Virtual Reality Engineering

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Lecture - 71
Haptic Devices and Interfaces

Welcome back, today we are going to talk about the, you know machine Haptics. We are starting a new second face of our course and machine Haptics. So, far we have been looking at the human Haptics part of it. Whatever we have learnt in human Haptics, we are going to use it to simulate the Haptics part of it.

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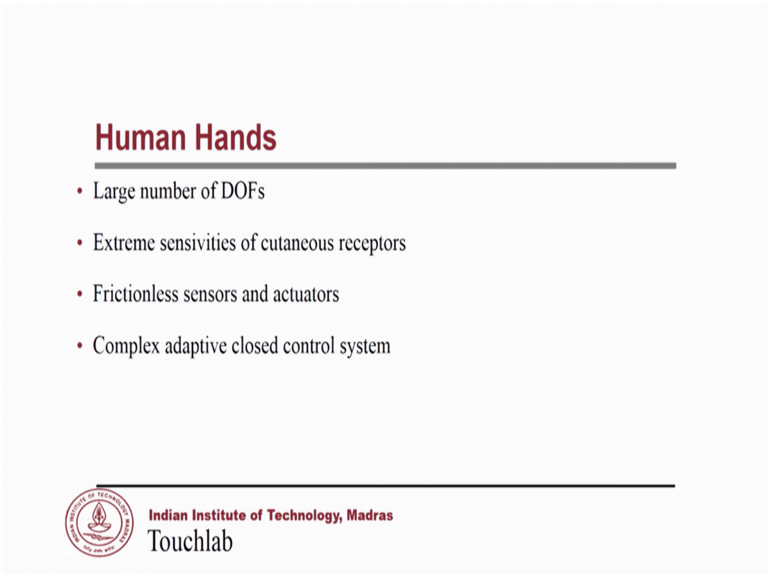

So, before we see the human Haptics. Again if you look at just to summarize what we have been learning is specifically about the human hand is that, human hand has large number of degrees of freedom. You are talking about you know 23 or 24 degrees of freedom and extreme sensitivity of the cutaneous repre receptors, specifically in the finger pad, the cutaneous receptors are extremely sensitive and when we design machine Haptics we have to achieve this kind of cutaneous receptors sensitivities.

The joints if you look at it, the joints are or sensors and actuators without frictions, so very very less frictions ok. So, in our machines Haptics also we have to achieve this kind of frictionless sensors and actuators. And the control systems, when we look at it is highly adaptive control systems ok. We are going to see how or what kind of control systems we are going to develop for Haptic devices and also how to make it turn our adaptive control system for these Haptic devices.

So, if you look at the way we handle objects, it can be divided into 3 different grasp, type of the grasps; one is the contact grasp, where we can use only one finger and our you know thumb alone or you know hands for the purpose of contacting objects hand in our combing condition.

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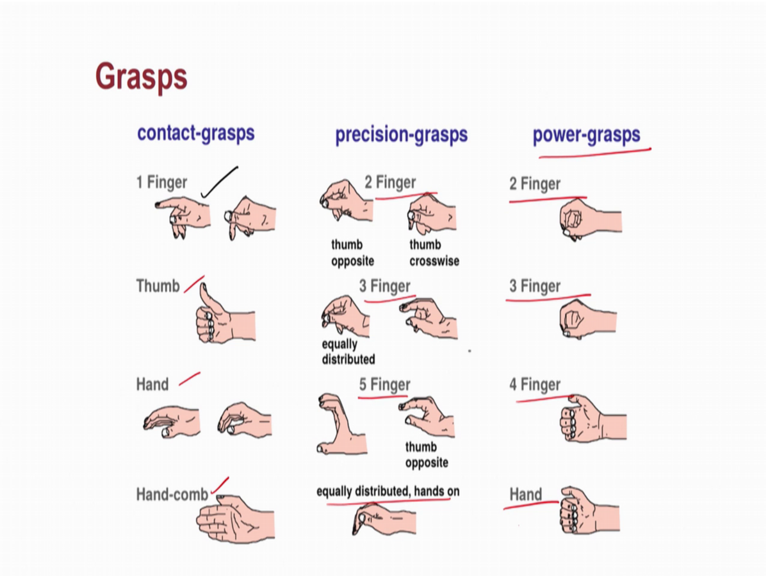

These are the different contact group, contact grasp. Precision grasps where we emphasis on their control that is. So, minimum we use 2 fingers for precision grasps or 3 fingers for equally distributed precision grasps or 5 fingers or you know equally distributed 5 different fingers on.

And then power grasp, where we emphasis on the force generated in the human hands. 2 fingers can generate some force, 3 fingers can generate more force, 4 fingers or the entire our hands can be used.

Now, when we generate, how are we going to enable this in the machine Haptics is what we are going to see. It is a very complex task and it took the research as started about you know 1960s, it is a very 60 years old topic. How the research evolved is also we are going to see in the human machine Haptics.

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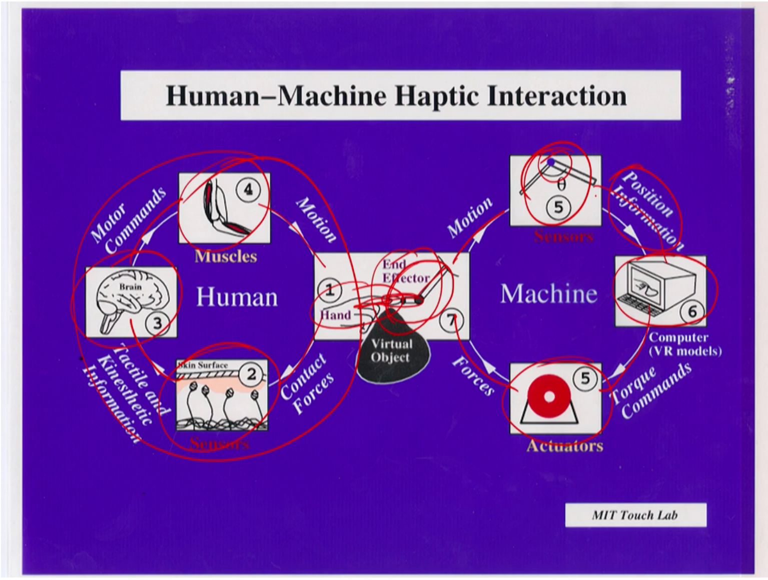

So, this cycle if we look at it, this is what we had understood in the earlier class where we focused on the human Haptics and the same thing is what replicated in the machine Haptics. In the human Haptics essentially if you look at the only the contact purpose of the grasping. When an user is touching an object, let us say it is a real object, the contact forces are sensed by the mechanoreceptors and the mechanoreceptors are conveyed to the brain, where we perceive and we react to the perception using the motor commands and the motor commands are given to the muscles, the muscle generate forces and motions and that is how the hand moves and perceives objects.

The same thing we can convert it into machine Haptics, where where the motions, suppose if the human finger is attached to the end effector of a robotic device. This robotic device movement can be sensed by the sensors, movement sensors and the that is going to give the position information to the computer.

The computer can generate torque and then actuators can apply force to the end effector and that will be the end effector will be resisting the movement of the user; that is how we can feel the forces.

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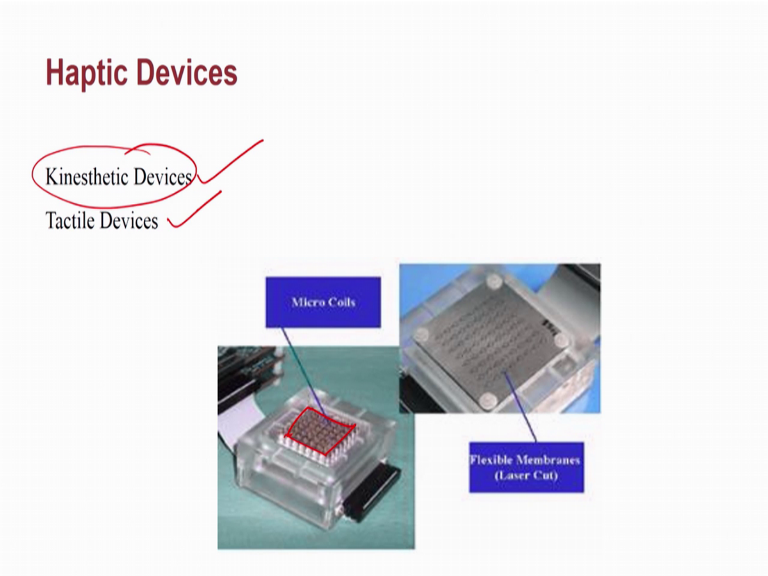

This is one way of machine Haptics, this is called the, you know kinesthetic devices because we are using the only the kinesthetic sensors over here, the joint sensors, where the position information is inferred and that is what is control; that is called the kinesthetic device. Another classes of Haptic devices is the tactile device, where there will be an array of pins, it will move up and down depending upon the profile of the surface, it can generate that is the tactile devices.

This two different classes of devices or are in Haptic, machine Haptics. We will focus on kinesthetic devices in today's class, later on we will focus on the tactile devices.

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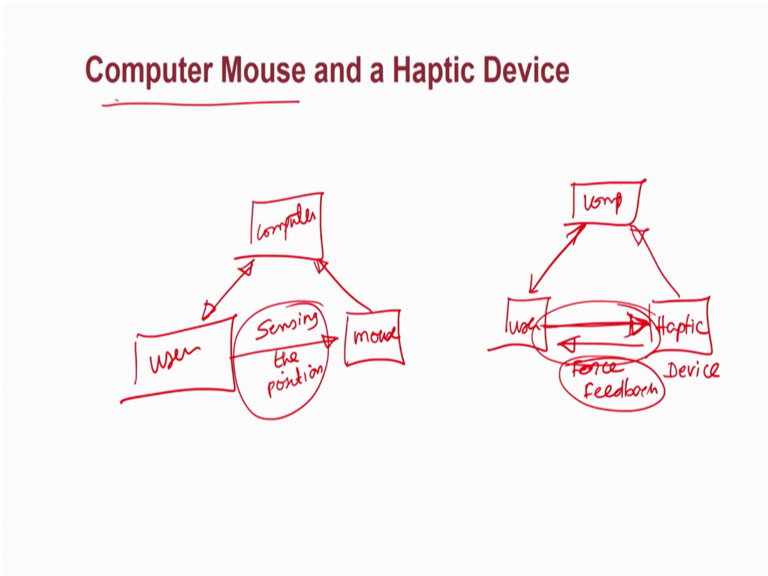

So, we are all aware of computer mouse with a very short introduction to what a Haptic devices. Can we differentiate between a computer mouse and a Haptic device. So, we have the computer over here; let us say this is a computer. We have the user over here, let us say this is a user and we have the computer mouse over here.

So, the user are see the computer and he uses the mouse and the mouse interacts with the, the mouse interacts with a computer, probably the user also can be you know view back, the visual feedback given to the user; that is a very simple you know model of the mouse.

What will happen if it is a Haptic device? We are talking about the kinesthetic device. Suppose if we have this computer again and if you have the user again user can interact with the, with a computer and just like a mouse the Haptic device also is going to be attached to the fingertip of the user and this is going to be connected to the computer.

So, it is almost like a computer mouse what could be the difference? The difference is that the Haptic device not only sensing, this is sensing the position, sensing the position of the user right. So, it not only senses the position, but also feedbacks the user, force feedback to the user. So, this simultaneous sensing as well as actuation is the you know very important distinction between a Haptic device and other devices, other sensing devices.

Think about your cell phone, cell phone, again it is a touchscreen we call it as, but again the touch screen it is acting like only the sensing the position, it is not going to you know give you touch feedback at all. So, as apple calls their I phone devices as a Haptic device; that is technically wrong, it is not going to give you force feedback, depending upon the position it is giving you a general feedback, it is simple vibration, it is like you know touching a button or whatever that vibration is a very very limited vibrotactile feedback, it is not a Haptic feedback Haptic feedback.

We are going to see in detail that it has to give a force feedback ok. Vibrotactile feedback is not the force feedback; you are going to see the differences over here. So, the simultaneous sensing as well as the force feedback is one of the important characteristic of a Haptic device.

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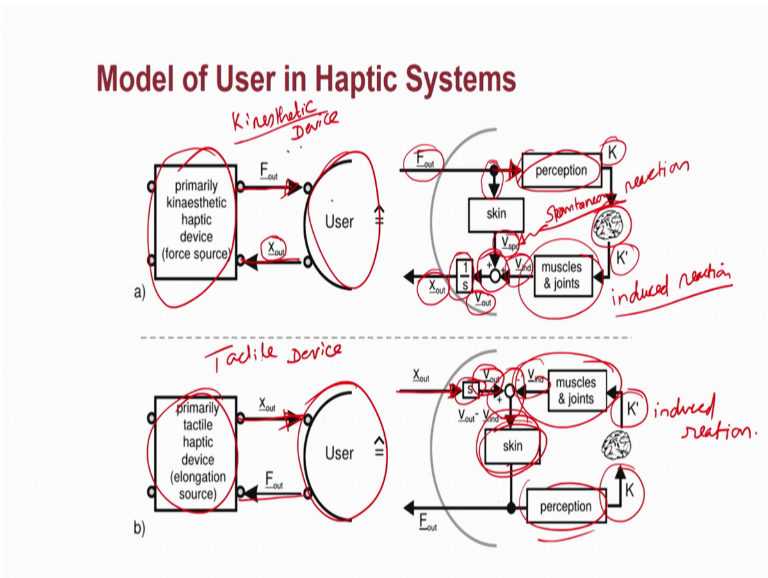

Now, let us look at the, you know model of a user in a Haptic system. So, essentially let us say we have the device kinesthetic device and here we have the user the user moves the finger and therefore, is giving a position out to the device, position and is input to the kinesthetic device and the kinesthetic device generates a force output and that is going to be given to the user ok. That is the in a kinesthetic Haptic device.

If you model the user, so the force output is coming from the kinesthetic device and this force output is changing, stretching the skin tactile, let us say tactile system as well as the kinesthetic system. So, V SPO is the let us say, this is a spontaneous reaction, spontaneous, spontaneous reaction of the user for the force which is coming from their the device and he is also perceiving, because of the forces, he is a, he is perceiving the forces.

Let us say that perception of the forces is k and that is given to the cns perception system and there is a reaction to the perception ok, and the reaction is converted into action to the muscle and joints and that reaction is going to be let us say induced, induced reaction. The spontaneous reaction is the unintended reaction, voluntary reaction; this is the induced reaction, conscious reaction.

together they are all summed up so we get a final V out and this final out V out we can convert that into you know X out; position output and that is what given to their the user. This is one simple model of user using their kinesthetic device.

The same thing if you look at for the tactile device this is for the tactile device. This for the kinesthetic device so, in the tactile device what he is doing is, we are going to keep the finger on the array of pins. So, you are going to move it, you are going to, let us say apply force onto the tactile devices and the tactile devices are going to move the pins up and down depending upon the configuration you want to see, let us say a brain system that is our typical tactile system right.

So, in this case how are we going to model the user? Again the position output is coming from the tactile devices and this tactile device, let us say; that is converted into now v out velocity out using the you know differentiation, and that differentiation is again and sensed by the skin and for.

So, here the user is perceiving the, the user is, has a perception of the tact tactical device and the perception is converted into reaction. This again an induced reaction rate, induced reaction, voluntary reaction and then voluntary reaction is moving the fingertip on that fingertip movement is summed up and then the resultant velocity is what given to the skin, and then that is what the user is actually perceiving. This perception is again there is a whole cycle of it. So, that is a tactile device is model of a user. What we will be focusing is only on the kinesthetic device.

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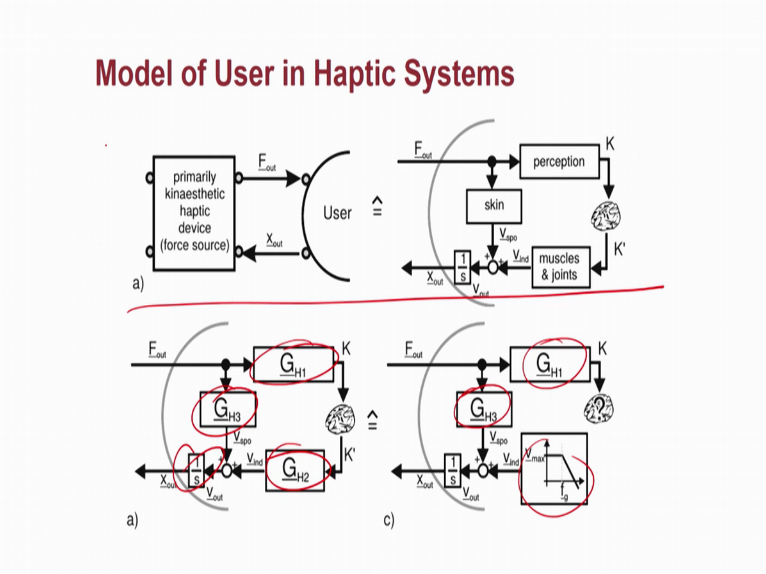

Now, this model of the user, we can consider that as a you know, all those abstracts can be converted into a transfer function, looking from the systems point of view. We can turn make it as a transfer function of each of the small blocks and this transfer function, so if we can find out and we can have a much better control of the devices, and that is one of the important and stages of machine Haptics; that is also involved in the human Haptics.

How are we going to evaluate each of these transfer functions ok, that says you know it is still an active research add and people are you know still struggling to find out, how to find out the transfer functions or of each of the blocks ok. This is for kinesthetic system and then next slide is for you know tactile systems.

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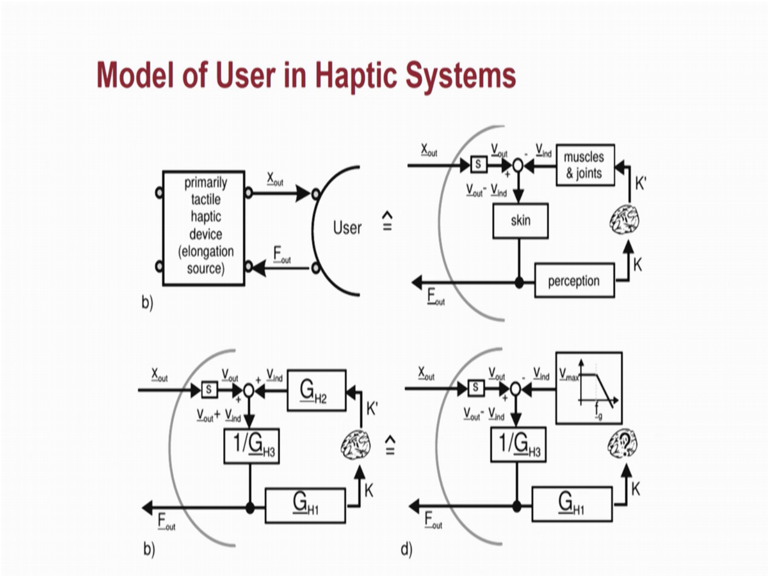

We will see in details in the coming classes, but I hope you see how we are approaching the machine Haptics all right.

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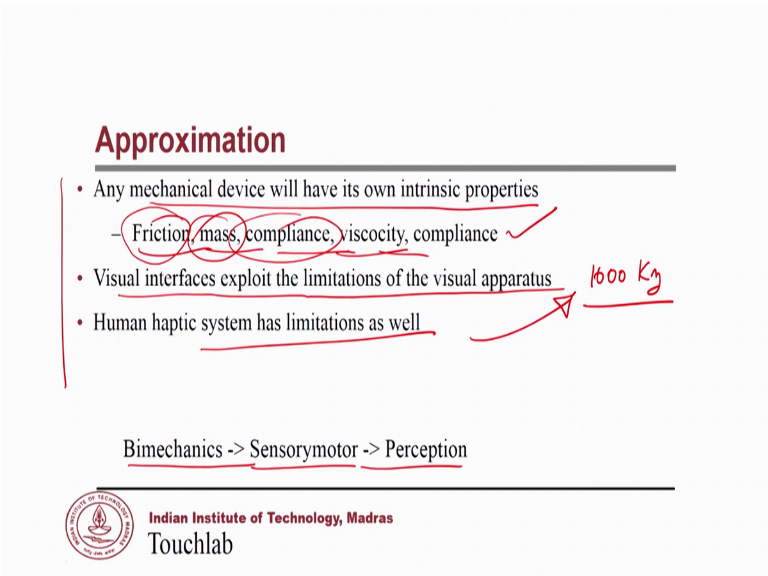

So, now we have an idea about you know how we want to go about it, but the one of the major important and challenge in the human Haptics is the, the actuator ok. So, any mechanical device will have it is own intrinsic properties. So, it will have friction, it will have mass compliance, viscosity, but what we are looking for is that, you know then you know here device or an actuator with a friction, an actuator without mass, an actuator which can deliver a lot of you know very high range of a compliances or very less right amount of viscosity.

So, these are all ideal conditions. With ideal conditions only we can design a better Haptic device. So, visual inter interfaces exploit the limitations of the visual apparatus the you, you are watching this display, the visual display which is flickering at 30 hertz. Those of you are watching the video, it may be flickering you know 60 hertz and that 60 hertz is decided exploiting the limitations of the visual apparatus.

Similarly, can we find out what is the limitation from the, our Haptic systems which we can also exploit in the design of the Haptic systems. So, in the human Haptics we studied that we need at least 1000 hertz in order to, in order to make the user not feel the vibration, that could be equivalent to you know 30 hertz in the way in the in the visual systems. Whereas, in the Haptic systems we are going to talk about the 1000 hertz update rate.

Human Haptics systems has also limitations and that limitations, a lot of limitations one of the limitation limitations is that and, until 1000 hertz we will be feeling the vibrations just like the visual systems. So, we need to understand the biomechanics sensory motor systems leading to the perceptions, that is what we have done in the human Haptic systems.

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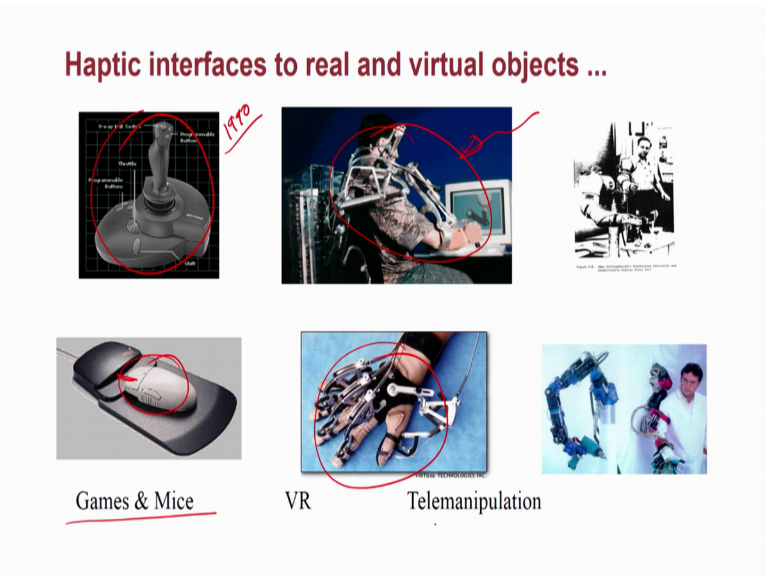

We will use lot of those numbers from the human Haptic systems. These are all some of the already available Haptic devices. One of the first Haptic devices which came into market, sometime in 1990s is this force feedback joysticks ok. I think I am I have a you know very nice personal anecdote of.

Now working with the inventor of the first force feedback joystick, it was a lady ok, that is Marcus, she is alumnus of MIT, she started this company, very small company ok, she made this the force feedback joystick and then sold it to sold it to Microsoft for a huge money. There was a time the dot com and our Bubble is yet to come ok, she made a lot of money and then she started making more companies and then invested in a lot of you know dot com companies and then finally, you know it was a, she lost almost all the money back.

So, I had a chance to work on this first force feedback joystick, when Microsoft was sued by one of the another companies is for designing and for that pattern on this is a first force feedback joysticks. So, we had to make some demonstrations and to make it as a legal case and then produce it in the, you know court to win the case there was a.

So, that is one of the first force feedback joysticks, and then came you known force feedback mouse have you seen this. So, the you know the ordinary computer mouse will not resist your moments, but suppose if the position of the mouse can be restricted in a 2 D ok. So, that using a 2 D Haptic device; that is the computer mouse.

So, there are exoskeletons again one of the earlier ones or major challenge with the exoskeleton is that, you can see that the amount of you know linkages and then actuators in the human hand it is enormous, what we want is all these devices should be you know as light as possible. In fact, it is a zero mass is what our ideal requirement is that is not at all possible.

So, you have to, the user has to carry all this masses and it is going to generate a small force on your finger ; that is going to be killing the feeling of the emotion, the feeling of the purpose of the Haptic devices. Similarly the you know cyber glove also. So, we are going to review all this machine Haptic interfaces in a detail later.

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This is the, you know one of the few reason exoskeletons. One of the earlier 2 D Haptic device is called the pantograph. Sorry.

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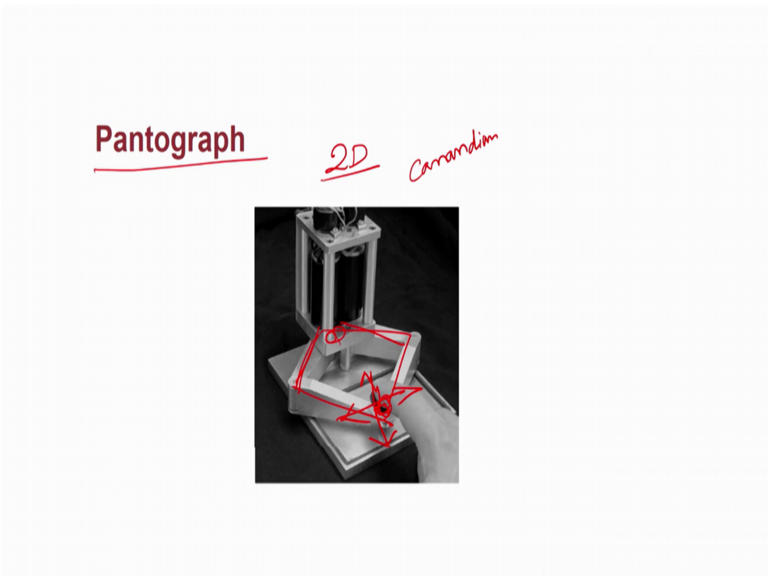

So, this pantograph has a parallel architecture, the user is holding over here and he moves in 2 dimensions and there are two actuators for one arm, or one actuator for one arm another actuator for another arm. So, there are two actuators which is controlling the position of the x and y axis. This is from Canadian Canadian academic institute which is very well known called the pantographs we have.

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Again we are going to see in detail I drive for navigation is one of the latest Haptic device, but it is a one degree of freedom and you know how many of you have heard about BMW in the latest versions has this device is called the I drive. So, just hold the knob over here while driving is essentially in the Europe, if you look at it the roads are very very you know fine. You can drive the car at you know 200 kilometers per hour or whatever it right.

So, when you are traveling at 200 or 300 kilometers per hour or, a very small mistake you do, if you take off your eyes from the road off of you are in great danger. So, we need a lot of interfaces to help the user or the driver or to manipulate objects in the car without taking the eyes off from the road. So, there are ac switches, there are a fan and radio there are so many controls in the dashboard of the car ok, but the user has to you know access it, but he cannot take the eyes off the road ok. One way is using this I drive you just you know reach it and then navigate all the controls in the dashboard using only one point contacts ok.

So, it has a 1 degree of freedom, using this simple Haptic feedback you can control many of the things. So, even though it was considered as you know major technology BMW had this device in most of the cars. At the latest edition of the BMW this is not there ok. So, it may be a good exercise for you to find out why BMW did not include the, I drive in the latest cars I would like you to think about it.

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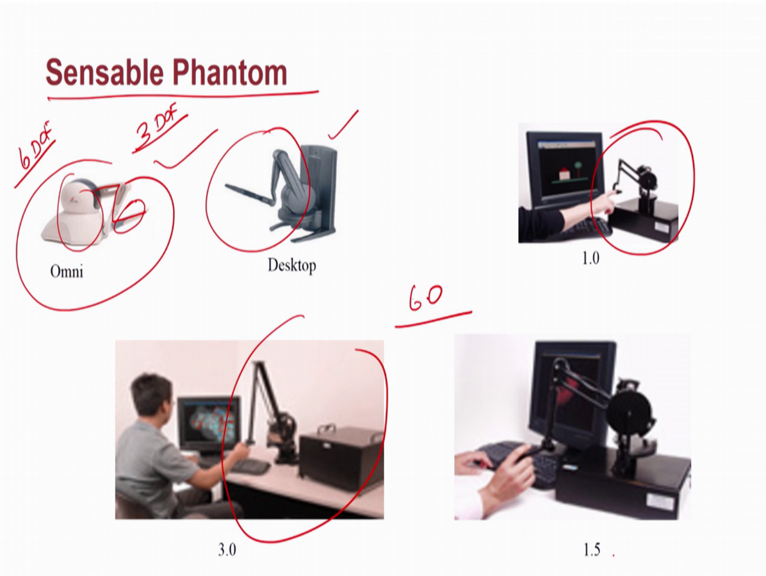

The market leader in the Haptic devices is called the sensible phantom ok. So, sensible phantom you hold this stylus like a pen and then move this manipulator and this device is going to give you a resistance, this is. This device is a startup company from MIT and still it is the leader, in the you know Haptic devices. Each one is a you know.

This is a 3 degree of freedom force feedback, but it is a sensing is 6 degree of freedom ok. Sensing is different from the actuation back. So, sensing can be you know 6 degree of freedom, but you know force feedback is only 3 degree of freedom. These are all the higher end.

Here it is going to be you know work space is going to be more, more force it can generate and this is even higher version and this is even higher version and there is one version, this is 1.5, there is one version. Now 6.0 also is there ok so, 6.0 is going to be astalos a human being and we can move our hands in a large workspace ok, that cost is very very high ok. We are going to study in detail how this phantom is working.

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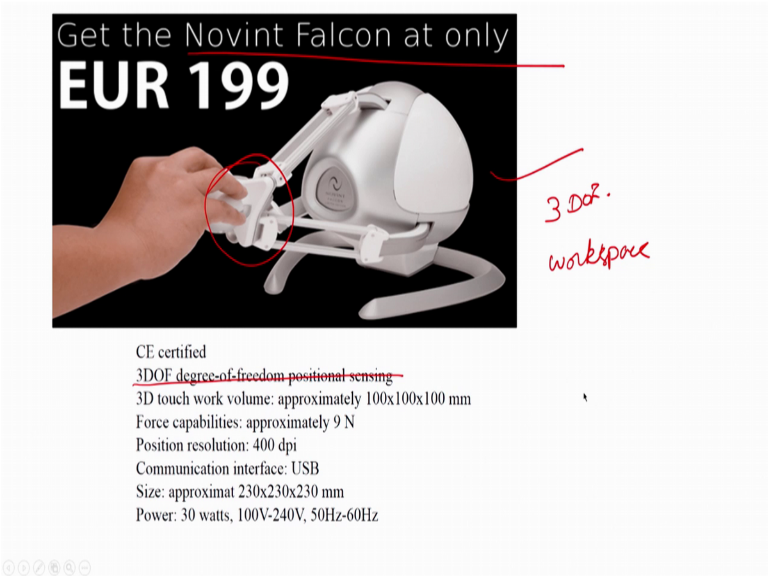

One of the cheapest devices in the market is called the Novint Falcon. Again is as one of the inventors of this Novint Falcon is from MIT, it costs just 200 dollars or 200 Euros as a it is now it is resolution is very poor, the force feedback also is very poor and workspace also is very poor. it is a very small work space and it is again a in a 3 DoF 3 DoF position sensing as well as the you know force feedback both of things. Again we are going to see how to make a very simple Haptic device as a part of this course ok.

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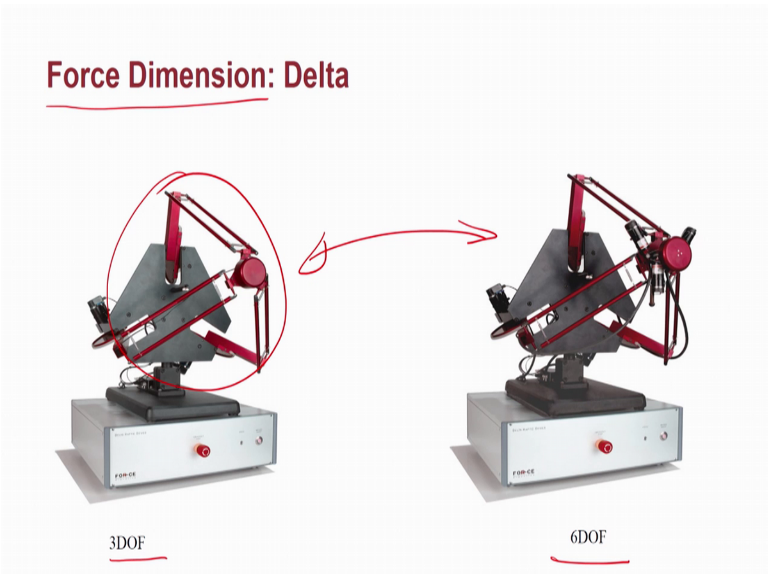

So, recently there are new players, apart from the sensible phantom, they are called you know force dimensions which can give you know more forces and there are 3 DoF versions and there are 6 DoF versions and again we are going to see different architectures of the Haptic devices, if these are all parallel architectures, where the phantom one which you have seen earlier that is all the serial architectures, we are going to see [noise what are the different kinematic chains, use to develop develop Haptic devices.

Most of the things with this devices all this, any Haptic devices can be considered as a advanced robotic devices ok. We are also going to see what is the difference between the robotic device and Haptic device. So, all this concept the robotic device students, and so can we will find out you know lot of commonality between the Haptic device design and the, you know robotic devices and you will find and what more is needed in order to design a Haptic device. It is much more challenging than just developing a Haptic robotic device ok.

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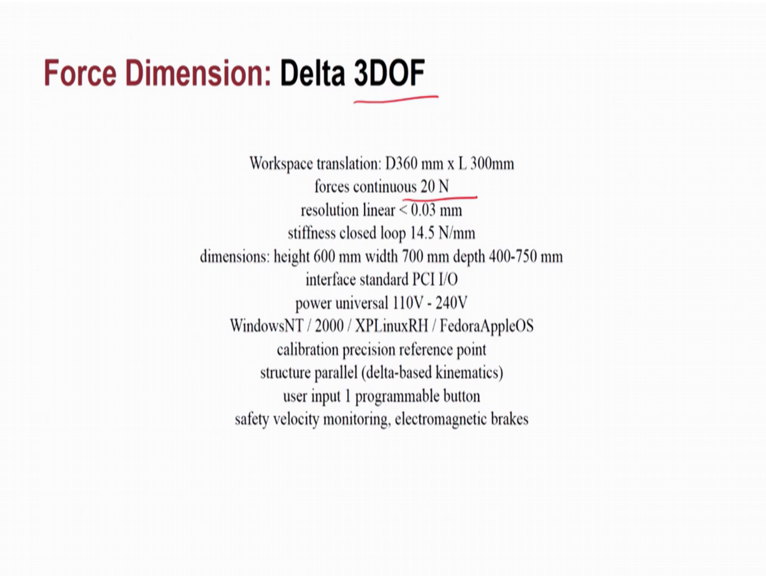

These are the specifications of the, you know delta 3 DoF. Again the maximum force, it can give you is the 20 Newton, 20 Newton is about how much 2 kg. If you can hold a 2 kg weight that much force it can give you in each of this degree of freedoms.

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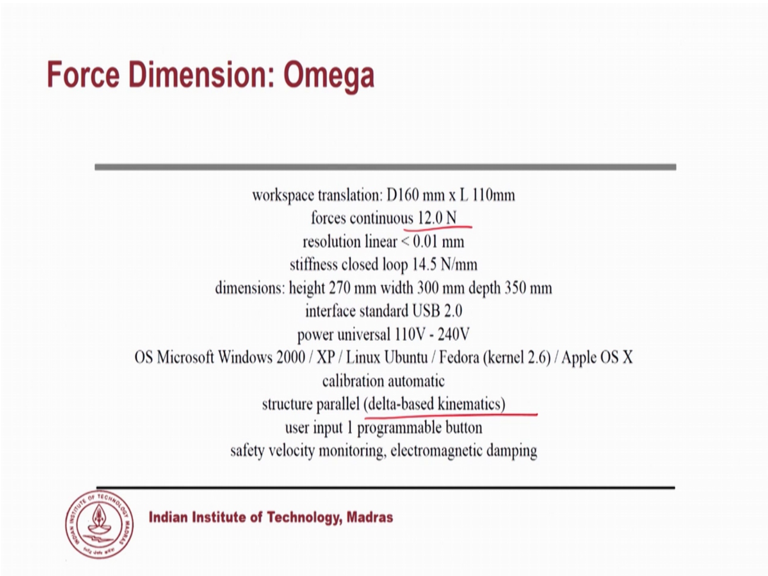

They have a recent version of omega. Again and the difference is that 6 degrees of freedom and they have you know 12 Newton which is much lesser and it is using that delta based a kinematics, those of robotic students will understand, it is a parallel specifically delta structure, kinematic structure.

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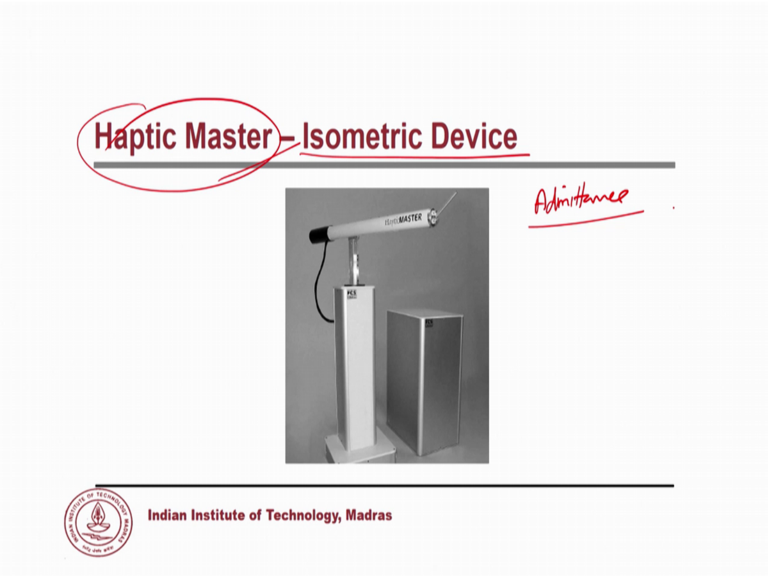

Ah We are going to see different type of the Haptic devices as where or one and device is called the Haptic masters, because it is a very well known it is a very distinct, different from all the existing Haptic devices. It is the isometric device. It is also called the admittance device. We are going to see when we are talking about the different control systems in the (Refer Time: 30:50) for the Haptic devices, you are going to use either impedance devices or admittance devices.

Most of the Haptic devices available in the market use the impedance control. Whereas, Haptic master is using the admittance control. We are going to see different isometry, this is impedance as well as the admittance in the coming classes ok.

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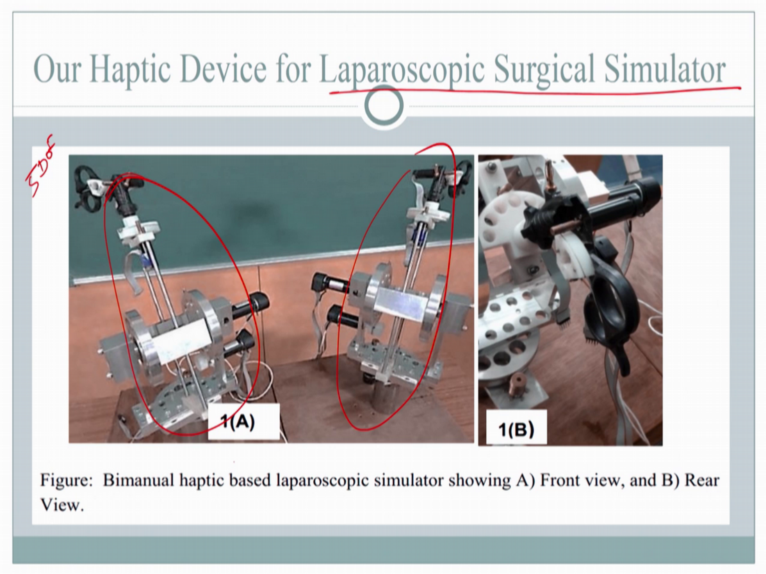

This is our own and a Haptic device which we have designed, specifically for the laparoscopic surgical simulator. This is a you know, this is for one hand this for the another hand, each hand is a 5 degree of freedom sensing as well as the force feedback, both the sensing as well as the force feedback.

Sorry the work space requirement is as dictated by the laparoscopic surgeons, whatever they wanted that has been incorporated over here. If such a device has to be bought imported from other countries it cost about to 2 crore. Whereas, you know in IIT Madras the whole device has been fabricated within the campus and it cost much less than you know you know 5 lakhs ok, that is see you know innovation we could bring it.

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So, that device has been put in the inside the small box over here and the final device what the doctors will use is going to be something like this ok. This is one of the our research scholars using this device ok.

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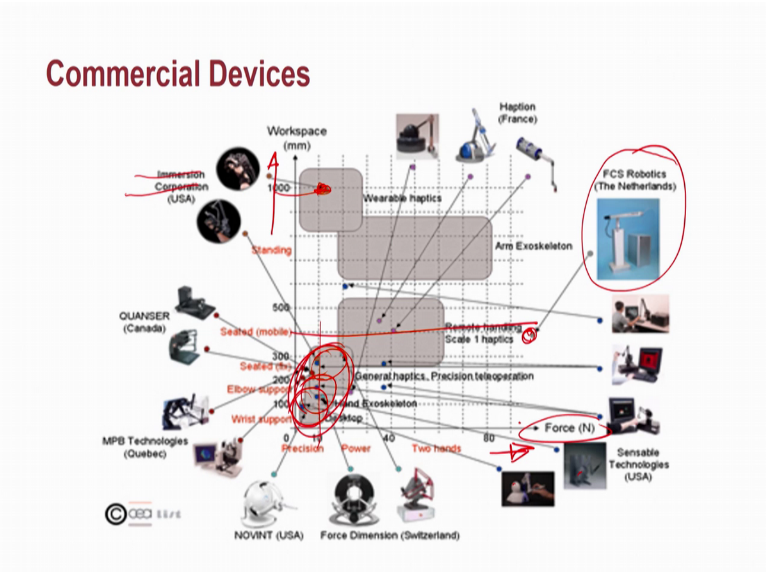

All the commercially existing devices can be compared in two different axis. Suppose if you compare in the x axis of how much force they are generating and in the y axis how much is a work space ok. So, our sensible phantom is somewhere over here, desktop phantom, sensible phantom is precision power 2 (Refer Time: 33:09), there is a sensible phantom, quanser ye, now in falcon, it is over here. These are all over here sensible phantom.

The little higher version is going to be here; even more little higher version is going to be over here. So, where is if you look at the, if you look at the another device called the Haptic master it is going to be over here. It can generate you know very large force and the workspace also is very high compared to the other devices. So, most of the devices are over here ok.

Student: Sir that is the admittance time right.

This is the admittance time; yes. So, we this device if you look at it this is a immersion and corporation it is a force range is very less, but it can have a very large work space, depending upon the range of the work space and the force it can generate the cost also vary.

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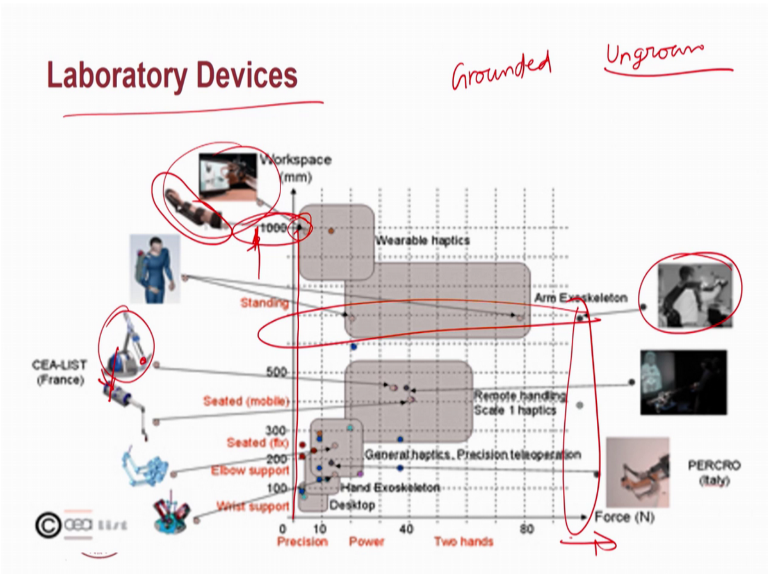

These are all commercial devices, but there are devices available in the laboratory still. Again x axis force versus workspace, if you look at it and that there are you know exoskeletons which can have a you know large amount of forces as well as the work space. There are you know in the, for example, this device it is again like a like exoskeleton, but the force it can generate it is very very less and it is work space can be very high.

Again the problems with the exoskeletons all those devices can be divided into two categories; one is the ground based, grounded or ungrounded. So, if you look at this devices, it is its grounded, it is staying on the ground. So, any force it is generating, it has to be you know compensated by the reaction force the reaction force can be transmitted to the ground. Whereas, the forces you are generating in the exoskeleton they are all ungrounded. In fact, it is called a Bodily grounded.

So, the generated force has to be you know compensated by the reaction force on your skin ok. So, those are the challenges. If you have a force which is generating on the finger, if you have a small exoskeleton then whatever the force you are generating, it has to be transmitted over here itself. The reaction force has to be transmitted over here ok.

So, is, will that destroy the immersion will, will that destroy the purpose of generating the Haptic feedback that is all the question. Those were the challenges now researchers are still facing.

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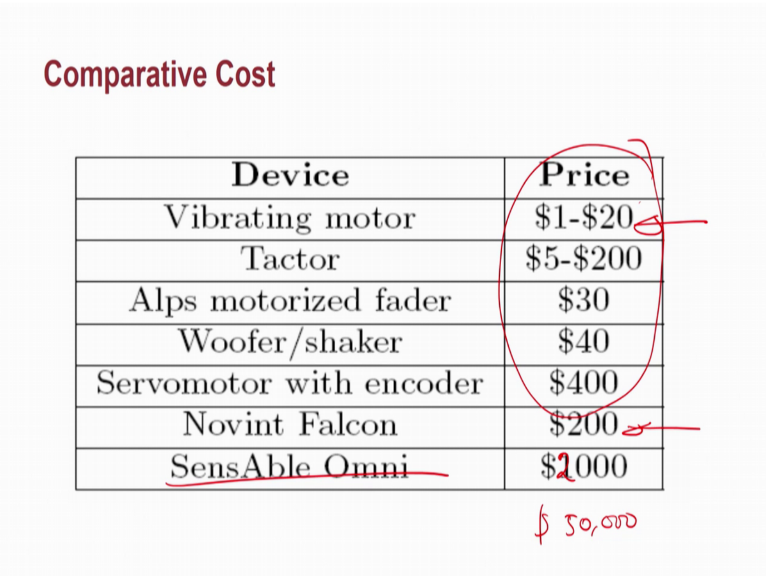
Comparative Cost

Device	Price
Vibrating motor	$1-$20
Tactor	$5-$200
Alps motorized fader	$30
Woofer/shaker	$40
Servomotor with encoder	$400
Novint Falcon	$200
SensAble Omni	$2000

So, there are you know cost wise we can compare it, it can go up to dollar you know 50,000 each, each device can cost about 25 lakhs.

So, SensAble Omni, maybe it is about 2,000 dollars or 3 2500 dollars as of now ok. Now in falcon as I told you it is 200 dollars. Other vibrotactile devices can be much more simple, simple vibrotactile device, it can be even 1 DoF, but it can develop only the vibrotactile feedback, not the not the Haptic feedback.

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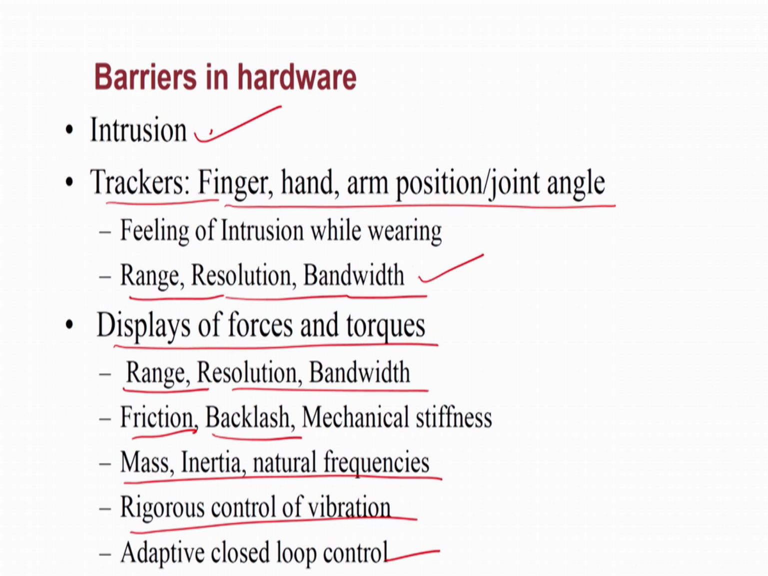

So, in all these things as I told you actuator is a major issue. So, we are still searching for the ideal actuator, in the whole of the one important challenge in the Haptic device, if you ask me that is the now finding the right actuator, ideal actuator, we are still to invent an ideal actuator for the Haptic devices.

So, without intrusion, how are we going to generate the force feedback that is the challenge. So, we need to find out the, you know position. So, we need to find out the trackers in order to give you the range and resolution and the bandwidth, whichever we have learnt in the human Haptics, all those things, you know without the intrusion we need to find out it we need to find out the positions.

And then when you are generating the forces and torques again actuators is going to be a challenge. Again we know what is the range and resolution and bandwidth of the forces which the human can sense. Can we find out actuator which can match this requirements, frictionless and backlash ok. Backlash in the sense when you turn front and back there should not be any you know change in the pos, change in the, there should not be any you know gap ok. If you use a gear devices, there is a small gap as a backlash.

So, gears cannot be used in Haptic device at all ok. If you cannot use a gear then what are, how are we going to generate force and then transmit the force.

Student: (Refer Time: 39:10)

So, all those details we will study in the in a later classes. Again as we said mass has to be 0; the inertia has to be 0; that is not possible ok. How are we going to overcome all those challenges, the rigorous control of the vibration and an adaptive control, this also challenges.

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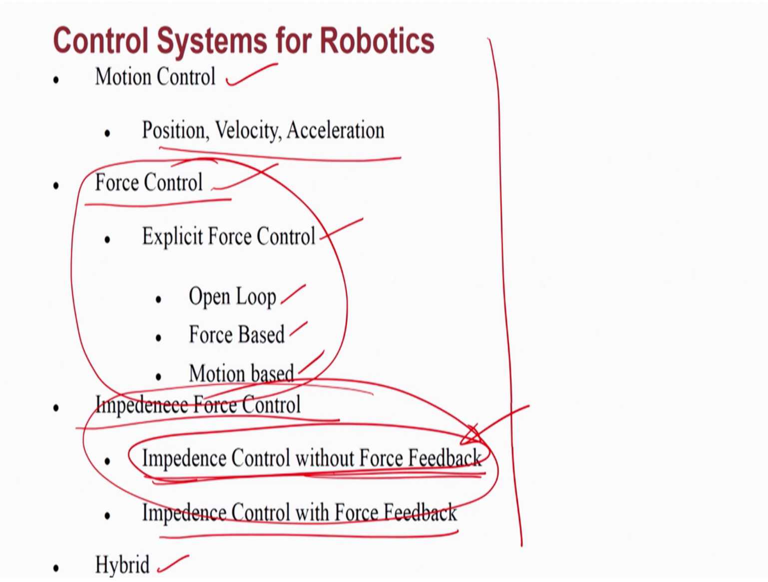

So, each of these challenges which we are going to see it in the later classes, as far as the control system is concerned. Again for those students who have taken the robotics classes ok. If you if you, if you see you can classify all the control system for robotics into majorly four classifications. One is the motion control, where you can control either the position velocity or acceleration or the force control, where we can explicitly control the forces or the implicitly control the forces. In the explicitly control forces again we can have a open loop or a closed loop.

In the closed loop we can find out whether the force based explicit force control or motion based explicit force control ok. Again I will go into the details it. Instead of controlling the force, I think most of the robotic control systems are force control based, which is not going to be useful for us. We are going to see that impedance control is what now we need. I think in the human Haptics class we talked about why impedance control is necessary ok.

In the impedance control again we, we can have two different types impedance control, without the force feedback impedance control, with force feedback and then finally, the hybrid of any of these things is what you will find it in the robotics. We will be focusing mostly on the impedance force control and specifically impedance control without the force feedback. So, all the sensible phantom are most of the devices, they are using this impedance control without the force feedback.

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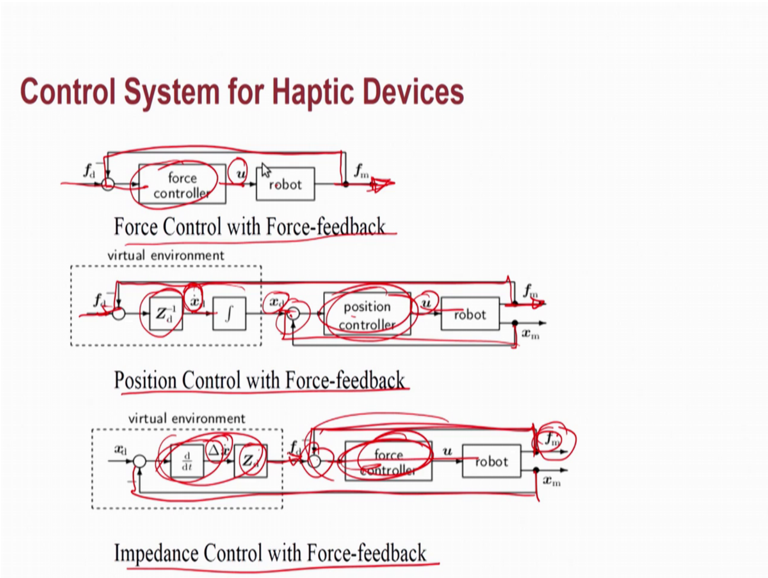

So, essentially if you look at the block diagrams for the force feedback. Suppose if you have a force controller and let us say this is a target force and suppose if the controller, the robo is giving the force output, the generator force can be compared with this and then force control or can have a output. This is the change in the length yeah and that is given to the robo, this is a force control with a force feedback, you are controlling the force over here.

Another possibility is that position control with a force feedback. Again the output is a force, the input also uses a force, but the position can be sensed and then given to the position controller. The position controller can be given to the robo, but the force also can be given back, sensed and then and inverse of the impedance.

We can multiply it or integrate it to get the ok, inverse of the impedance and to get the velocity and velocity if you integrate it we will get a position, and that position is again controlled. So, there is a you know positive summation over here and that can be controlled. This is the position control with the force feedback.

Impedance control with a force feedback in the impedance control what is controlled or is the impedance, where the force controller is over here, the force at the output is measured and then summed up over here. The position from the output is measured and given to the impedance controller over here. The impedance control we are finding the velocity and then that is multiplied by the impedance, what we get out, is the force and then that force is summed up with the output force or differentiated with output force and that is what is controlled over here.

So, in Haptic devices, we will be using much simpler one, because you know measuring the force at the output is going to be extremely difficult it is going to add a lot of cost to it. So, without the force control.

Student: Position.

Position alone can be used to control the impedance and that solves the problem ok. So, there will not be a force controller, they will not be force measurement, but there will be a position feedback and then the impedance controller will be there, that is what the usual for example, the sensible phantoms have been using it ok. We will look at different other control systems in the coming classes.

So, as I think I mentioned and why we needed the impedance control in the human Haptics class.

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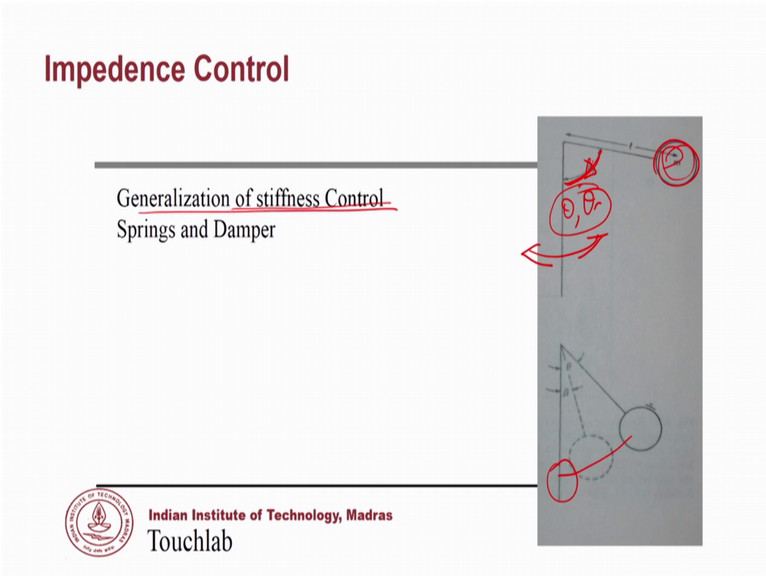

You remember we needed the, not only the angle for example, this is a hypothetical pendulum. If we control the position of the pendulum with the angle control alone and it will swing back and forth, if you control will the pendulum not only with the angle, but also theta dot, then we can control it and then make it not swing beyond this position and that is what we have.

So, that is the reason we needed the impedance control. Impedance control is the you know generalization of the stiffness control, which we have seen in the earlier classes.

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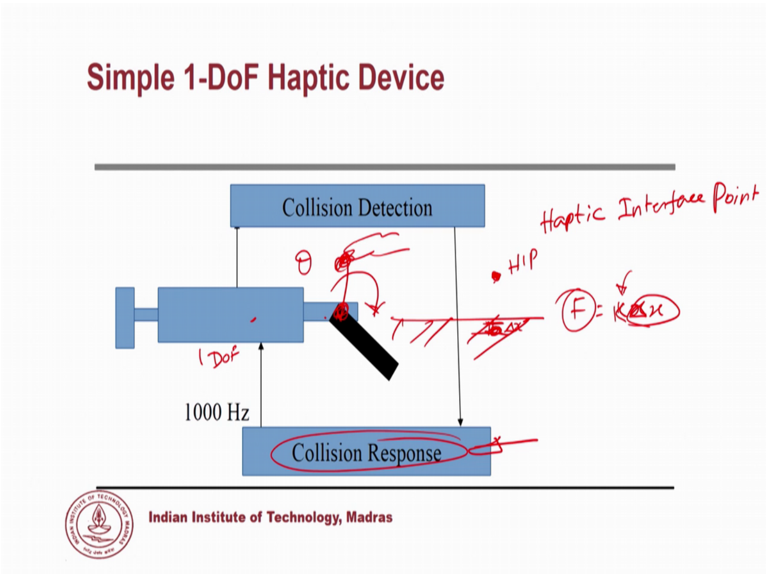

So, this is a simple Haptic device which you all going to you know make a simple Haptic device. Suppose if we have a rod and this rod is where you are going to hold it ok, and then you can rotate it. Let us say this is a 1 degree of freedom Haptic device so the angle can be measured.

So, let us say there is a virtual wall over here and this is a position. Let us say this position is represented by this, this is called the Haptic interface point hip. So, this Haptics interphase point we can check whether it is colliding with a virtual wall at every frames. If it is not colliding then we do not have to generate a force feedback. If it is colliding suppose at some time it has come in there, then we need to find out how much force it has to generate.

For example how much torque this motor has to generate in a 1 degree of freedom. So, we will have a different models of force response. For example, simple is, it depends upon the, you know depth of penetration we can find out F is equal to k x it is a simplest model, k into ok. Let us say delta x this is the delta x. So, we know that delta x. Let us assume that the virtual wall has some stiffness and therefore, we can find out the force and then force can be converted into torque, we can ask the motor to generate the torque. This is a simple simplest a 1 degree of freedom Haptic device.

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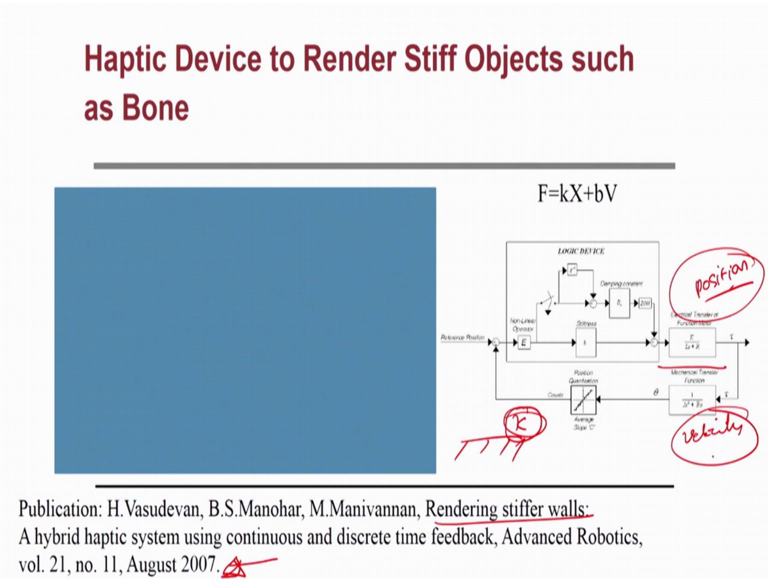

We have developed a 1 degree of freedom Haptic device in our lab, but having two different loops; one is controlling the position, measuring the position and another is measuring the velocity. So, in order to render stiffer walls, the virtual walls what you have, there is going to be a you know maximum limit on these stiffness what you can have, as far as the stability is concerned.

So, in our earlier work we measured position as well as velocity and then increase the maximum stiffness of a virtual wall that can be rendered by the same Haptic device. This is one of the our earlier works in 2007, the student who had worked on this is right now working in Apple designing Haptic devices ok.

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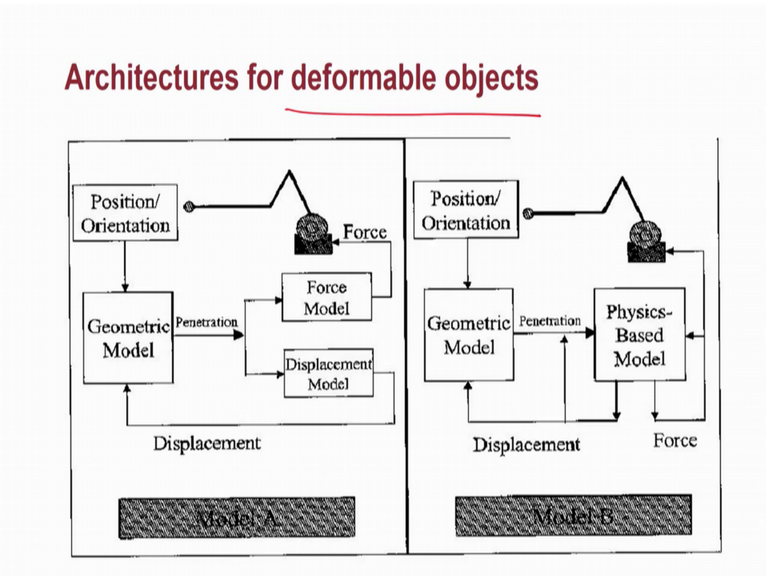

There are or, all these devices or for you know rendering a rigid object, but you know we can also have you know deformable objects rendered. We will see the details of deformable objects rendering in a later class.