Introduction to Robotics
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Lecture 2.5
Kinematic Parameters

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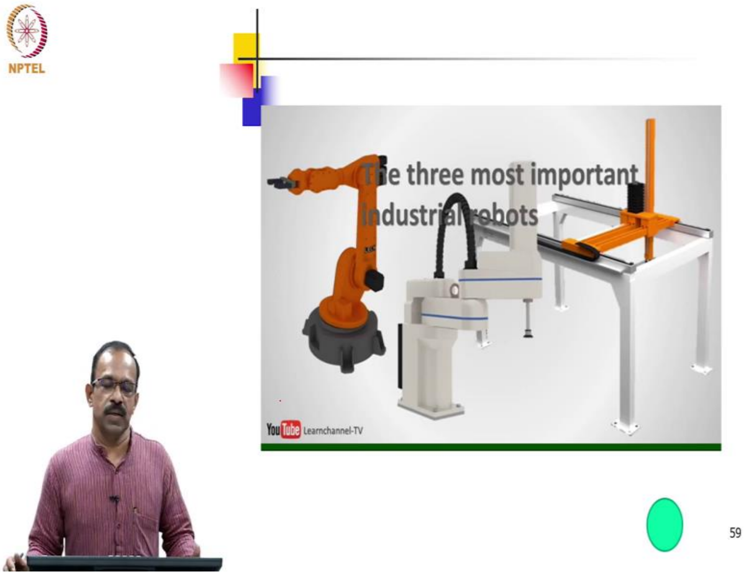

Hello, welcome back. In the last class we discussed about the robot architectures, the body and arm assembly configurations. And we found that there are two types of joints; the rotary and prismatic, and by arranging these rotary and prismatic joints, we will be able to get different body arm configurations. And we found that there are five types of architectures that is possible for industrial robots, it is known as the jointed arm architecture. Then we have this Cartesian robot, and then we have the SCARA robot. So, I will show you a small video here to highlight these three important type of robots.

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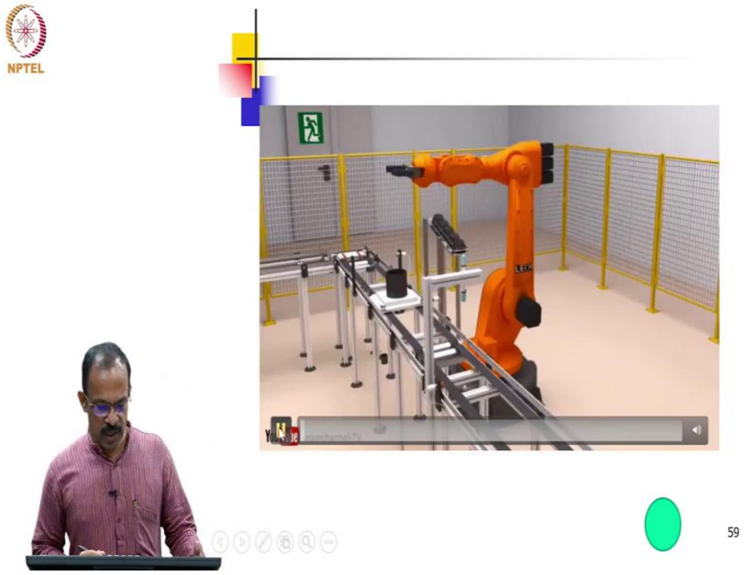

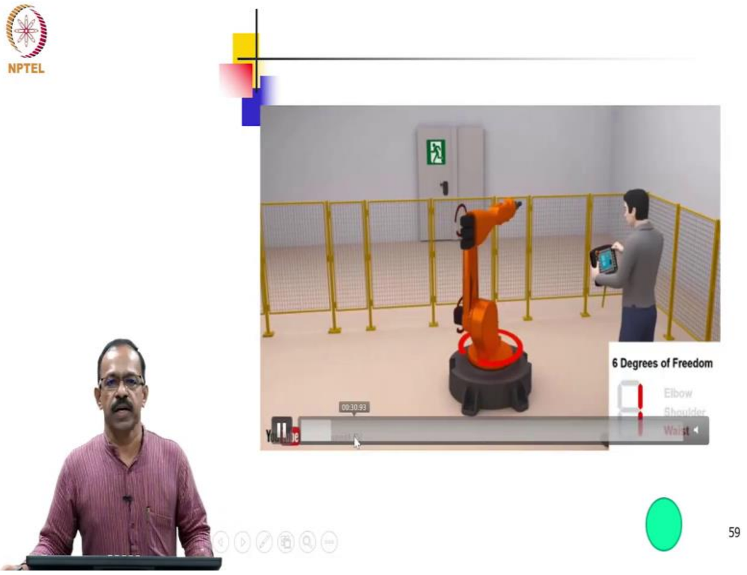

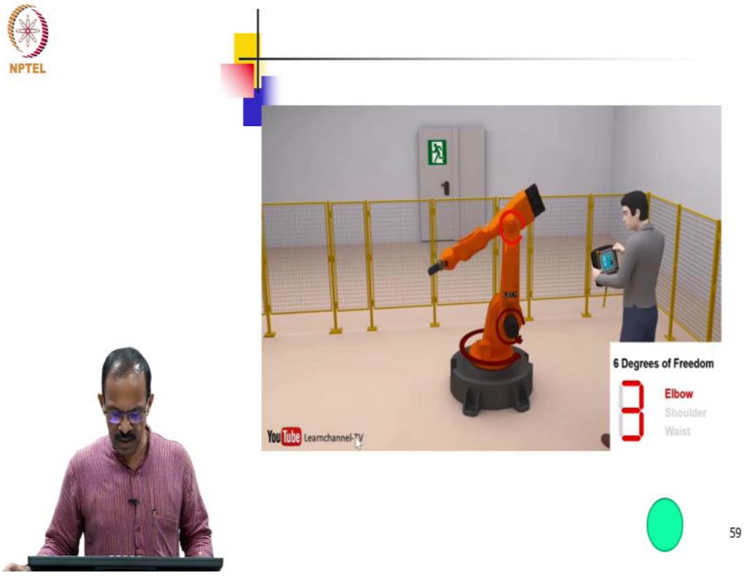

So, you can see this is the most commonly used robots which is the 3 R type RRR type, or jointed Arm architecture, okay. So, you can see here the different joint axis, you have the first joint which is the rotary joint, then you have the second joint which is moving now, and then you will be having that third joint also that will be used as the joint which would be used for positioning. This is the one, this is the third joint, that is the most commonly used rotary kind of robots.

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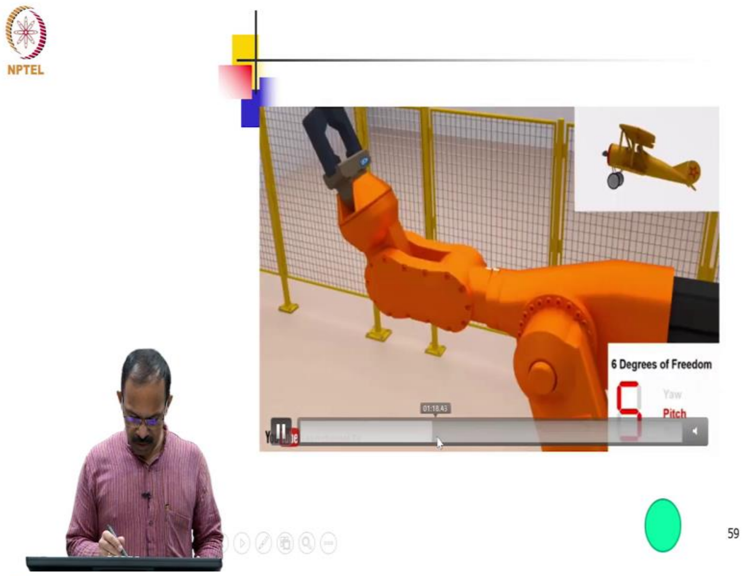

So, let me go forward so, it has various applications of this robot.

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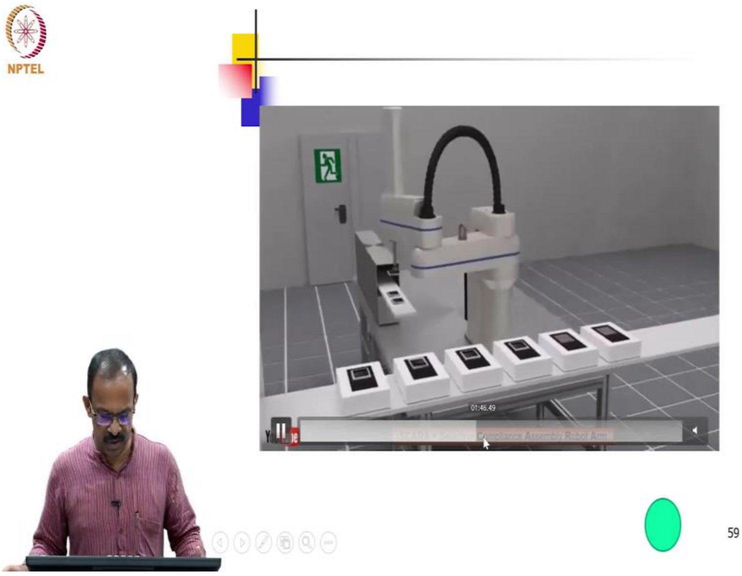

Now, it's the second one is the SCARA configuration, you can see that there are 2 R joints and the 1 P joint.

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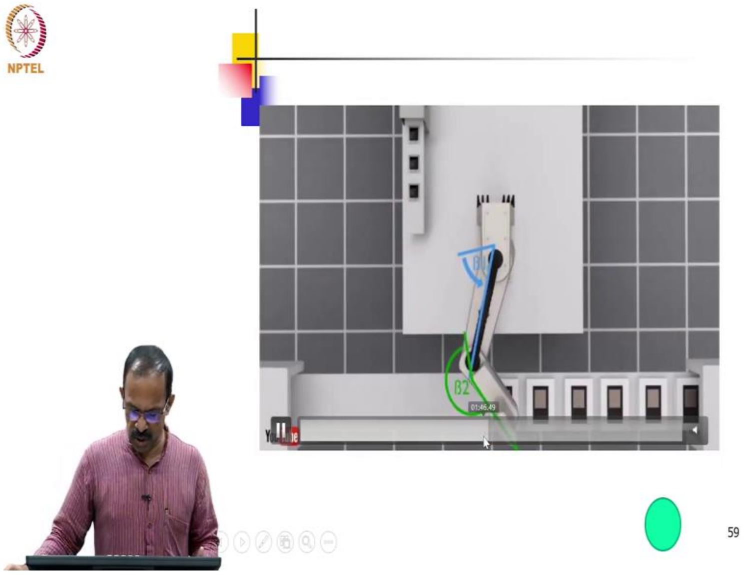

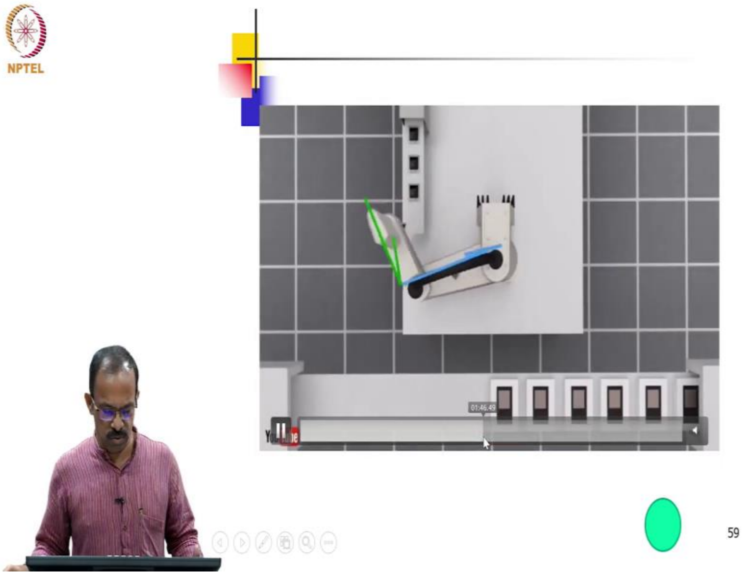

So, you have the last 1 is the prismatic joint and then 2 rotary joints and all the joint axis are in vertical direction. So, this can be used for positioning and assembly applications and it actually provides you a compliance in the horizontal plane because all the joints are in the vertical axis and the workspace of this is shown there.

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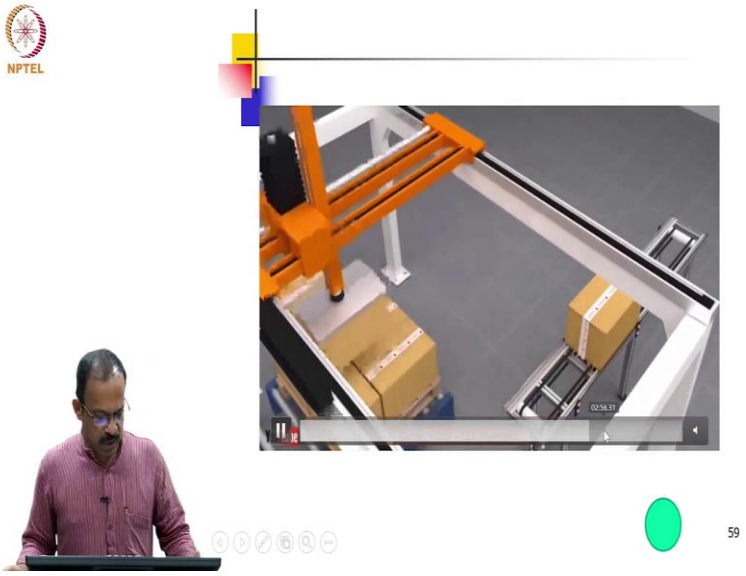

And the third one is the 3 prismatic joints, which we call it as the Cartesian robot. So, this Cartesian robots are again used for pick and place applications. The only difficulty with this kind of robot is there the space required for them is large compared to their workspace otherwise, they are very easy to control because all the three motions in x, y, z axis so it will be easy to control. So that is the advantage of having this robot.

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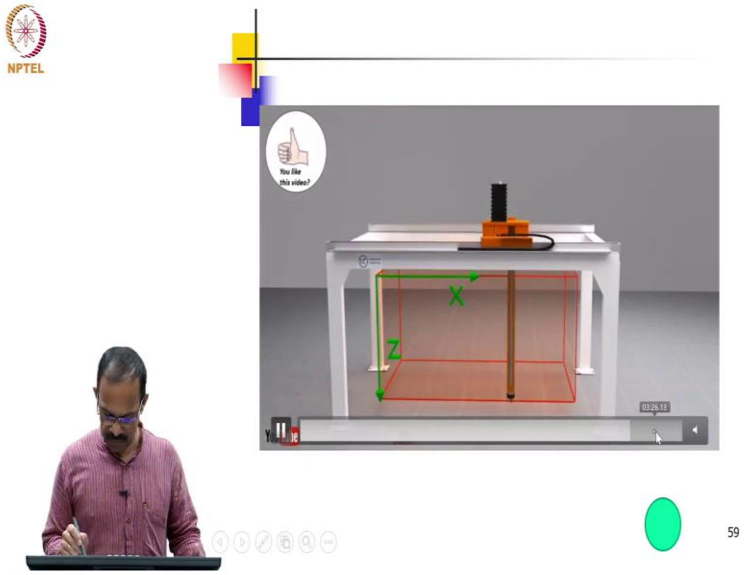

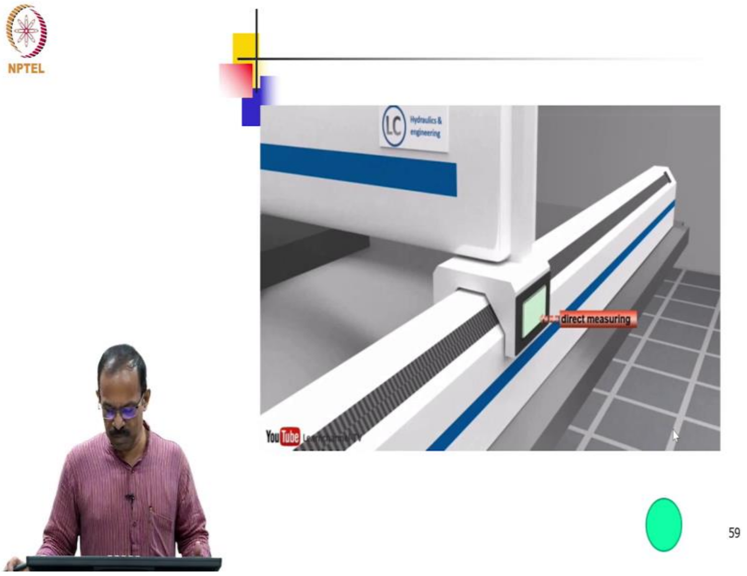

Okay, so you will be seeing this kind of robot in many other applications also in industries and as well as in many other places, you will be able to see these kind of robots in use. So that actually gives the three important robots that are being used in the industry and the body and arm configurations of the jointed arm, Cartesian and SCARA they are used for positioning the wrist in the 3D space.

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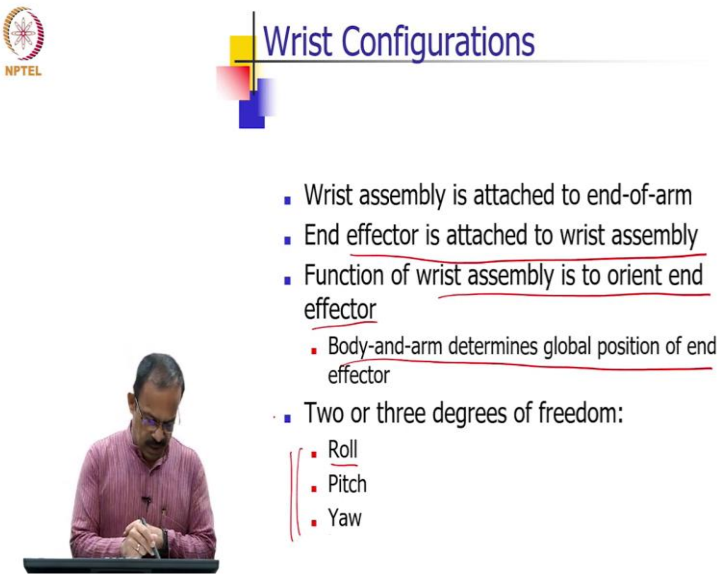

Now, if you look at the wrist to configurations, there can be different types of wrist assemblies, to be attached to the end of arm and their end effector is attached to the wrist assembly. So, we will be having the end effector which is attached to the wrist assembly and the function of wrist assembly is to orient the end effector. So, you can actually orient the end effector using the wrist assembly because wrist assembly has more 3 degrees of freedom and therefore, you will be able to orientate the end effector using these 3 degrees of freedom.

So as I mentioned the body and arm determines the global position of end effector and the 2 or 3 degrees of freedom wrist actually allows you to get roll, pitch or yaw. So these are the three orientations that is possible using the wrist assembly, so body and arm give you the position and the wrist gives you the orientation roll, pitch and yaw.

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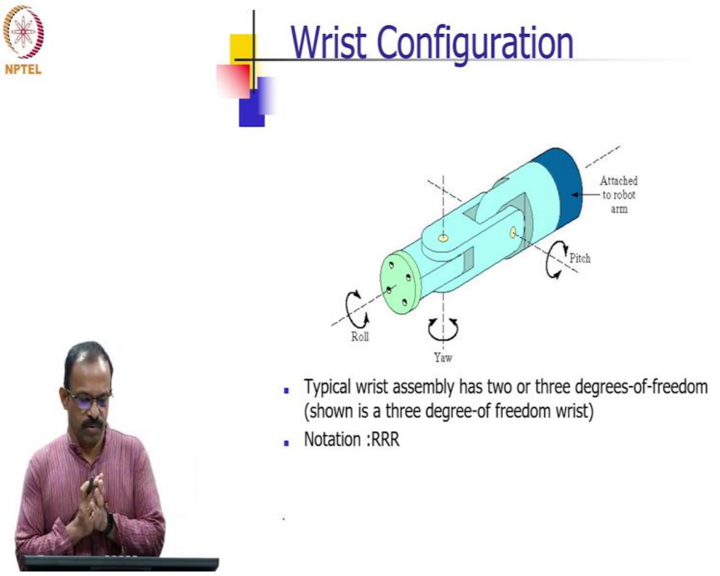

This is a typical assembly of wrist configuration. So, we can see that you need to have 3 joints so 1 you see is basically, this is the pitch axis and this is the yaw axis and this is the roll axis. So, the roll is along the z axis, so this is the wrist so you can actually here this is the roll motion and this is the pitch motion and this is the yaw motion. So, in a mechanical wrist assembly you cannot have all the 3 joints at the same point I mean, difficult to have. Unlike our wrist somehow we are able to get all this though they are not exactly at 1 point.

So, here you can see, this is 1 axis, pitch axis, the vertical yaw axis and the roll axis. And all are RRR so all the joints need to be rotary for orienting, positioning you can have prismatic joints, but for orientation you cannot use a prismatic joint so all the joints will be rotary joint and this part will be attached to the positioning part. So, you have the body and arm part, so the body and arm part will be attached to this, the wrist assembly and then this point you will be having the tool connected to it. So, the body and arm assembly and tool are connected through the wrist assembly so that is the use of wrist in the industrial robots.

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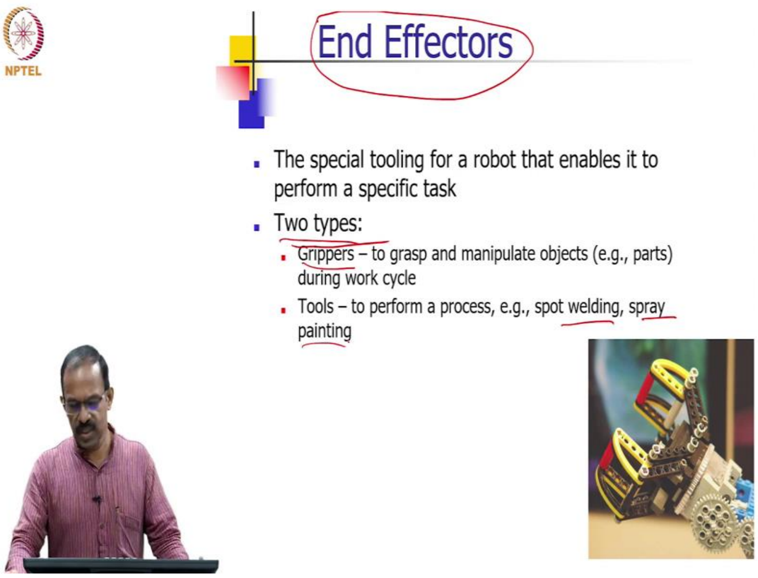

So, we discussed about the body and arm configuration, we discussed briefly about the wrist assembly and the wrist actually can have different ways of assembling these joints, it can have a spherical wrist also, where all the 3 joint axis intersect, we will get a spherical wrist. And at the end of the wrist you will be connecting the end effectors, the end effectors are the tools which are attached to the wrist assembly in order to get the necessary work done.

So, you can have 2 types of things; 1 is the gripper, and 1 is the other tools. So, gripper is basically for grabbing an object so you can have two finger gripper or three finger or multi finger gripper can be used for manipulating objects. So, we can have pick and place or manipulation of objects can be done with the help of grippers.

And other tools that can be attached are the welding tools or painting guns or any other tools you want to attach you can actually have it as attachment to the wrist assembly, that is the way how we will be using the whole robots for practical applications.

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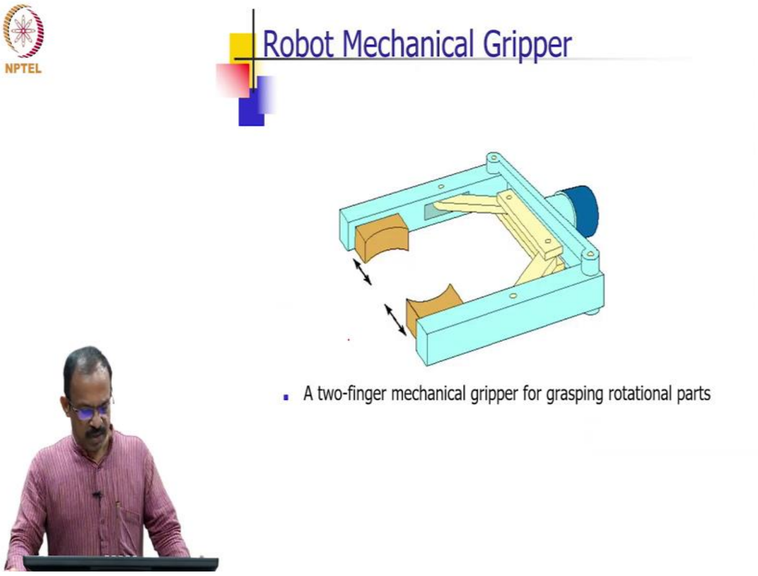

So this is a example for 2 finger mechanism for gripper. So normally gripper is not continuous part of the robots, and therefore the motion or this degree of freedom is not added to the robots degrees of freedom. So we will be having six degrees of freedom for the robot, but then the gripper will be having additional degrees of freedom.

So in this case, it's a 1 degree of freedom gripper can actually have an open or close motion, and this is a 2 finger type. So you can have a mechanical linkage to control this, you can have an addition motor here, it can be mechanical or pneumatic or hydraulic any powering mechanism can be used and then we will be able to get a motion here. And depending on the application, you can have a type of fingers designed in such a way that you will be able to get a proper grip of the object.

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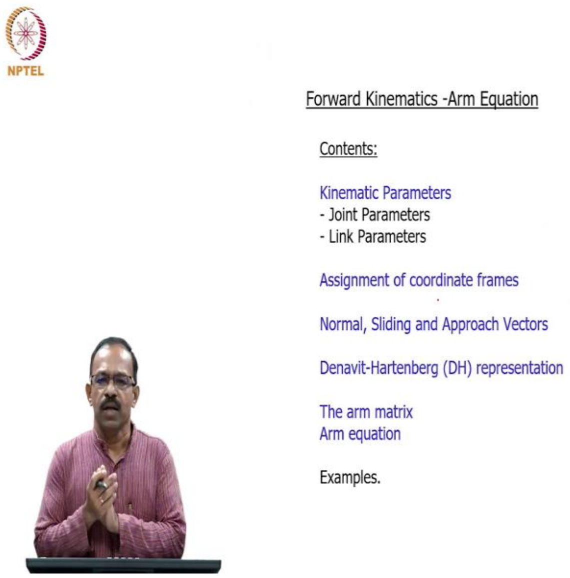

So thats all about the basic structure of robots or the mechanical construction details of a robot. So this is important to know when we have to discuss about the kinematics because about the degrees of freedom and how they are assembled, what is the body and arm configuration these are important in order to understand the kinematics.

That is why I discussed that part before we talk about the forward kinematics of the robot or sometimes we call it as the arm equation also. So, in the previous classes, we discussed about the basic coordinate transformation, and how the coordinate transformation can be used to represent the position and orientation of 1 coordinate frame with respect to the other coordinate frame as well as when the coordinate frames are moving, how can we represent those transformation using these transformation matrices.

Now, we need to apply those principles into the robots and then see how it can actually be represented or how the relationship for kinematics can be developed using those transformation matrices. So, here we will be discussing few points; 1 is the kinematic parameters of the robot, where we define two things that the joint parameters and link parameters.

And then we will see how we can actually use this information to get the transformation for developing the kinematic relationship. So to do that, we need to do something to assign the coordinate frames. So in 1 of the classes I mentioned that there are methods by which we need to assign coordinate frames to the joints to get that transformation.

So, we will see how the coordinate frames can be assigned and then we will talk about something about normal sliding and approach vectors how we can actually get this approach vectors using the coordinate transformation. And finally, we will have something called Denavit-Hartenberg representation for robots. And then we will talk about the arm equation and then take few examples to discuss. So, I explained what is the need for forward kinematics in one of the classes.

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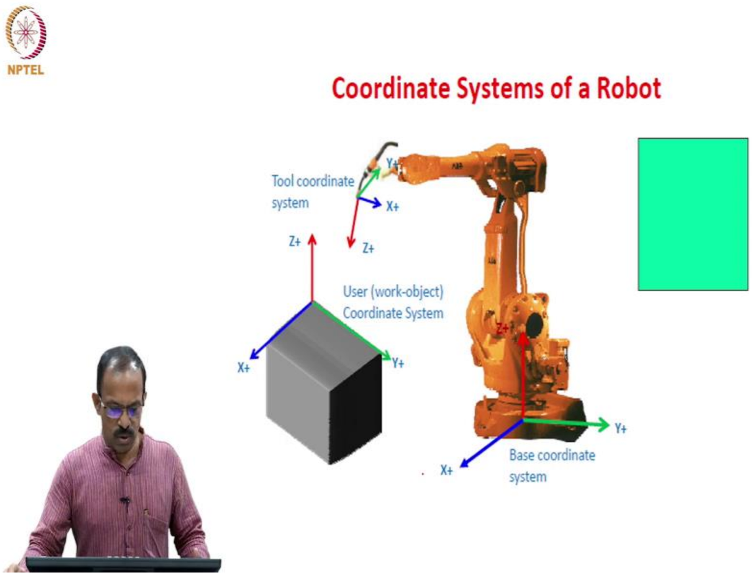

So, most of the time what we will be doing, we are interested to know the position of the tooltip, and if you move these joints how these tooltip gets affected is the relationship we are interested in, that is where we want to know the kinematics. So, if we supply these joint values theta I put just these joints parameters as theta, if I substitute these values of the theta, can I get the position x, y, z of the tool is my problem.

So, how do I get the position of the tool, if I know all the joint values of the theta that is basically the kinematics problem here. And in order to learn this, or in order to develop this relationship, we need to define few coordinate frames in the beginning. So this also explained in one of the classes, so we define a base coordinate frame like this.

So we will have a base coordinate frame attached to the base of the robot, all the measurements, all the position and other things can actually be referred to this frame and we call it as the base coordinate frame. And then we will define a tool coordinate frame at the end of the tool that actually represents the position of the end effector. Whatever the end effector we are using, we refer that as the tool coordinate frame so that is the frame which is of interest to us, we want to know where the tool is going with respect to the reference frame.

And in addition to this, we define something called a object frame or the workspace frame, work object or coordinate system or the user coordinate system, which is to represent the position of an object. If I want to manipulate this object, then I need to know what is the coordinate of this object.

So, we define an object coordinate frame or a user coordinate frame. So, these are the basic frames we define in order to talk about the kinematics of the robot. And once we define this frame, we can actually represent all the other measurements or the position of the joint with respect to this coordinate frame. So, that is the importance of having a coordinate system for the robots.

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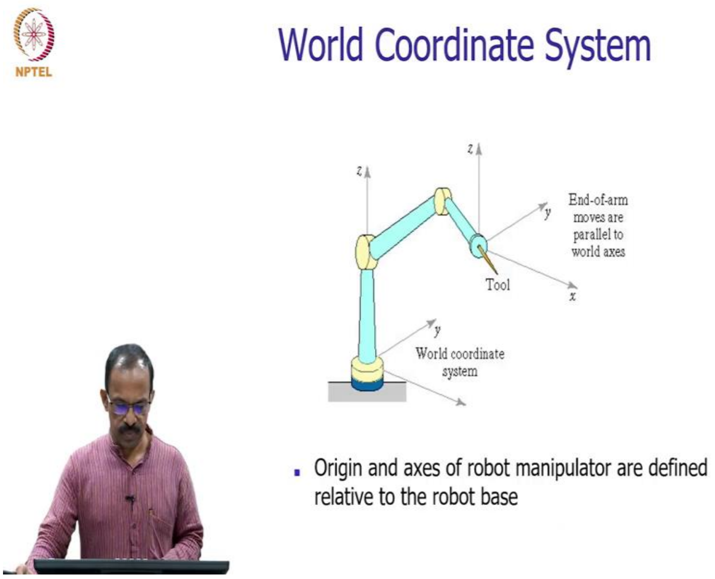

So, I already mentioned this world coordinate system, the basic coordinate system is known as the world coordinate system and this is known as that tool coordinate system. So, origin and axis of robot manipulator are defined relative to the robot base. So, we have the robot base and then we define all the coordinates with respect to the robot base.

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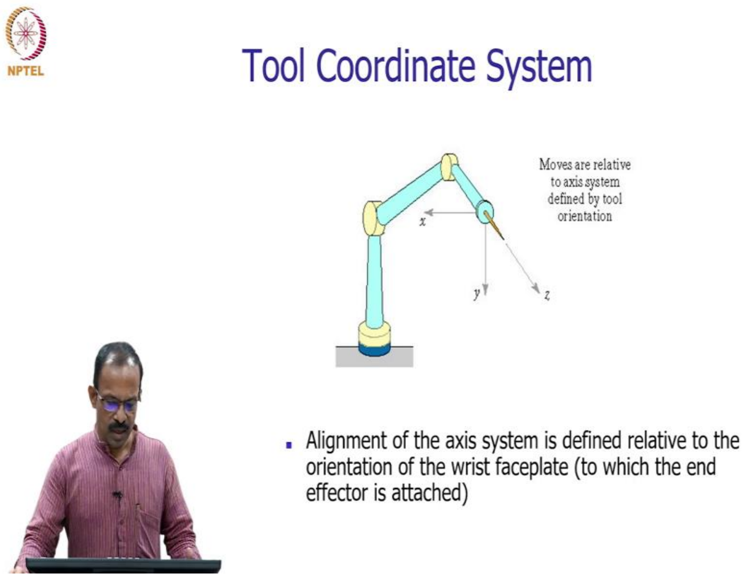

And that tool coordinate system, so we define this as the tool and then we define a tool coordinate system, and we define these coordinates based on some criteria. So I will explain that how do we assign the coordinate frame later, but we will be having 1 coordinate system at the tooltip.

So, the alignment of axes system is defined relative to the orientation of the wrist faceplate to which the end effector is attached. So, this is the wrist faceplate, where you will be attaching the end effector and the coordinate system will be defined with respect to that, so there is a tool coordinate system. So, we have a base coordinate system and a tool coordinate system.

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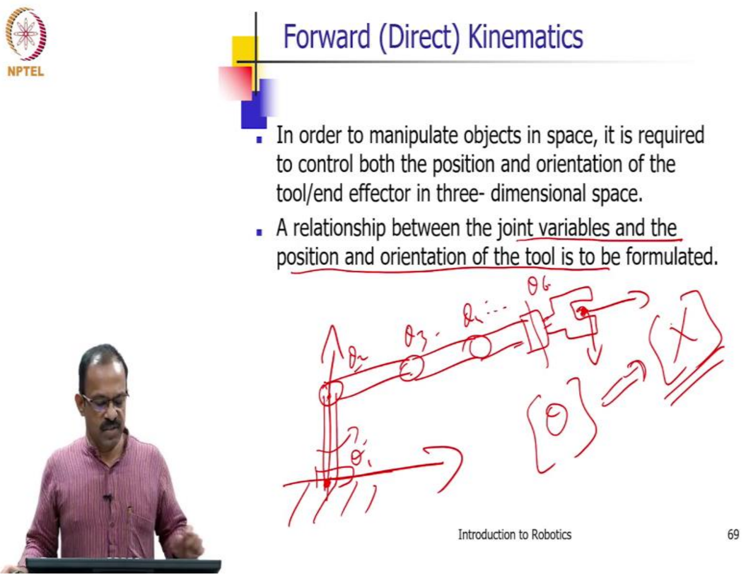

Now, coming to the forward kinematics relationship, so as I told you, you have a robot so you have 1 joint here, and then you have another joint, a joint here. It can be a rotary or prismatic joint and assume that this is the wrist and you have the tool attached to it. And you have this base coordinate system and you have this tool coordinate system so this is what we have. Now, we know that this can actually rotate so, there is a theta, there is another theta with respect to this theta 2, theta 3, theta 4, etc to theta 6 and we want to know the position of this.

So, this is the tool and this is the base and what is the position of this tool with respect to this reference frame when theta 1, theta 2, theta 3, etc are changing. So, that problem is known as the forward kinematics problem or direct kinematics problem that is this theta are known are the joint variables, we call this as joint variables because this can actually vary, at every joint you can have a theta varied and therefore, these are known as joint variables. So, if I know these joint variables, can I see what is the X position and orientation of the tool? Can I get this X is the forward kinematics problem or the direct kinematics problem?

So, a relationship between the joint variables and the position and orientation of the tool is to be formulated. So, how they are related, how can I develop a relationship between these two coordinate frame is the forward problem. And we found that whenever this is moving, there is a way to represent the relationship between this 1 and this 1 using a coordinate transformation matrix.

But, since there are multiple joints, and each joint can actually affect the position, we cannot directly write the relationship because it's not a single transformation, there are multiple transformations involved and therefore, we need to have a formulation, a systematic formulation in order to represent x as a function of Theta.

So, x need to be represented as a function of theta and that is basically known as the forward kinematics problem. So, let us see how to develop this relationship or how to develop this formulation using the coordinate transformation matrix.

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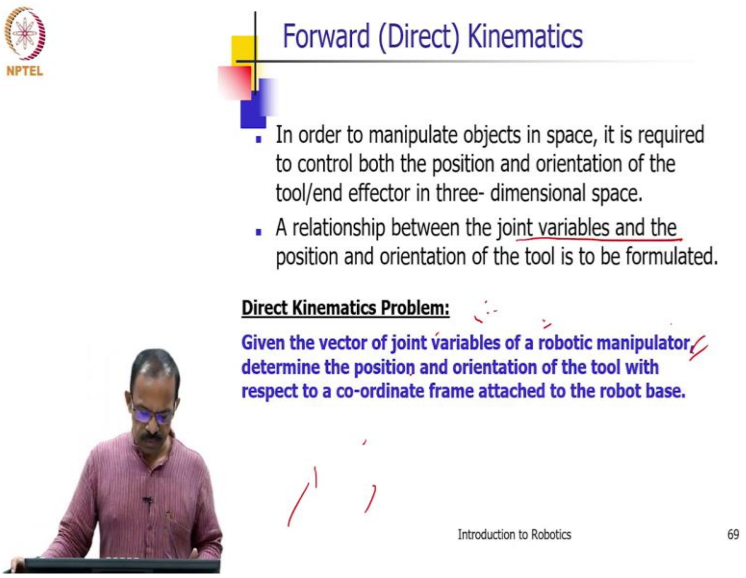

So, we can define the direct kinematics problem as given the vector of joint variables so it can be theta or D prismatic joint or rotary joint so generally we define it as a joint variable of a robot manipulator determined the position and orientation of the tool with respect to a coordinate frame attached to the robot base is known as the direct kinematics problem or the forward kinematics of the manipulator.

And we need to have a concise formulation of a general solution to the direct pneumatics problem. Since there are multiple joints involved and these joints can have different configurations, or joints can be assembled in different ways as we saw in the robot architecture, we need to have a concise formulation for the general solution to the direct kinematics problem.

So you should be able to use this formulation for any kind of robots, whatever maybe the robot configuration, we should be able to apply this rule and get the formulation that is basically the problem of direct kinematics.

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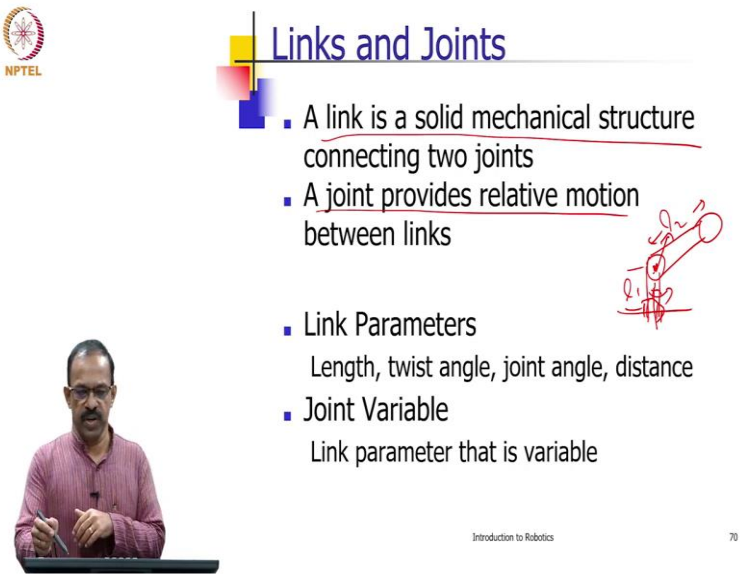

So we already saw these links and joints, so a link is a solid mechanical structure and joint provides relative motion between links. So in order to develop this forward kinematics relationship, first we need to look at the parameters of the robot because there are a lot of mechanical parameters involved in the robot, for example, the link, it has got some length and there will be some displacement between the links in 3 dimensional space, so we need to look at those parameters first and then see how these parameters contribute to the kinematics of the robot.

For example, I have this joint. So, I have 1 joint here and 1 joint here. So, this is the length of this link, this is the length of this link. And suppose this joint and this axis is like this, and this axis is vertical so I can say that this is the axis. So these two axis are 90 degree apart and similarly this link length and this link length are also different. So how these link length and the access of the joints affects the kinematics also is important.

And therefore, we need to study the links and joints from their design parameters and therefore we define these parameters as the length of the link twist angle, joint angle and distance. And joint variable is the parameter that is variable. So, we have a joint parameter that is actually varying also.

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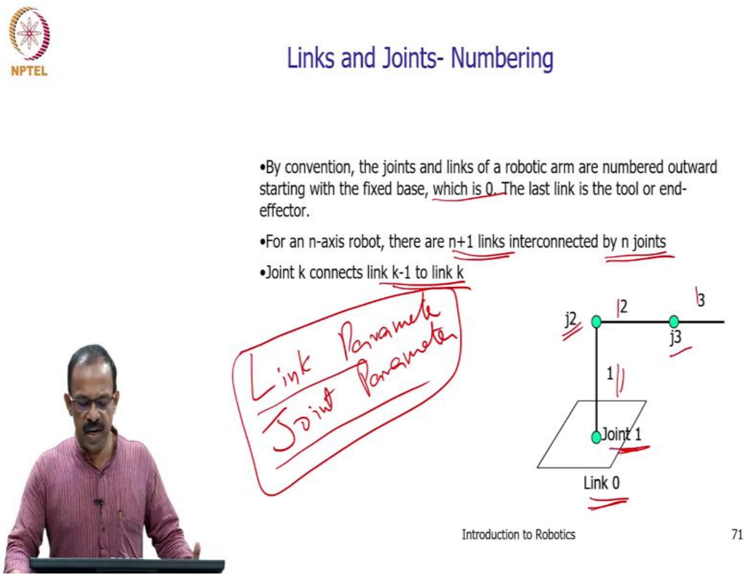

Now, we will look at this and then define how these parameters can actually be defined in the case of a manipulator. So, first we start with the links and joints, so we will start with the link zero and then joint 1, then link 1, joint 2, link 2, joint 3 and link 3. So, this is the way how the links and joints will be numbered.

Then, so that is the fixed base is link 0 and the last thing is the end effector. Then for an N axis robot, there are n plus 1 links interconnected by n joints, so we have n plus 1 links connected by n joints. That is what actually you can see here, including the links 0 there will be n plus 1 links. And the joint K connects link k minus 1 to link k, this also we discussed earlier.

So, joint k connects the link k minus 1 to k, and we need to define this parameter, so as I told you, there are two important parameters one is known as the link parameter, the other one is the joint parameter. So, we will see what are these parameters connected to the links and joints of the manipulator. So, you can see that link 0 and link 1 are connected through a joint 1. And similarly, joint 1 and joint 2 are connected through the link 1. So, positioning of these joints and the way they are arranged in the manipulator leads to these parameters link parameters and joint parameters.

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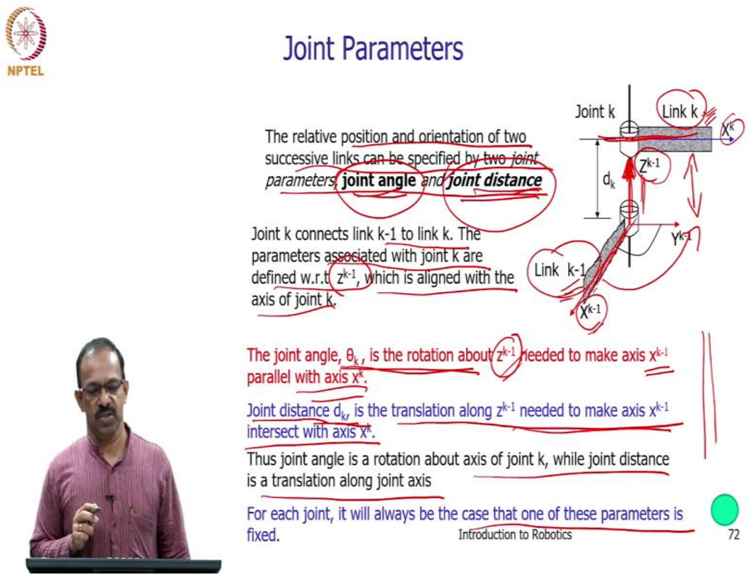

So, let us define these parameters or try to find out what are these parameters. So, for example, we take an example for a simple model of a manipulator. So, we can actually see here, I consider this as a manipulator and there is a joint like this. So, we can see it can rotate like this, then there is a joint like this which can rotate and there is a joint which can rotate like this.

So there are joints and links here so now I can consider this as link 0, then link 1, link 2, link 3, etc, then I have joint 1, this is the joint 1, joint 2 and joint 3. And you will see here the joint axis is like this first one, second one is like this and third one is like this. So, we can see the links and joints can be arranged in different ways, though all are rotary joints, it can have different joint axis and that actually gives you a different configuration also.

Now, we need to define something called a joint parameter. So, the joint parameters basically talks about the relative position and orientation of 2 successive links, which can be used for using parameters called joint angle and joint distance. So, these are the two parameters that we can define as the joint parameters, which are the joint angle and joint distance.

Now, if you look at here, so this is joint K and this is link K and link K minus 1. So, you have link K and link k minus 1, for example, I take this as the link K and this is K minus 1. So, you have link K and link K minus 1 connected by a joint k. So, this is the way how we can say, so link K and link K minus 1.

So, joint angle and joint distance are the two parameters, so you have joint angles and joint distance. Now, joint angle so joint k connects link k minus 1 to K, the parameters associated with the joint k are defined with respect to z k minus 1. So, assume that this is the z k minus 1 that is a rotation joint axis and this is link k minus 1 and this is link k. So, you have these two joint link K and link k minus 1 connected by a joint k and this is measured with respect to z k minus 1. So, the z k minus 1 is aligned with the axis of joint k, this is aligned with the axis of joint k. So, you have k minus 1, link k minus 1 link K and joint k and this axis is known as z k minus 1 axis that is the joint axis.

Now, the joint angle theta K, the joint angle theta K is the rotation about z k minus 1 needed to make axis x k minus 1 parallel with axis x k that is, you have this link k and this link k minus 1. So, how much just to be rotated in order to make these two parallel, link K and link k minus 1 parallel is the joint angle theta K.

And that is measured with respect to this z k minus 1 axis, so this is basically the joint angle. So, now you can see suppose, this is the way this initially, so this is link k and this is k minus 1 link, this is Kth link and this is joint axis how much I have to rotate this one to make it parallel is the Theta K, that is that joint angle.

How much this theta is a joint angle is the rotation about z k minus needed to make axis x k minus 1 parallel with axis x K. So, this is the x k minus 1 axis and this is the x k axis. So, how can I make these two axis parallel and what is the rotation needed is basically the joint angle theta k. Then, the d k is the joint distance d k is the translation along z k minus 1 needed to make axis x k minus 1 intersect with axis x k.

So now, you have the distances, suppose this joint was not like this, this joint had to some distance like this, suppose the joints are like this. So, this is link k minus 1, this is link k and the axis of this link is here x k and this link is x k minus 1 link axis is here, x k axis is here. So, there is a distance between these two links and that distance is known as the d k.

So, in this case if I make it like this, then both are aligned so d k is 0, but if there is a distance between these two, then that d k will be the joint distance, so that is the way how the joint distance is defined. So, you have two joint parameters, one is known as the joint angle so joint angle is the angle required to make x k minus 1 parallel with x k and that is measured with respect to z k minus 1.

And d k is the translation alongside z k minus 1 translation needed to make x k minus 1 axis intersect with x k. So, this axis and this axis intersect at this point so that is basically the joint distance d k. So, this is the way how these two parameters can be defined joint parameters.

Now, we have the link parameters also, we will discuss the link parameters in the next class. So, the most important one is the joint parameters, joint angle and joint distance. Joint angle is the angle required to make x k minus 1 parallel with x k that is joint angle measured with respect to z k minus 1 and then d k is the distance traveled translation along z k minus 1 needed to make axis x k minus 1 intersect axis x k. And out of this variable, always one will be a constant. So, out of this variable, joint is along x axis, one of these will be always constant.

For each joint it will be always the case that one of these parameters will be fixed. So, in rotary joint theta will be variable and the prismatic joint d k will be a variable and the theta will be constant for the prismatic joint and d will be constant for the rotary joint so that is a property of these time parameters. So, out of these two parameters, one will be always variable, the other will be constant. So, let us stop here, we will discuss about the link parameters in the next class. Thank you.