Mechanics and Control of Robotic Manipulators
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Lecture 3
Introduction to Forward and Reverse Kinematics

Hi, welcome back to Mechanics and Control of Robotic Manipulator. Last lecture where we stopped is basically role of a robotic engineer or design engineer. This is a slide we stopped. And I said that the next lecture we would be talking more about robot mechanics. So, we were given a small indication so how we can start, you can say understanding.

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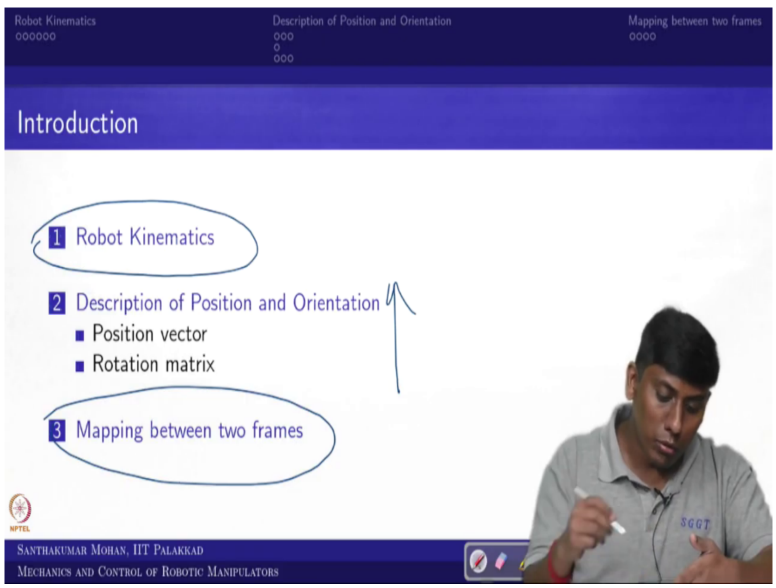

So, before that let us go back to the previous slide, so where we stopped. And then we will talk about robot kinematics very detail. Then we will talk about what are the way to describe the motion. So, obviously there are two ways. So, then we will talk about the mapping between you can say between two different frames, because you know like manipulator is set of bodies in the sense it is multiple body system.

So, then we need to have each body at least one frame would be there but as per the, you can say robotic manipulator one link would be having two joints. So, that is what we are going to see in upcoming lecture. In the sense you can see like one frame to another frame that you can say mapping can be done. So, this is what we are going to cover in this particular lecture.

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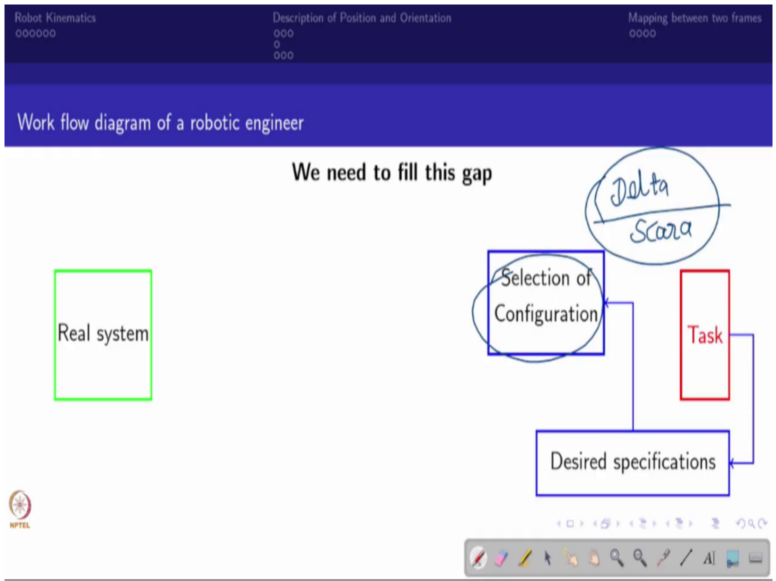

So, let us go back to the slide so where we stopped. So, this is a slide where we stopped. We talk about the workflow, or you can say the basic idea behind the robotic or design engineer. So, what would be given? So, the design or the task would be given. For example, here I say that the robotic assembly is given. So, what are the aspects you would immediately think as a engineer or probably the original robotic engineer will see?

So, these are the specifications, or you can say these are the user inputs. So, these are the user inputs are given. So, what I can choose? So, obviously in order to achieve or accomplish this task we need to think about the real system, right? So, that is the next case. You can see the real system is going to come. But real system from the task there are several choices.

For example, even I said the robotic assembly. So, there are several manipulators are available for the robotic assembly. So, in that sense there are several chances. So, for example, it comes from 20k to probably 2 crore worth manipulators are there. How will you choose or what will be the selection of yours? Or will you make your own? So, if that is a case what exactly from the task side would be known?

So, the user would be given some input. Based on that you would be come up with what you call, already I said, you can see, already I said the desired specification would be obtained. So, what that mean the desired specification in the sense? So, based on the user input you would be coming with some kind of technical background on the, you can say system or background on the task.

But this would give one of the things. What it is what would be the body arrangement, whether for example, the robot can be fixed on the top? Or fixed on the base? Or it is put it on the desk? So, these all will be selected. And similarly, the robot should have these many numbers of active joints and all those things will come. So, what indirectly it will give; based on that you will come up with one aspect called selection of configuration.

For example, in our case the robotic assembly probably, the choice would be probably either a Delta robot or a SCARA robot. So, now these two are your choice. Finally, you end up with probably a Delta or SCARA robot. Then you can see on-shelf in the sense industry catalogue or the commercial on-shelf there are several such SCARA or Delta, even the brand to brand it get changed. The price also will get changed.

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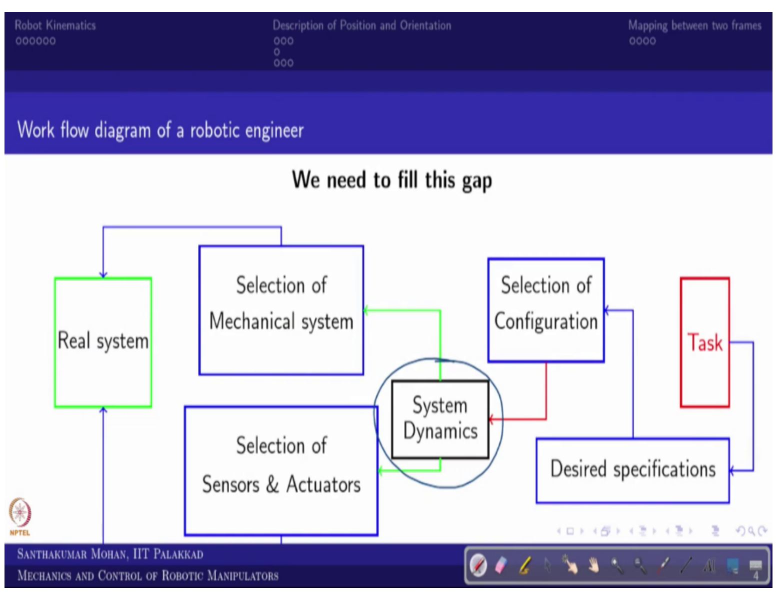

So, now in that sense what one supposed to know? You have to see from the real system. So, what are the two things will come? So, one is selection of mechanical system. The other thing is selection of actuators and sensors. So, now these are the aspects which come from the real system. And this is the thing, which is come the, what you call a task.

So, now what we said, so these two things would be bridged by the system what you call system dynamics. So, that is what we have discussed in the last session. So, obviously each and every stage would be iterative. But what we say that the gap between the real system and the task would be filled based on the system dynamics.

So, that is what we discussed. So, now the system dynamics will fill the gap. Even the example I gave that the simple pendulum, how will you design and fabricate. So, there are several aspects, right? If you know the system dynamics even you can easily make it several of these selections or probably fabrications and all, right? So, with that will come back to the original content of this particular lecture. So, now you got idea, right? What idea? The system dynamics is one of the key. So, that system dynamics how you will relate.

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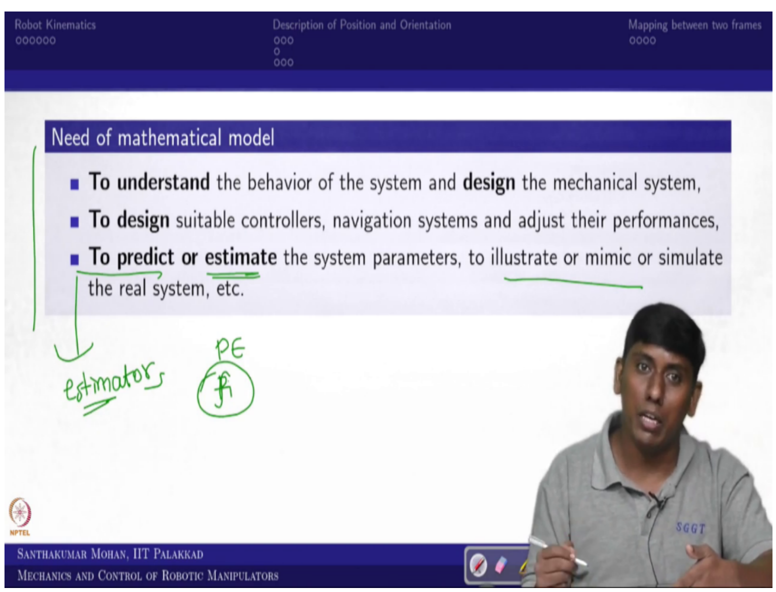

So, the system dynamics we can simply call mathematical model. So, what the mathematical model can do? If recall the example what we did in the, you can say, simple pendulum? So, you have to select several things, right? So, you have to design. I will, I will just make it. So, you have to design. So, you have to say, so design aspect is there then so far design you will be doing some selection. And then this is the mechanical side.

Then you have to think about the control design. So, even further if you look at it sometime the parameter would not be known. So, you have to estimate, right? So, if you take these all the cases the mathematical model what it does? So, it does several of important thing. What? So, one is to design it is going to give. But how will you design? So, you will only design based on the, so understand, right? So, in the sense, so what the mathematical model will give?

So, it will give one simple aspect. So, you can see like to understand the system behavior and consequently you can design the mechanical system. So, this is one thing. And you all of know that robotic system is no longer only mechanical device. It is slaved by the controller. So, then the controller design also can be done based on the mathematical model.

Especially if you talk about manipulator. So, most of the manipulator come from the model-based control. In the sense if you have a mathematical model, you can design the controller more appropriately. So, further you know like the robotics system required some kind of sensing system, navigation systems and all.

So, if you think about even extended to mobile manipulator or mobile robot so you can obviously design the navigational system. Or you can think about these two systems performances you can adjust with the help of mathematical model. So, for example, your controller tuning, or you can say your navigational parameter estimation, these all can be tuned according to the availability of the mathematical model.

So, then the next step what you can see, this can be used for, for example, estimating the system parameter. Mainly you can say to predict the system parameter. The prediction is even it is kind of estimator. But this estimator can be a different way what you call; it is system estimator. But what I am calling the system parameter estimation. So, one is parameter estimation.

The other one is filtering. So, both the cases we can use if the mathematical model is available. So, that is what the whole idea, so to illustrate or mimic or simulate the real system we can definitely use the mathematical model. In fact, in this course we are going to use that is what as the predominant area. So, if that is the case you know now understanding what is mathematical model and why we are using mathematical model?

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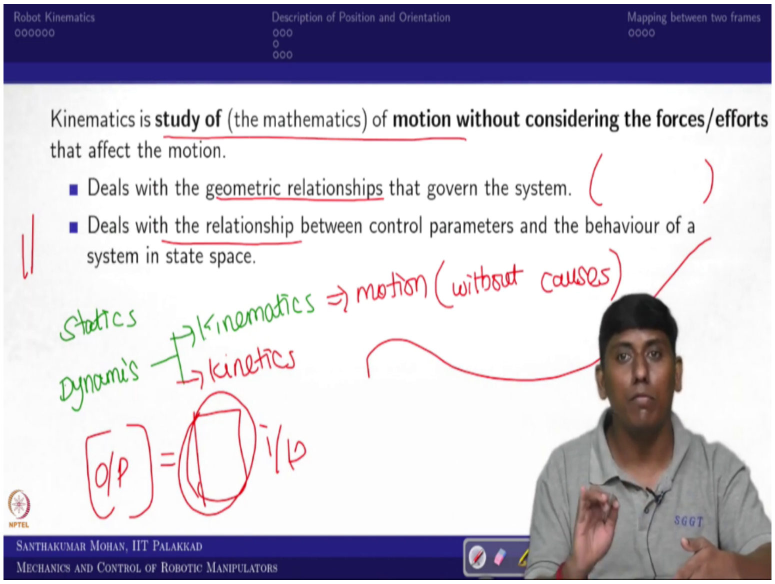

We will start with the very basic. So, what very basic? You know robotic system is one of the mechanical systems. This is involved with you call motion. So, obviously the motion can be classified based on the physics. So, there are two things, so which is you call statics and dynamics, right? So, these all you have seen.

And the dynamics can be further classified into, so what you call kinematics and the other one is you call kinetics, right? So, what is kinematics? Kinematics is nothing but the study of motion. So, you would be bothering about motion but without the cause of motion, so are like the causes. So, that is what the case. In the sense for example, now you are looking the football game.

Imagine that if you are actually tracking only the ball. So, what you are seeing like who is hitting and what way he is hitting and how much force they are applying, these all immaterial. You are just seeing that the how the ball is moving, right? So, in the sense what one can see? The kinematics is nothing, but it is also part of mathematics, but what we are trying?

Study of motion without considering the forces or efforts that affect the motion. That is what I said without the causes. So, in that sense what exactly it will give idea for us? So, there are two things. So, one is actually the geometrical relationship that govern the system. This is what we are going to use as a bigger aspect called robot kinematics.

The second thing is this will give a relationship between the control parameter and the behavior of the system in a system, you can say, space which we simply call state space. In the sense what you have? You have input and you have system motion what you call output. So, this relation you will get. So, if you have this relation what you can do?

You can get a better idea about the system and as well as you can think about even better controller. So, in the sense what you can see? We are going to talk about the kinematics. What is kinematics? Study of motion without considering the forces or efforts that affect the motion. So, now we specifically keep this, and we will go. When we come to dynamics, we will see what is difference between kinetics and robot dynamics? Right now, we will go with kinematics.

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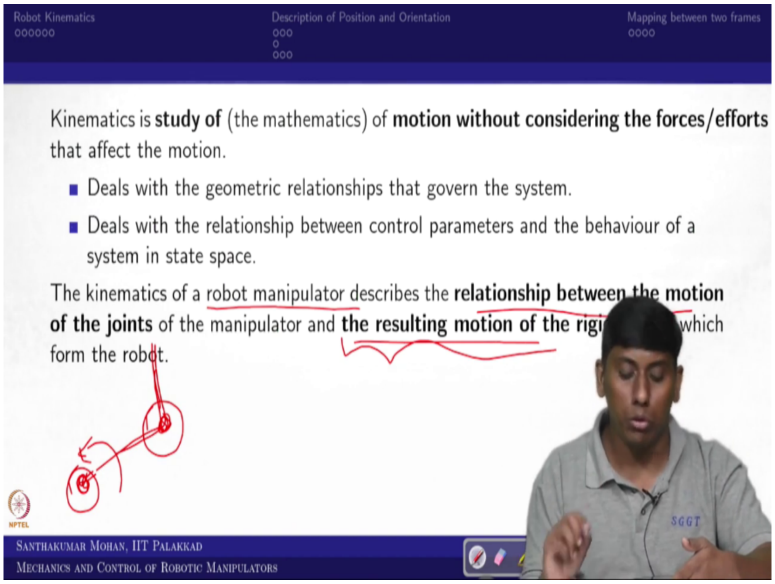

So, if you talk about kinematics what we are really bothered? So, here the robot manipulator describes the relationship between the motion of the joints and, you can say, the resulting motion of the rigid body which forms the robot. For example, now you take this is what the body. So, if I rotate this, if I rotate this what will happen to this set of bodies?

How it is arranged? Or how it moves individual body? Although I am giving the motion on the joint but what we are seen that the resulting motion of the rigid body that is what we are focusing. So, in the sense you were I hope now to clear what is kinematics and what robot is going to or robot manipulator what we are going to talk.

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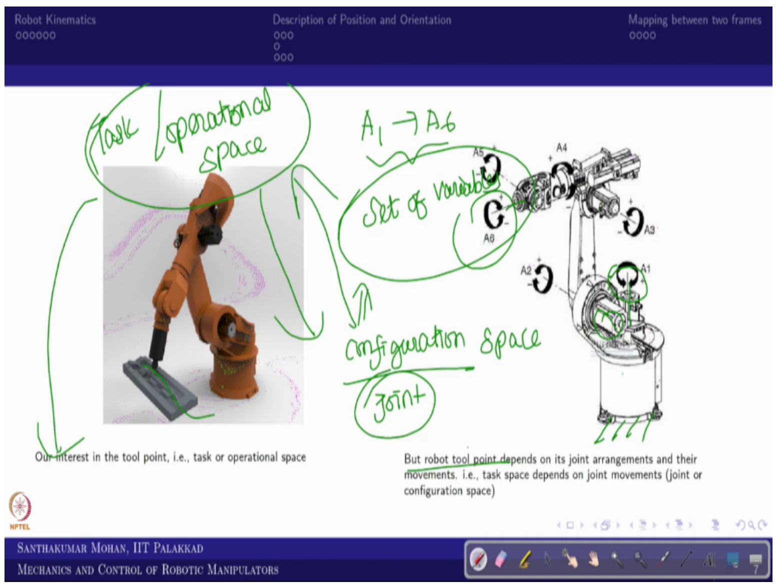

So, if that is the case, we will go even furthermore. What furthermore? So, I am taking one of the industrial robots. So, this industrial robot is something like engraving or you can say some kind of machining tool which is in-house at the end. So, this is guided through some sequence of motion. In the sense when we are focusing this is one of the robot manipulators what would be our interest? Our interest is the tool point.

How the tool point move on this metal piece so that the predefined you can say engraving or you can say machining can be done? So, in the sense what you can see this end effector motion is important. This end effector motion is Px, Py and Pz. And this will be having some set of other variables. For example, this is the orientation the tool supposed to be. And this is the rotary or, you can say rotational speed, of the, you can say, end mill, all those things. So, in the sense what we are we are bothering about the task.

The task would be having set of variables. That set of variables is going to give some kind of space. So, the set of variables, so I am making as a small set, so what this give? This gives as a space, as a set. So, I am calling in a mathematical term as a space. So, what that mean? So, the space is related to what? The task or the operational entity. So, this space I am calling so operational, so operational space. So, this is what we are always interested.

But if you look at this manipulator what you can see? There is one motor here, one motor here, one motor here, one motor here, another motor here like that, right? So, you have set of motors or set of joints. This is connecting the set of body in such a way that this end effector is following. If you look at the next picture you make, be getting very clear. So, for example, you can see this is the base. So, this base to this end effector is having set of bodies.

So, these bodies are connected in series and there are several actuators. In this particular robot you can see there are several actuators, in the sense A1 to A6 there are 6 joint motions which are powered. But these are the motions are making this end effector to follow certain profile. So, if that is the case what you can see?

So, this A1 to A6 having some set of variables, so these variables are creating one space. So, that space is what? It is it is configured one body to another body. So, we have already seen what is configuration. So, obviously this is related to the configuration. So, we call this is configuration space. Some people call this is based on the joint, so they call joint space.

So, now what we have? There are two relations. So, one is configuration space. So, the other one is task or operational space. So, there are two spaces. But we are interested this. But the robot knows only this. So, we need to map between these two, either this way or this way. So, this is what we are going to call as kinematics. So, that is what we are putting into next picture.

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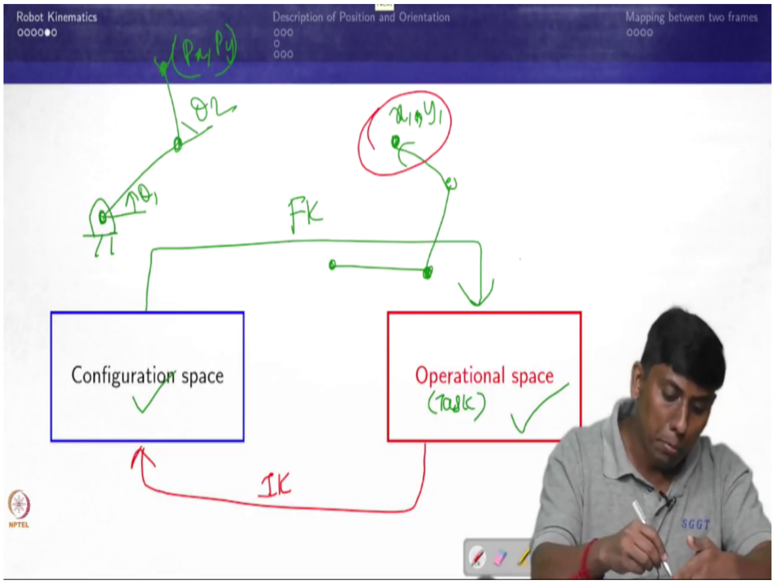

You can see one side, the configuration space or we call joint space. So, the other side, what you have operational space or task space. So, now we are like mapping, in the sense, you take the set of bodies, and you know, what is the angle?

For example, I am taking, this is the rotary to a rotary manipulator. So, you can see like this joint angle theta 2 and theta 1 is I fix. What I will get? This end effector point which is Px and Py would be available to me. So, in that sense what? So, I have configuration variables. So, I am trying to find out what would be the operational variable.

So, this is straight forward look like, right? In the sense it is forward kinematics. So, strictly speaking we are talking about geometrical model, but this is what in general be call forward kinematics. The other way round I say that this is the x1 and y1. So, I want to, I have a manipulator. I am just showing that. So, this is the manipulator.

This manipulator I have to make sure that this comes here. In the sense what? So, I have this. So, in the sense I know the operational space variable. Can I find the configuration variable? In the sense for given task space variable can I arrange the set of body in such a way that it fulfills that? So, this is what you call inverse problem. So, we call inverse kinematics.

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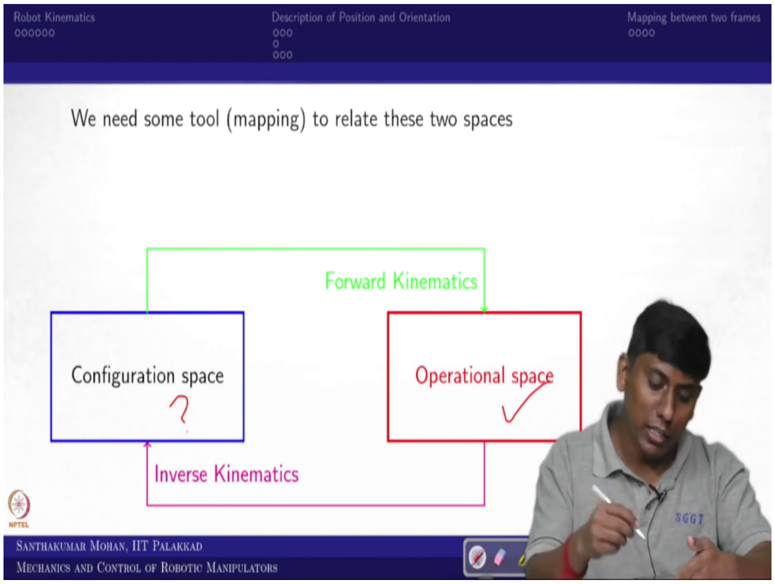

So, now we will see the proper pictorial way. So, we need to map these two. So, for mapping this, what we are seeing? If configurations variable is known and we find what is operational space this is what you call forward kinematics. And the other way around you know this and you are finding this so this is what you call inverse kinematics.

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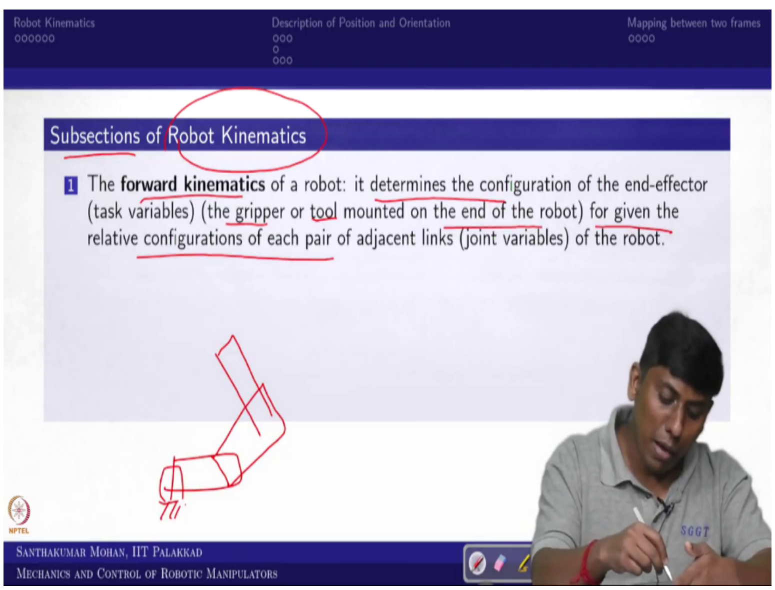

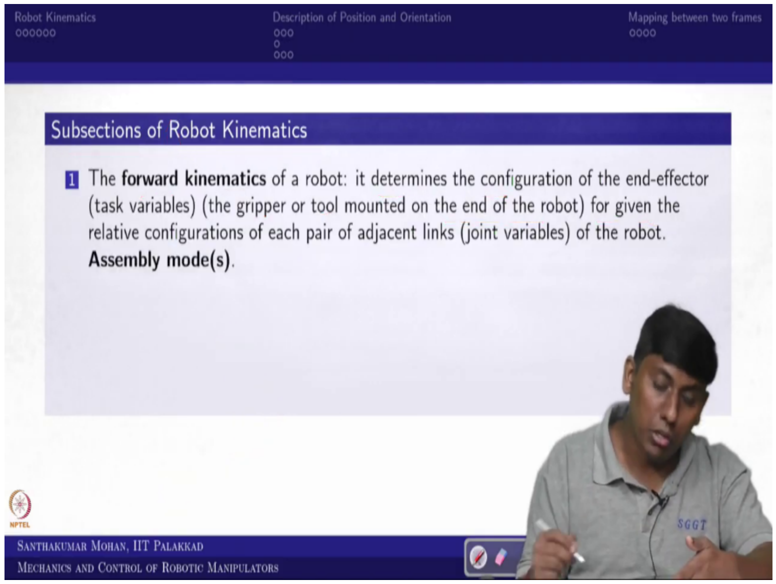

So, I will write this in a more verbally, in the sense I am writing in a more clear way. So, you can see the robot kinematics is having two subsections. One is forward kinematics. What that? It determines the configuration of the end effector which we mean, say that the task space variable or task variable in the sense most of the cases it would be a gripper, some of the cases it is like it tool mounted on the end effector of the robot for given relative configuration of each pair of adjacent links, in the sense the joint variables are given.

So, what would be the, you can say robot end effector point? So, this is what we call forward kinematics. For that what one can easily understand in the easily understandable way? So, you can see like I give this individual body. So, I say this is one body. And this body is arranged with another body this form. And another body is arranged this form.

So, like that what I am taking? I am taking from the, you can say one end to the free end I am assembling one body to another body. So, then what we can call this forward kinematics in more, you can say, parallel robot community and all? We call this is assembly mode. So, you are assembling the set of body in such a way that you will give the final end effector.

In the sense you take the free body and put it and assemble so that you will get some kind of mode. So, that is what you call assembly mode. I hope you are clear on this.

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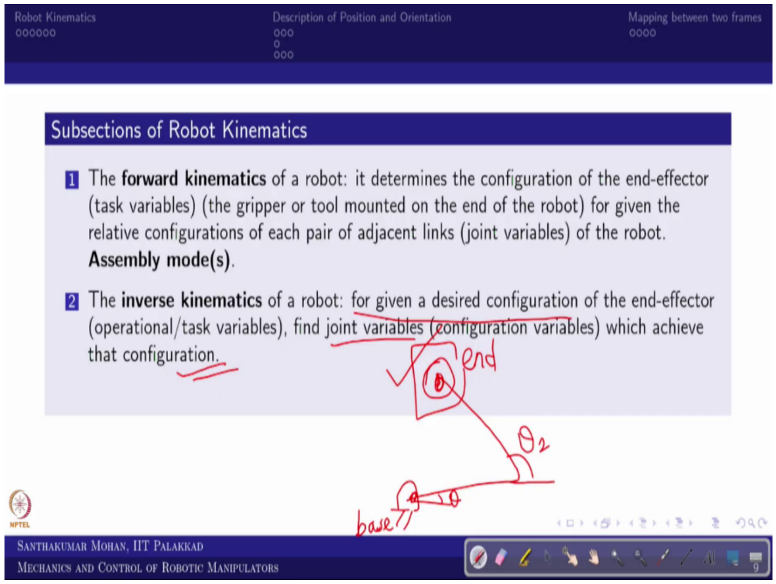

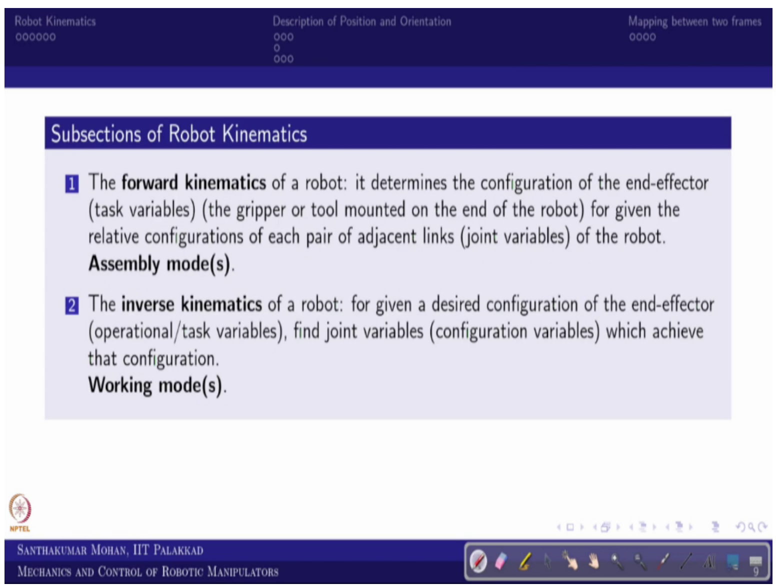

So, let us move the next one. What is that? So, that is nothing but the inverse kinematics. So, what is that? So, for given the desired configuration of the end effector which we mean to say the operational or task space; find variables, in the sense what variables, the joint variables which are you call configuration variables which achieve that configuration.

So, in the sense what we are trying to see? We are having something. This is end, so this is end effector and this is the base. So, you are given base and end. You see that how to arrange this. So, in the sense what you have? So, you have the working end, and you are trying to arrange your body in such a way that it that is making. In the sense what we can call?

This is inverse kinematics where the end effector point is given with the respect to the base, and you are trying to make sure that what angle it is supposed to be required. That is what you are trying to find out. This is very close to that working nature. So, some people call this is working mode. So, this is the two different classification of what you call robot kinematics.

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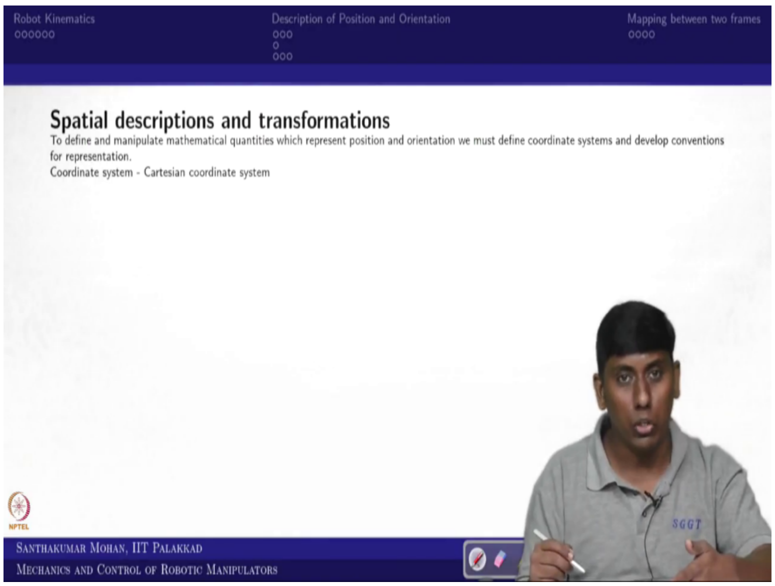

I will take one additional slide and end this lecture. So, the next lecture we will talk about more about the configurations and all. So, but let us take one simple slide. You already know like what is description. But why we need description in manipulator? Because we need to talk about the motion in mathematical quantity. So, here the motion is written into two forms, the position and orientation.

I already mentioned in the last lecture the position derivative and the orientation derivative would be linear velocity and angular velocity, and further derivative would be linear acceleration and angular acceleration. But what we need? So, we need to describe or define this as in a mathematical quantity. So, that what we can do? We can do further on what you call transformations.

So, what that one body to another body we can actually transform the information whatever available to us. So, for that what one supposed to know? We should have one clear definition on the coordinate system. I already said we would be using one of the standard convention called Cartesian coordinate system, so which in the sense mutually perpendicular axes, that is what we have used.

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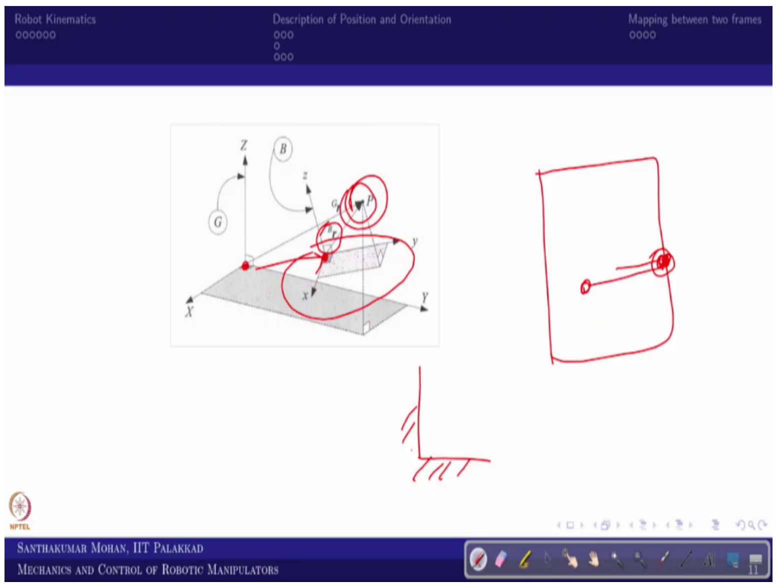

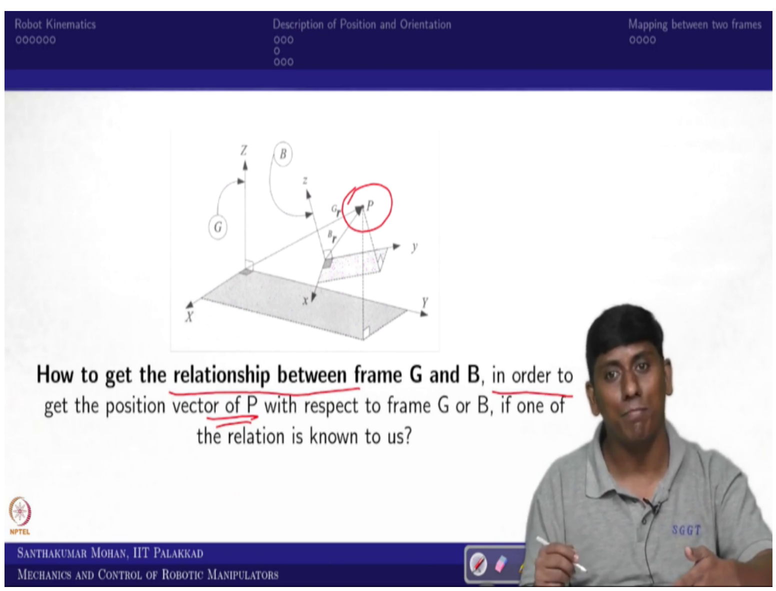

So, I end with this particular picture. So, what that means? You can see like this is the ground. So, there is one moving body. I have taken only set of frames. So, this is the body frame, and this is the ground frame. And now with respect to body I have known one point. Very simple example. You have one big car. The car one you can say front end which is what would you call the lamp post or probably the symbol or the logo of the car is kept.

So, now you know that with respect to the body this location. Now I assume that there is a ground. So, with respect to this ground can I define, in the sense, can I define this P point with respect to ground? But what I know? I know the information with respect to body. Can I transform? So, in that case what information you require?

You can see that the body we call B frame is orient with respect to ground frame and as well as translated with respect to ground frame. In addition to that the B frame is having additional point called P. That point P can I write it with respect to ground? So, this is what our interest.

So, if that is the case what we can do? We have to first understand how to describe the position and how to actually describe the orientation. Then we can actually say that how to get this relationship between ground frame G to the body frame B. Why we are looking at this? Because we need to have one information what we call P with respect to G or B. One is known. So, with that I am ending this particular lecture.

The next lecture would be talking about description of position and orientation. Then we will be talking about how to map, you can say, between two frame and finally we will end up with something called transformation matrix. So, before we are going to that, so I am ending this particular lecture. The next lecture we would be straight away talking about description of position and orientation. See you then. Thank you, bye.