Robotics
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Lecture – 03
Introduction to Robot and Robotics (Contd.)

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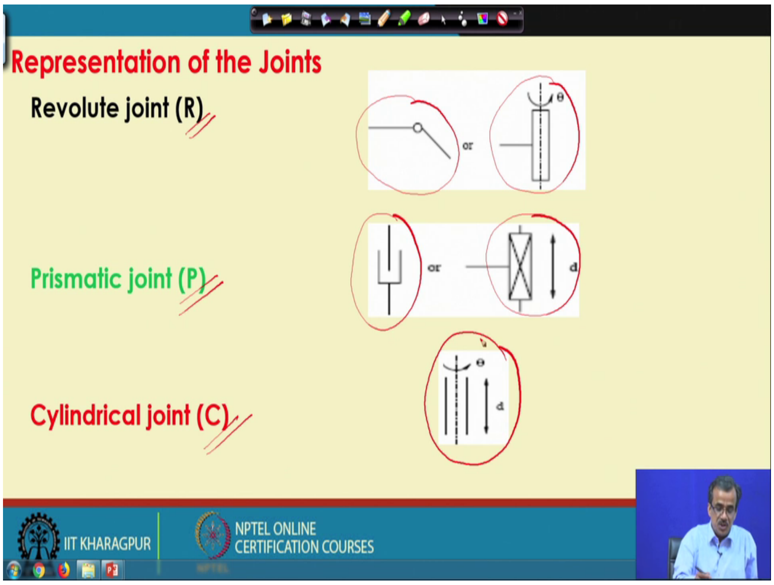

Now, let us see how to represent the different types of joints used in robot with the help of a few symbols, so that we can represent the whole manipulator with the help of the a few symbols. Now, here this revolute joint we have already discussed that is denoted by R. And this particular symbol is also used to represent the revolute joint. This is another symbol, which is also used to represent the revolute joint.

Now, then comes your the prismatic joint that is denoted by P, we use either this particular symbol to represent the prismatic joint or that particular symbol to represent the prismatic joint. Now, then comes your cylindrical joint, that is denoted by C. And here, so we can use, so this particular symbol to represent the cylindrical joint.

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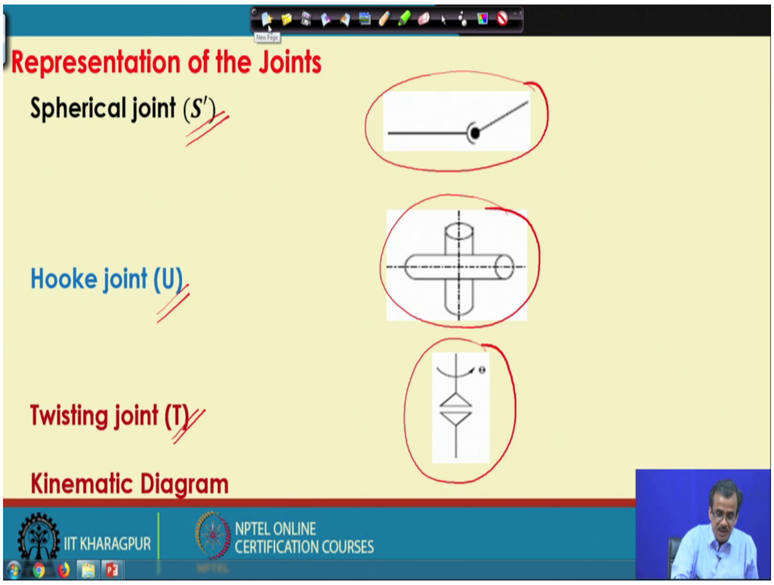

Then comes your the spherical joint, which is having 3 degrees of freedom, so that is actually a is represented using this particular symbol S prime, and we can also use this particular symbol to represent the spherical joint. The Hooke joint having 2 degrees of freedom is denoted by U. And it is also used, so this particular symbol is also used to represent the Hooke joint.

Now, then comes your the twisting joint, this is also a rotary joint, that is denoted by T. And this is this particular symbol is also used to represent your the twisting joint. Now, with the help of these particular joints, we can represent the manipulator. So, before you start doing kinematic analysis, so what a do is, we try to represent the whole robot or the whole manipulator with the help of, so these type of joints used for the these type of symbols used for the joints.

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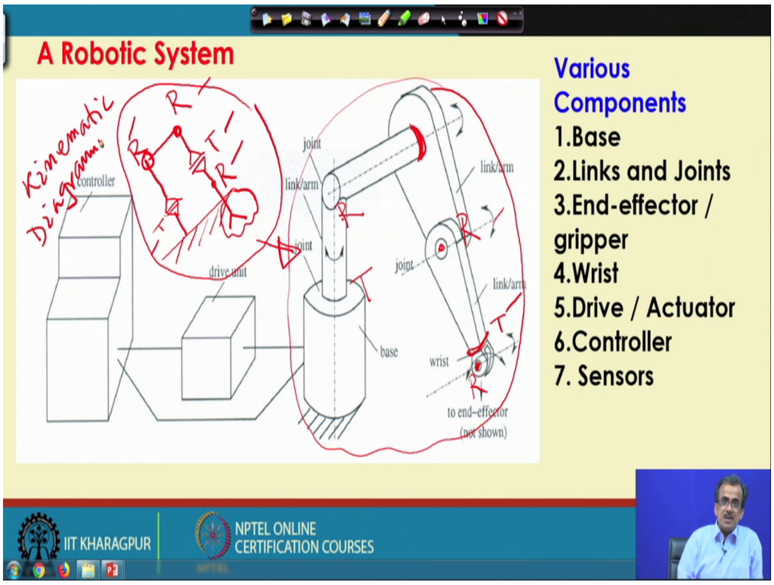

Now, let me take one example here, to take the example actually I will have to go back to the previous slides so where we consider a robotic system. Now, here in this particular robotic system supposing that say as I told that, this is one serial manipulator. And the same serial manipulator I just want to represent with the help of the symbols that means, I want to prepare the kinematic diagram of this particular the manipulator or the robot.

Now, let us see how to prepare the kinematic diagram. To prepare the kinematic diagram, what we do is, we start from the base. So, here I have got a fixed base, so this is denoted by fixed base. And I have got one twisting joint here, so here I have got a twisting joint. So, let me draw one twisting joint with the help of symbol, so this is the symbol for the twisting joint said T.

Next joint is here, that is a revolute joint. Now, remember here there is no joint actually this is rigidly connected. Here, there is no joint, the joint the rotary joint is here, that is a revolute joint. So, to represent the revolute joint we take the help of, so this type of symbol, this is the symbol for the revolute joint. Next joint is here, so this is another revolute joint. So, I am just going to use the symbol for the revolute joint.

The next is your so this particular the twisting joint, and this twisting joint is the wrist joint, so this is a twisting joint. So, I will have to draw one twisting joint here, so this is a twisting joint. And after that, actually I am just going to connect one end-effector or the gripper here. And this particular joint will be nothing but a revolute joint. So, there will be a revolute joint here, and after that there will be the end-effector. So, this is actually the symbol for the end-effector.

So, this is the last one is nothing but a revolute joint. So, let me repeat. So, this is the twisting joint, twisting joint, a revolute joint, revolute joint, revolute joint, revolute joint, then we have got the twisting joint, twisting joint. And here, so we have got the revolute joint with the help of which I connect the end-effector, so this is nothing but a revolute joint. This is what we mean by the kinematic diagram of these particular robot ok. So, this is known as the kinematic diagram kinematic diagram for this particular the robot.

In robotics actually as we mentioned little bit, that there are four modules. And all such modules are actually explained one after another, and these are all dependent also. So, gradually I will be discussing all such things. But, the starting point is the kinematic diagram, based on the kinematic diagram.

So, I am just going to carry out the kinematic analysis that is the kinematics, based on kinematics; I will be discussing dynamics, based on dynamics; I will be discussing the control, control scheme. And once that particular the robot is ready, now after that I will try to incorporate intelligence to make it intelligent and autonomous. So, all such things actually I am just going to do one after another.

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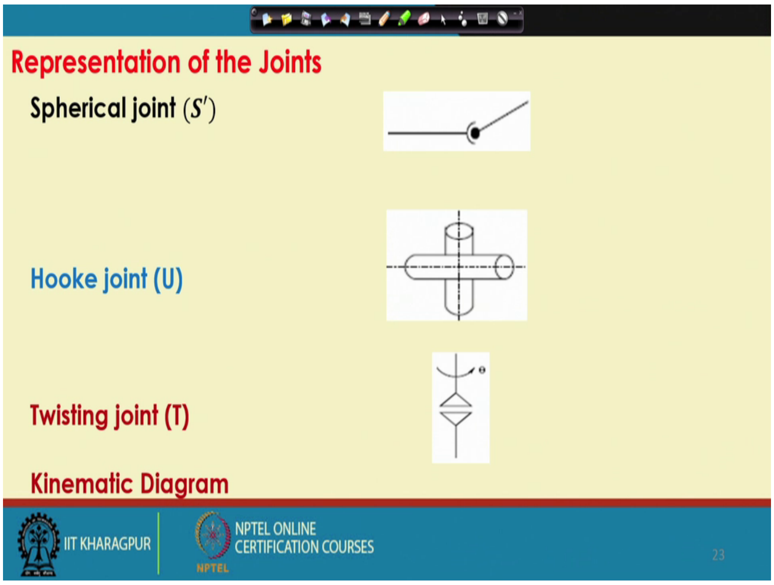

So, let us try to come back to the original, where we stopped. In fact, this is the place. So, we have seen how to prepare the kinematic diagram, and the purpose of kinematic diagram as I told that just to represent very simply with the help of a few symbols that complicated robotic system. And, so this is the purpose of your, that kinematic diagram.

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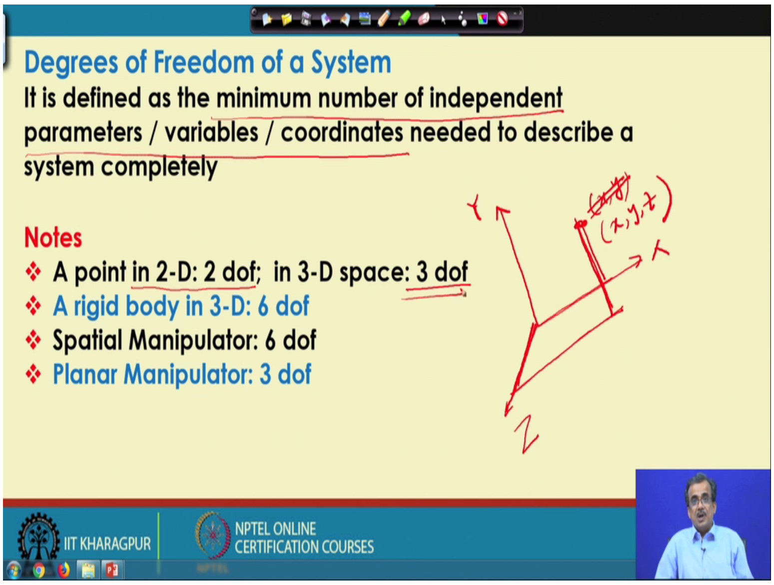

Now, once you have studied the degrees of freedom or connectivity of the different types of robotic joints. Now, I am in a position to discuss about the degrees of freedom of a robotic system. Now, the degrees of freedom of robotic system is defined as the minimum number of independent parameters, variables, or coordinates needed to describe a robotic system completely, and that is nothing but the degrees of freedom of a robotic system.

Now, before I discuss, the degrees of freedom of a robotic system a few preliminaries, which all of you know, I am just going to recapitulate. For example, say a point in 2-D plane has got 2 degrees of freedom. For example, say I have got a 2-D plane like this, say x and y. And if I want to represent a particular point, I need only two information, one is your, so this x information, another is y information. And supposing that it is having the coordinate x y, so I need only two information. So, a point on 2-D has got only 2 degrees of freedom.

Similarly, if I consider a point in 3-D, for example, if I add one more dimension here, say z, x, y and z so what I need is, so I need your the z information also to represent. So, your x, y and z information, so all 3 information actually I will have to find out, so this is one information, this is another information, this is another information.

So, in place of x y, now I need x, y and z. If I consider the 3 dimension, that means a point in 3-D space has got 3 degrees of freedom. So, I think this is clear to all of you. Now, a rigid body in 3-D has got 6 degrees of freedom. So, how to define that, how to how to explain that a rigid body in 3-D space has got 6 degrees of freedom.

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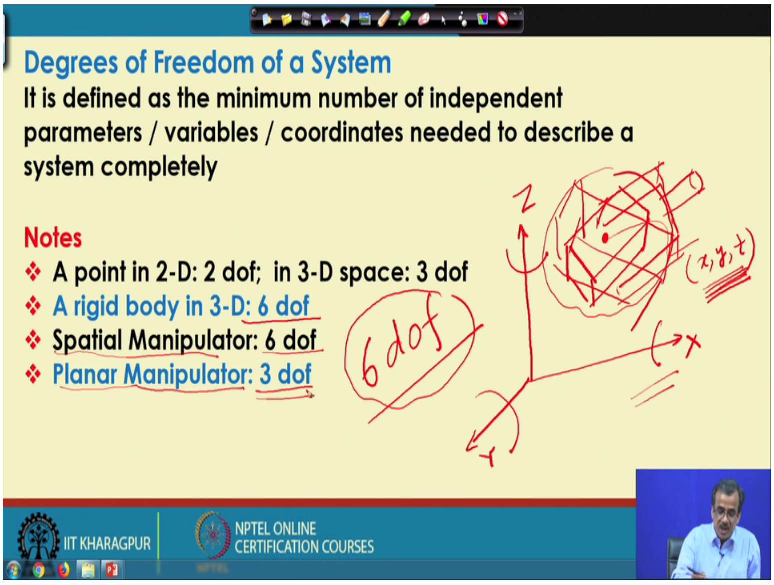

Let me take a very simple example. Supposing that I am once again considering X, Y and Z, so X, Y and Z, the 3-D space. And I have got one 3-D object, very simple 3-D object like this. So, this is the 3-D object, which I have. Now, if I want to represent, so this particular 3-D object in this 3-D space, how to represent. To represent this 3-D body in 3-D space, actually what we do is, we first try to find out the mass center. Now, supposing that the mass center of this particular 3-D object is this, and it is having the coordinate say x, y and z.

So, to represent the position of this particular mass center, I need three information, x y and z. And now this particular 3-D object can have different orientation also, so this is one orientation. Similarly, there could be some other orientation also, this could be another orientation. Now, for this particular orientation to represent the orientation, so once again I need to take the help of rotation about X, rotation about Z, rotation about Y. So, I need three more information. So, three information for position, and three information for orientation or the rotation that is why, a 3-D object in 3-D space has got 6 degrees of freedom ok.

Now, if I want to manipulate, so this particular 3-D object in 3-D space. For example, say one serial manipulator is going to come here, just to grip this particular object. Supposing that, it is going to grip it like this, so it is going to grip it like this, say I have got a gripper, say I have got a gripper here, and with the help of this gripper, say I am just going to grip it say. Now, with the help of this particular gripper, if I want to grip this particular object, what I will have to do is. So, this particular gripper should be able to grip this particular 3-D object in different orientation, and different position that means, if I want to grip with the help of a serial manipulator.

So, this serial manipulator should have ideally 6 degrees of freedom. And that is why, in most of the industrial robot is having 6 degrees of freedom. Ideally one industrial spatial manipulator should have 6 degrees of freedom. For example, if I take the example of PUMA, Programmable Universal Machine for Assembly. So, so it should have 6 degrees of freedom, ideally speaking.

And that is why, actually I have mentioned here, for an ideal spatial manipulator there should be 6 degrees of freedom. For a planar manipulator, which is working on 2-D plane, it should have ideally 3 degrees of freedom. So, by definition, a spatial ideal manipulator should have 6 degree of degrees of freedom. And a planar manipulator should have 3 degrees of freedom.

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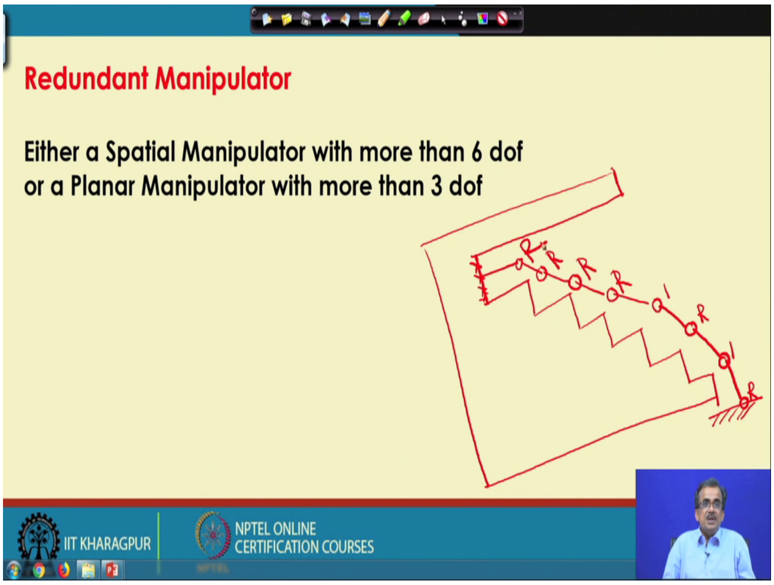

Now, comes the concept of the redundant manipulator. Now, remember sometimes to subs is specific purpose. We need to use some sort of redundant manipulator. And this redundant manipulator, if it is a spatial one, it should have more than 6 degrees of freedom, like 7 degrees of freedom, 8 degrees of freedom. If it is a planar manipulator, it should have more than 3 degrees of freedom; say 4 degrees of freedom, 5 degrees of freedom and so on. And as I told, these type of redundant manipulators are used just to have some specific purpose.

Let me take one very simple example. This is a very practical example. Supposing that, say I am just going to do some sort of welding with the help of a serial manipulator at a place, which is very difficult to reach. Let me take a very hypothetical example. Say this is the place, where I will have to do this particular welding, and this place is so remote, that it is not so easy to reach that particular place. And supposing that, this is the geometry, and supposing that it is so much constrained, so this is the scenario. And at this particular position, say I will have to do this particular welding with the help of a serial manipulator. And the base of the serial manipulated is here ok.

Now, if I want to do the welding here, with the help of a serial manipulator, the welding torch has to be gripped by the end-effector of this particular the serial manipulator. And to reach that particular point the base is here. So, I need to use a number of links, number of joints, so might be one joint, one link another joint, another joint, another joint, another joint, another joint, another joint, and might be then only I will be able to reach this particular the position.

Now, if I use this type of serial manipulator, which is a closed sorry which is a the open loop chain. So, how many revolute joint we are using one revolute; another revolute, another revolute, 4th revolute, 5th revolute, 6th revolute 7th revolute 8th revolute. So, I am using 8 revolute joint here, and that means, this particular manipulator should have more than 6. Now, how to determine that degrees of freedom, I am just going to discuss after some time but, here actually we need the mode number of the degrees of freedom, more than 6. This is a typical example of the redundant manipulator.

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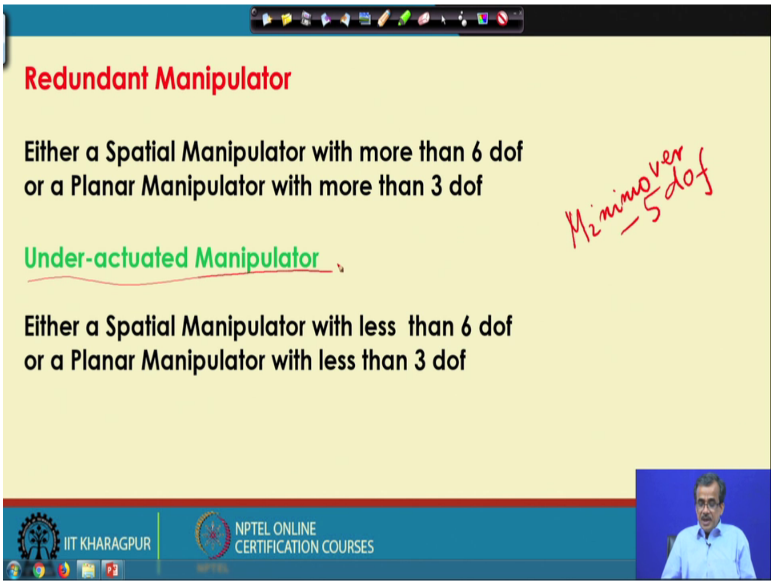

Now, similarly sometimes we use actually some sort of manipulator, which is under-actuated. Now, by under-actuated manipulator, we mean that this is either a special manipulator with less than 6 degrees of freedom or a plainer manipulator with less than 3 degrees of freedom. Now, here if I use a special manipulator with less than 6 degrees of freedom or a planar manipulator less than 3 degrees of freedom, that is called the under-actuated manipulator.

Let me take one example. Supposing that, one manipulator is working in 3-D space, and it is doing some sort of peak and place type of operation. So, so much accuracy is not required so, much precision is actually not required. And here, we can even use one manipulator, having you're the 5 degrees of freedom. For example, say we have got one manipulator, whose name is minimover. So, minimover is actually a manipulator having 5 degrees of freedom, and that is a spatial manipulator, so that is nothing but under-actuated manipulator ok.

Now, I am just going to take another very practical example, just to find out the difference between your, this the redundant manipulator, and this under-actuated manipulator.

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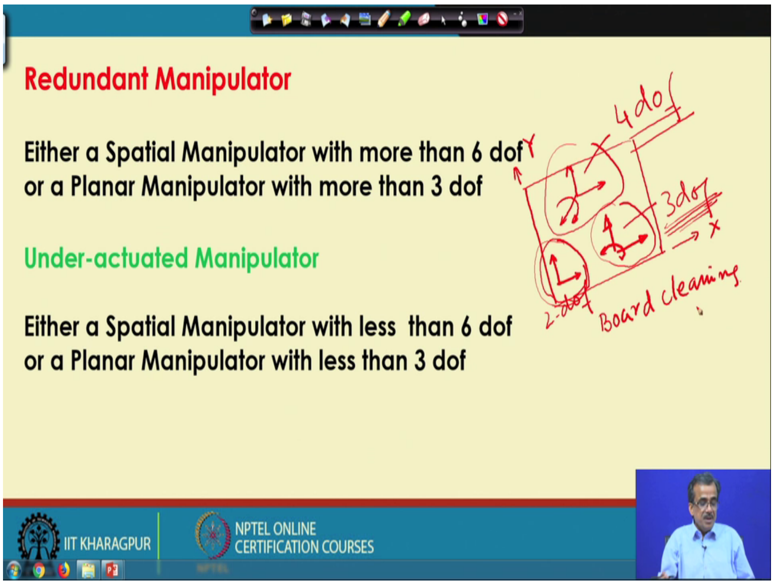

Let me take one task, very simple task. Supposing that, I have got one the board, the white board. Now, this particular white board, say I have written something, I want to clean it with the help of a duster. Now, what are the different ways, I can clean this particular the board. Now, this particular board is in 2-D. So, this is say the X direction, this is your Y direction, and Z is perpendicular to the board.

Now, if I want to clean this particular board, I can use the duster in different ways, let me take one possibility. For example, say I can use one duster in this particular direction, and this particular direction, only in two direction. So, I will move duster along X, I will move duster along Y, I can clean the board, so this is one way of cleaning the board. Another way of cleaning the board should be I can move along X, I can move along Y, and I can also rotate about this particular Z, Z is perpendicular to the board, so this is another way of cleaning the board.

Now, I am just going to show another method to clean the board. So, I will move along X, I will move along Y, I will move along this particular your the Z direction, opposite to the Z ok, and at the same time I will just rotate about Z are you getting my point. So, for the same task of board cleaning, so what I can do is, I can use three types of manipulator serial manipulator.

Now, if I use this particular manipulator, it is having 2 degrees of freedom. If I use this particular manipulator, it is having 3 degrees of freedom. If I use this particular manipulator, it is having 4 degrees of freedom ok.

Now, this is the 2-D plane. So, ideally speaking, if it is the ideal one, it should have 3 degrees of freedom. So, if I use this a manipulator with 3 degrees of freedom, that is an ideal. Planar manipulator for cleaning this particular board, but if I use this particular manipulator, this will be an under-actuated planar manipulator for cleaning the board. And if I use this particular board having 4 degrees of freedom that will be one redundant planar manipulator used for cleaning the board. I hope the difference is clear between the ideal manipulator, the redundant manipulator, and the under-actuated manipulator.

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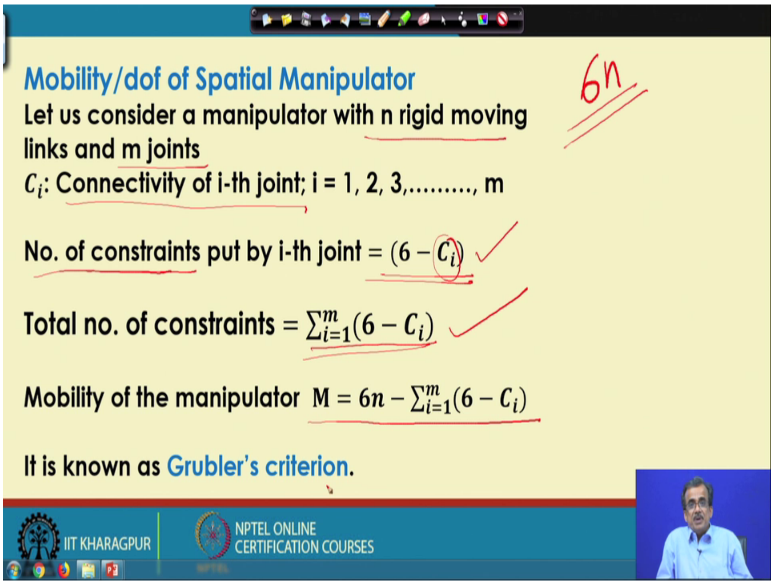

Now, I am just going to discuss the mobility or the degrees of freedom. So, how do mathematically calculate the mobility or degrees of freedom of a spatial manipulator. So, I am just going to start with the spatial manipulator, which is walking in 3-D space. Now, let us consider a manipulator with n rigid moving links and m joints. So, there are small n number of rigid links, and I have got small m joints. Now, as I discuss that each rigid body in 3-D space has got how many degrees of freedom, 6 degrees of freedom. So, I have got n such rigid links. So, I have got 6 n total degrees of freedom.

Now, C i is the connectivity of i-th joint. Connectivity of the joint I have already discussed, i varies from 1 to up to m. Now, a particular joint say i-th joined, if it is having the connectivity C i, it is going to put constraint, that is nothing but 6 minus C i, once again. So, C i is the connectivity of the i-th joint. And this particular i-th joint is going to put constraint, that is nothing but 6 minus C i. And similarly, we have got how many joints, small m number of joint. So, each joint is going to put 6 minus C i constraint. So, the total number of constraint will be summation i equals to 1 to m 6 minus C i. So, this is the total number of constraint. And this is the total number of availability.

So, this particular difference is nothing but the mobility of the manipulator denoted by M, and that is nothing but 6 n minus summation i equals to 1 to m 6 minus C i, and this particular formula is very well known Grubler's criterion. And using this particular the Grubler's criterion very easily we can find out, what should be the degrees of freedom of a particular the robotic system.

Now, the same thing we can also do it for the planar system. So, mobility or degrees of freedom of a planar manipulator. Now, I am going to consider planar manipulator, which is working on 2-D plane. And here, the same n number of moving links and small m number of joints connectivity is C i. And the number of constraint put by i-th joint is 3 minus C i. And the total number of constraint summation i equals to 1 to m 3 minus C i. And this is the mobility of the manipulator 3 n minus summation i equals to 1 to m 3 minus C i, so this is nothing but the mobility. And this is once again the well known Grubler's criterion.

Now, here I just want to mention one thing very purposefully. Particularly in in the in the previous slide, particularly let me go to the previous slide. So, particularly in the previous slide very purposefully I am using a particular term that is the mobility ok. So, in place of these degrees of freedom I am using this particular the mobility. Now, here I have something to say regarding the concept of mobility and the degrees of freedom.

Now, here on principle as I told by definition one serial manipulator should have 6 degrees of freedom. one spatial manipulators should have 6 degrees of freedom. Now, supposing that, one manipulator, one redundant manipulator is having certain degrees of freedom truly speaking, we should not call, it is having 10 degrees of freedom. Instead we should say that, it has got the mobility levels of 10.

So, because by definition the degrees of freedom can maximum b equal to 6, and that is why, if it is more than 6, we generally use the term mobility. We say that this particular manipulator is having the mobility level of 10, instead of saying that this serial manipulator is having 10 degrees of freedom. So, I think it is clear.

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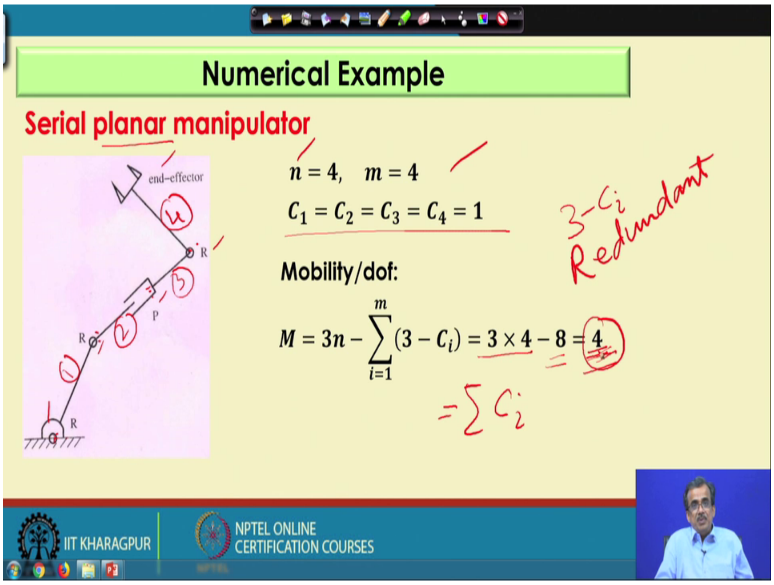

Now, I am just going to solve some numerical example. Just to show you, how to determine the degrees of freedom using the Grubler's criteria for some of the manipulators. Now, this is one actually the serial manipulator you can see, here all the links are in series ok. So, this is the fixed base first revolute joint, second revolute joint, the linear joint, the prismatic joint, the revolute joint, and this is the end-effector.

So, let us try to calculate its degrees of freedom or mobility. Now, here small n is nothing but the number of moving links. For example, 1, 2, 3, 4, so there are four number of moving links. The number of joints small m is equal to 4; 1, 2, 3, 4 - 4. Connectivity for each of these particular joint, this is the revolute joint, this is the prismatic joint, there having connectivity is equal to 1, each of the joint is having connectivity 1.

Now, supposing that, so this particular joint is having one connectivity, then how many constraints it put, this is a planar one. So, the number of constraints it is going to put is nothing but your 3 minus C i C i equals to 1. So, it is going to put two constraints. So, each of the joint is having one connectivity. So, each of the joint is going to put two constraints, so 2 plus 2 4 plus 2 6 plus 2 8. So, the degrees of freedom or the mobility M is nothing but 3 n minus summation i equals to 1 to m 3 minus C i n equals to 4. So, 3 n is nothing but 3 multiplied by 4, and total number of constraint is 8. So, I am getting 4.

So, although this is a planar manipulator, it is having 4 degrees of freedom that means this is one redundant serial planar manipulator, so this is nothing but the redundant planar serial manipulator. And another observation we should take. Here for this serial manipulator the degrees of freedom or the mobility is nothing but 4 and that is nothing but the sum of all C i values. Like each of these C i is equal to 1 you sum them up you will be getting 4, and this particular condition is true only for the serial manipulator, but not for the parallel manipulator.

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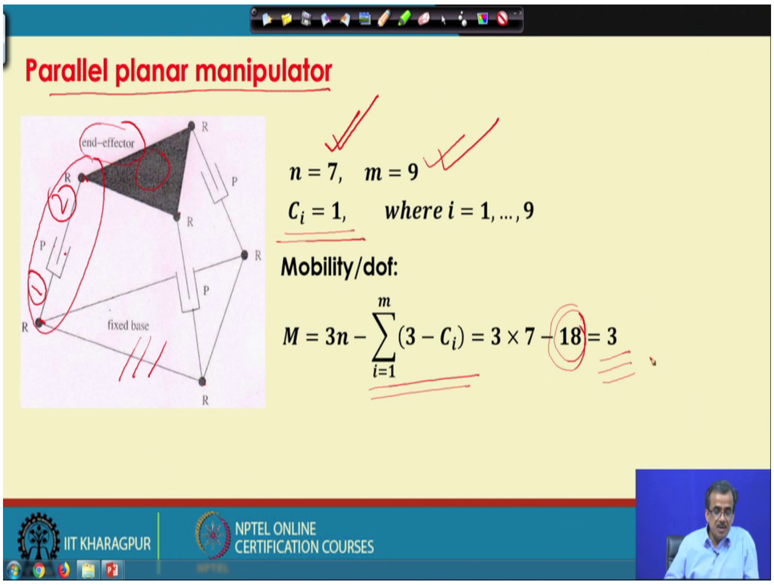

Then comes your parallel planar manipulator. Now, here this is very simple. So, this is the fixed base and the revolute joint I have. So, there are 3 links and here at the top we have got a top plate, and that is nothing but the end-effector. And at each link we have got a revolute joint, one prismatic joint, and one revolute joint. Similarly, we have got one revolute joint, prismatic joint, one revolute joint. And each link is having so how many how many constraints, how many joints that will have to count.

Now, here how many links we have, on each link I have got 1 2. So, 2 plus 2 4 plus 2 6 and this particular end-effector will be consider as a one link. So, I have got total 6 plus 1, that is 7 link. And how many joints we have, on one link we have got 1 2 3. So, 3 multiplied by 3, so I have got 9 such joints ok. And these are all, the revolute joint, and prismatic joint, each are having connectivity 1 that means, each of the joint is going to put, how many constraints 3 minus 1, that is 2 constraints.

So, each link is putting how many constraint, 2 constraint here, 2 constraints here, 2 constraints here, 2 plus 2 plus 2. So, one link is going to give 6 constraint and here also 6, here also 6. So, we have got 18 constrained. So, summation i equals to 1 to m 3 minus C i is equal to 18 M 3 n is 3 multiplied by 7, so, the mobility is coming to be equal to 3. So, this is an ideal parallel planar manipulator. So, this is the way actually we can find out the degrees of freedom or the mobility of different types of manipulators.