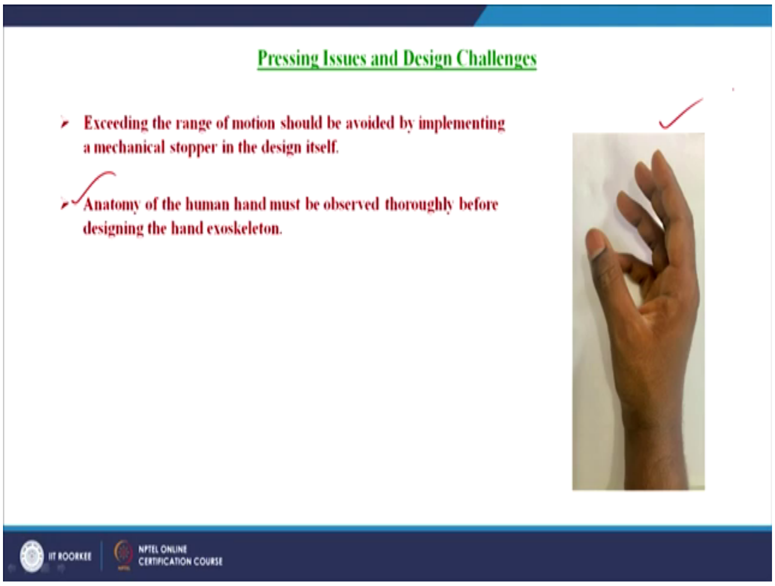

And another thing is; the range of motion must not be extended and it must be avoided by a mechanical stop by a simple mechanical stopper in the design itself. Then finally, the very important thing is; the anatomy of the human hand must be observed thoroughly before designing the hand exoskeleton. As you can see that the hand exoskeleton the hand the human hand forgot. First, we considered the hand in such a way that coming to the anatomy of the human hand it has 19 bones 19 joints and 27 muscles moving it. The human hand is moved by 19 bones 19 joints and 29 muscles.

There are a total of 14 phalanges bones of the fingers of the collective 5 digits and the five metacarpal bones meet at 14 joints. And, these make these fingers to move in various directions. Therefore, the natural flexion extinction which is the normal or the common movement of the fingers is basically flexion extension. Whereas, when we do flexion extension the abduction and adduction becomes passive. So, the designed or the developed the focus of the development of the exoskeleton must facilitate the natural flexion and extension of these fingers.

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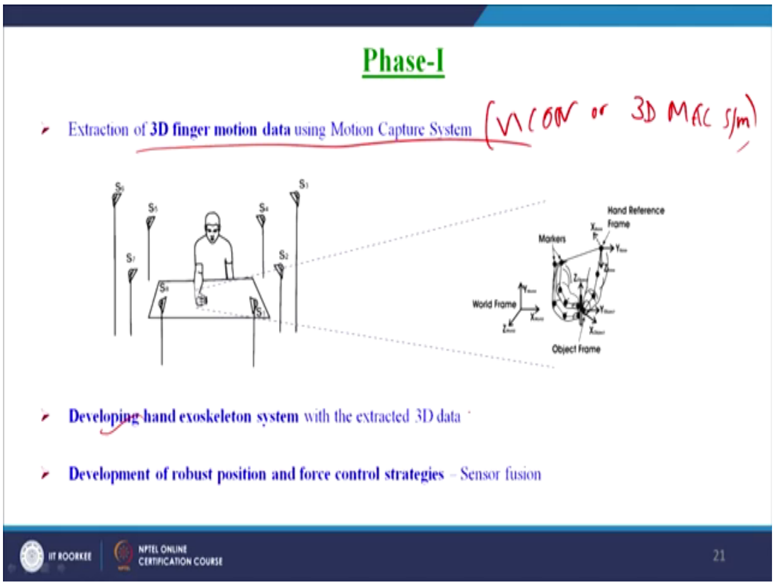

So, due to which the first phase and the development of exoskeleton must be having the extraction of 3 D finger motion data using motion capture system; either Vicon or 3 D max system in order to have the 3D finger motion data. And, from the data develop the hand exoskeleton. So, that the designed exoskeleton could be helpful in making on facilitating both the free finger motion and also the task oriented motion.

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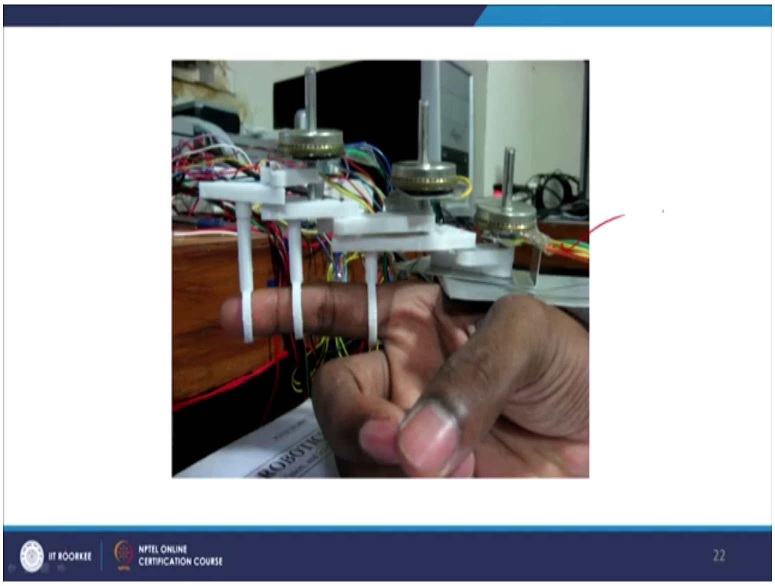

So, with that notion; we have developed the 4 bar based exoskeleton which will be discussed in the next lecture. Here it shows the index finger exoskeleton which is having the 4 bar mechanisms connected serially from the base till the distal part of the index finger and the conclusions coming to the conclusions finally with this lecture.

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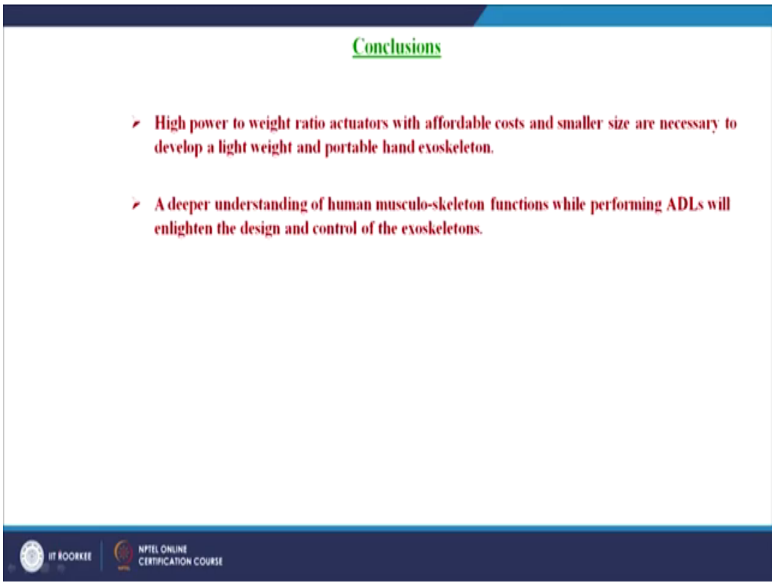

So, high power to weight ratio actuators with affordable cost and smaller size are necessary to develop a lightweight and portable hand exoskeletons. This observation and a deeper understanding of the human musculoskeletal functions while performing activities of daily living will enlighten the design and control of normal exoskeletons for the hand.

Thank you so much.