Mechanics and Control of Robotic Manipulators
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Lecture No: 02
Introduction

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Welcome back to Mechanics and Control of Robotic Manipulators. So, last lecture what we have seen basically we gave an introduction to the course, so very basically we, very informally we started what is Robot and we started talking about what is manipulator and types of manipulators. In the last lecture itself I said that this particular second lecture going to talk about Robot mechanics, basically the introduction to Robot mechanics, then we would be talking about degree of freedom and finally we have end with the kinematics.

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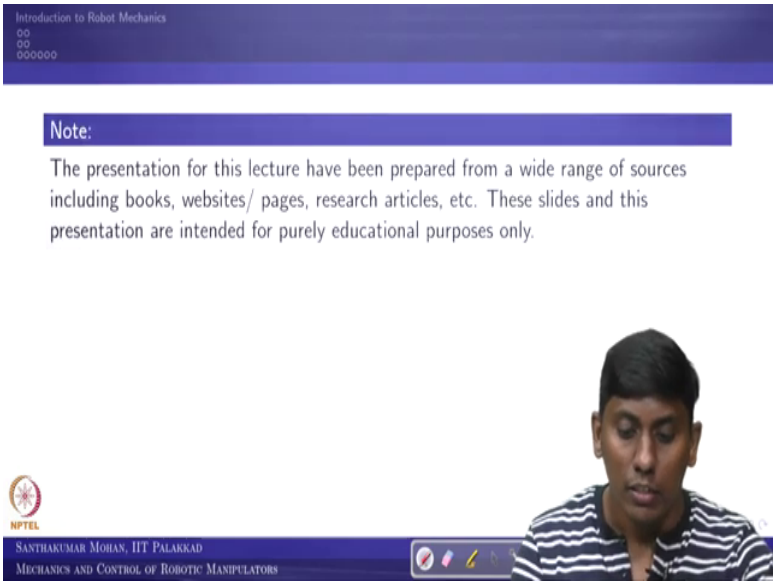

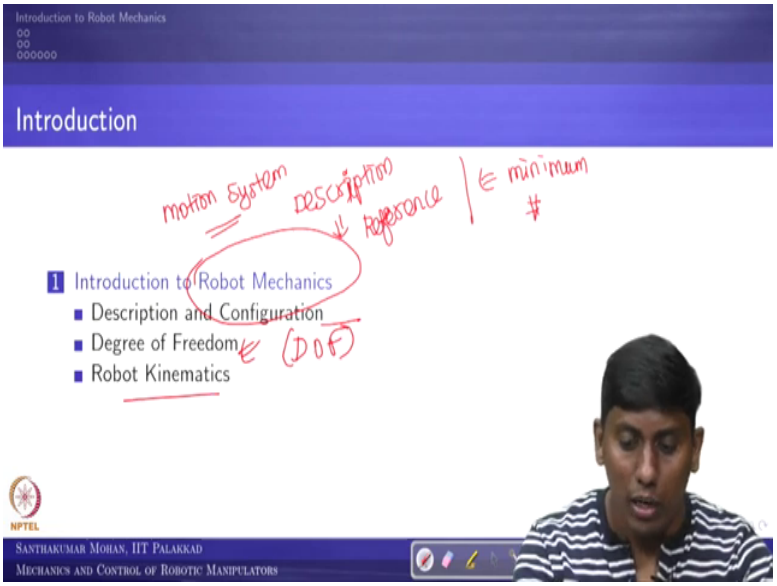

So, in that sense what we are focusing here is basically the mechanics. So, the mechanics come with several things because it is a motion system. So, the motion system needs to be defined. So, in the sense the motion needs to be defined, so we should know what the description is! So, what is the description? Then we should know, for describing you should have a reference.

So, then for referring it so you should have the minimum number of variables, so minimum number, these all would be coming. So, in the sense we would be talking about this particular

lecture, would be we seeing very specific robot mechanics, we will see what is configuration, what is description and what are the description? we can see!

Finally, we will start a very simple keyword called DOF, in the sense degree of freedom, then we end with the robot kinematics. So, this is what we planned for this lecture, let us see what we can cover in this.

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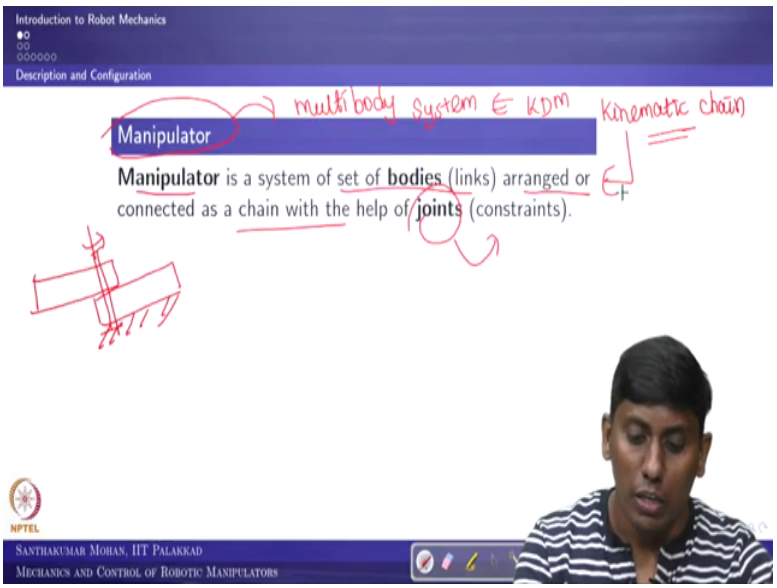

So, we will start the manipulator. You know manipulator can be defined, so an effector that has an effect on the environment, which has effect on the environment causes motion of the objects around, you call it is manipulation, the device which you call manipulator. If you talk about manipulator, obviously it is, you can see it is multi body system or multiple body system. So since, it is multiple body system, so we have studied whatever in the kinematics and dynamics of machinery may not be straight a way you can apply.

So, then we should know what the method we can do it. So, but this is also very similar what you have studied as a linkages or mechanism or kinematic chain. This is also like one kind of kinematic chain so what it would be having set of bodies arranged or connected as a chain with the help of joints which we call constraints.

For example, now you take one body, this body is connected with another body in the sense your constraints, in the sense you take this body and ground it with this pin. So now, what happen, the ground and this pin is grounded. Now, this body is rotate with respect to this pin.

So now, what you did, you have constraint these two body with this particular you can say connection. So, that is why the joints we simply called constraints.

And generally, the bodies in manipulator we call link. So, this is the basic idea, so now you know manipulator is very simple. It is very similar to what you have studied as a kinematic chain in your, you can say kinematics and dynamics of machines course. Bur here it is multiple body, there also multiple body and here multiple degrees of freedom will come and we will see how that can be further enhanced. That is what we are going to see.

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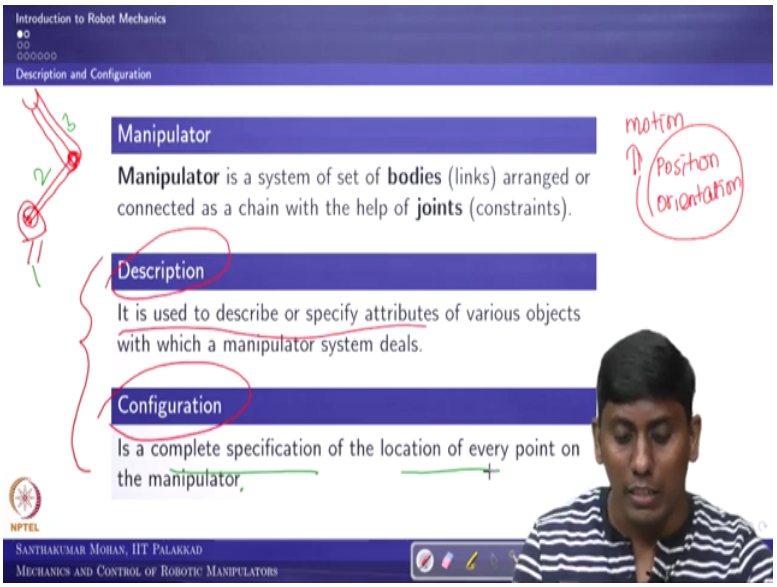

If we are talking about that, there are two keywords which are thrown, so what, so you need to provide some kind of information about that or you have described something about this motion system, so then we need to have some kind of attributes which is going to describe. So, in the sense what we are, use a specific attribute of various object with which a manipulator system deals. So, this is what you call description.

For example, if you talk about motion system, what are the description you have to give? The motion description you need to give, the motion description can be further given as, so positional change or you can say the orientation or rotation change. So, these are the two changes you have to mention, so in the sense you have to describe the position orientation further, you have to describe the positional change, orientation change with respect to time, like that you can keep going.

So, in that sense, you can see that the description is one of the keys, for describing you should have some reference. For example, so are calling me as short height and dark skin, so these need some reference, the same dark skin cannot be applied if we go probably some of the, you can say continental countries like African countries and all. Why, because the dark is relative with respect to which entity you are.

The similar way the short in height may not be applicable if we go to Mongolian countries. So, they may be shorter than me, then I cannot be called as a short. So, then you should have a reference, so you have to make one of the references. In this particular course we are going to talk about one of the major reference systems which we are going to consider here is the Cartesian coordinate system, which means the three mutually perpendicular axis consist.

So, that coordinate system we are going to use. So, further what we have to see, so the set of bodies how it is arranged, that make one configuration. So, in the sense, for example, I take, so two bodies I taken and took the ground, so now I am arranging it like this. So, this is one body, and this is another body, so this body is arranged in such a way that it is a circular pin is connected and now if you look at this is 1, 2, 3, bodies are there.

These are arranged, it is giving what, it is giving some kind of arrangement, this kind of arrangement what we are going to call as a configuration, so what that mean, it will give a complete specification of location of every point of that system. So here, it is manipulator, so in the sense what; if you call configuration that would be complete specification of the location of every point on the manipulator.

So, for example, if I take, this one of the configurations which is I call two serial rotary links as a configuration, then this can give all possible you can say points of the manipulator, in the sense location of every point on the manipulator. So that is what we call configuration.

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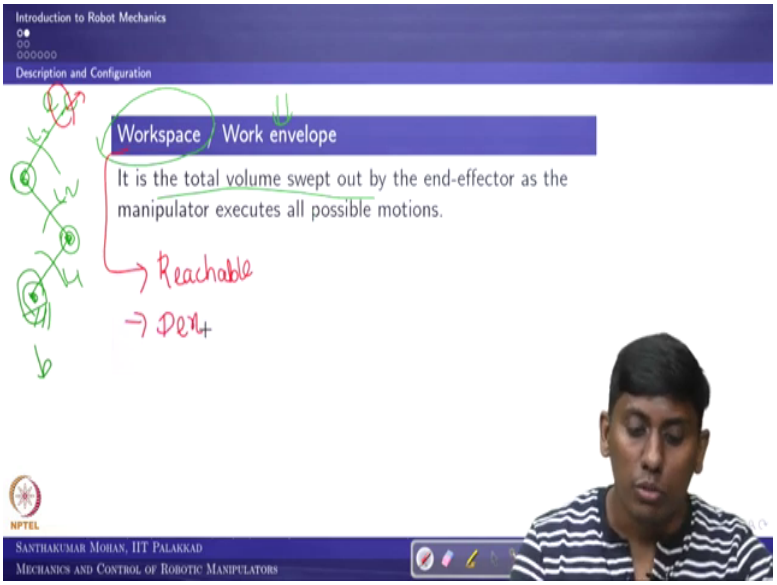

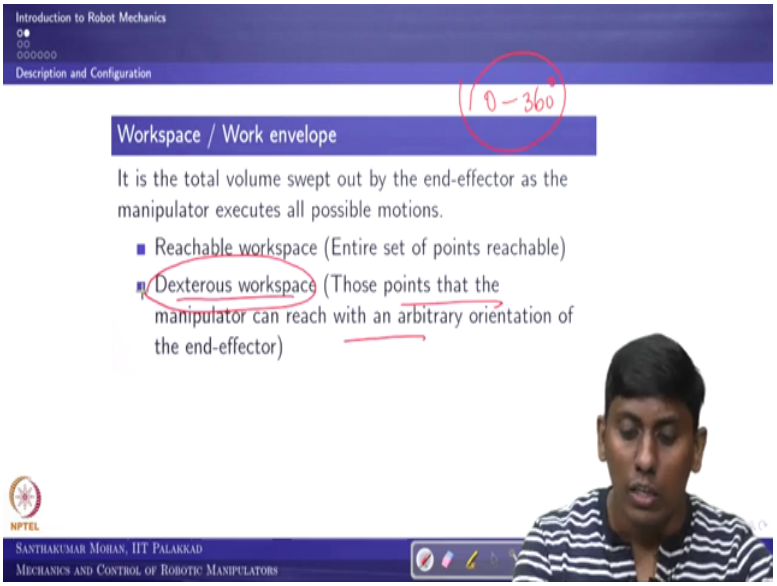

So, now we will see further and further, so what we are seeing further and further, we would be throwing one of the keywords called workspace or work envelope. What that mean? You know we are talking about Robot that to manipulator, you assume that this is one of the you can say serial chain manipulator, and this is the end, and this is the base.

So, this is base and end, so this end-effector how much it can cover. So, by rotating these three links, how much area it can cover. So that is what we call workspace? If it is in a 3D case, it would be giving a work envelope or work volume. So, this is what we simply call

workspace. What that mean? It is the total volume swept out by the end-effector as the manipulator executes all possible motion.

For example, I connect one of the motors here that rotate 0 to 360 this is also going to rotate 0 to 360, this is also going to rotate 0 to 360. So, then this length l1, l2, l3 all are known, so what would be the, all possible configurations of the system. So that is what you call work envelope or workspace. So now, you got this, so then you can see the workspace can be further classified, so one is all reachable point you call reachable workspace.

But, certain point you can see the orientation of the end-effector can be arbitrarily fixed anything, in the sense this is the end-effector orientation, this can be orient 0 to 360, then that would give a small confined workspace, but what additionally it will give, any given orientation it can fulfill, so then what you can see that is you call dexterity, so in the sense that workspace you called dexterous workspace.

So, that is what we are going to call, so one is reachable workspace in the sense, entire set of points reachable, in other way around you can say, entire set of configurations possible you can see, and that is what you called reachable workspace. If you look at the end-effector point and trace it on the configuration that is what you called reachable workspace. So now, in that subset, the dexterous workspace that mean those point that the manipulator can reach with any or an arbitrary orientation of the end-effector.

In the sense it can go 0 to 360 degrees of the orientation of the end-effector. So, that is what you call the dexterous workspace. So now, I hope you clear what is envelope, what is description, what is configuration.

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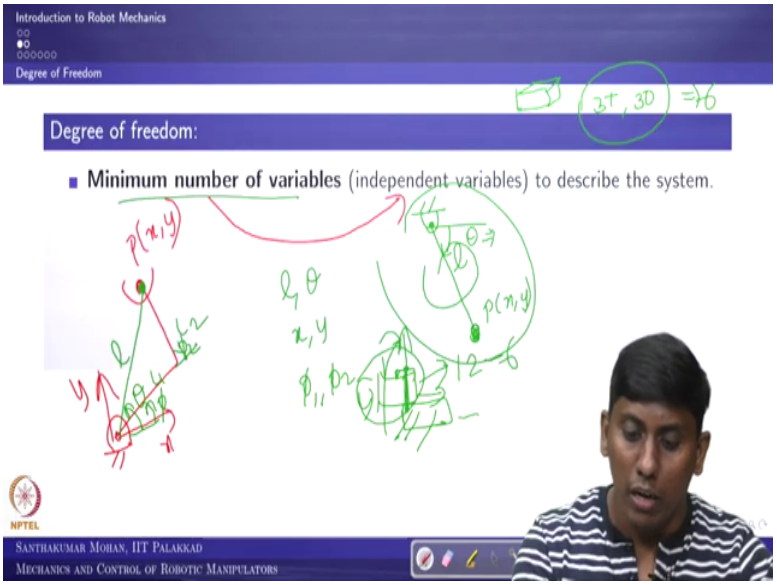

We will go one additional phenomenon which is important for the course, what is that? degree of freedom. For understanding this I am just giving a small example, just small example. So, somehow you are attended my lecture. So, one of your faculty who come across, he visited IIT Indore when I was there, so he has come across and you are trying to explain about me, unknowingly you forget my name, then what you are going to give.

So, you are going to describe about me so that your faculty who was come across IIT Indore can recognize me. So, now what you may say that, so he is one of the Robotics experts. So, in that case IIT Indore probably 3 or 4 would be there. So, you can say that sir he graduated from IIT Madras, so in that also there are two people who graduated in IIT Madras and working in the same department. So then, you say even mechanical, I already said it is same department.

Further you have saying that this faculty travelled Germany, in that case also two of the faculty travelled and stayed in IIT Madras for their PhD. Then finally you say that right now he is in IIT Palakkad. So, then he is easily recognizing, “Oh, you mean to say Santhakumar, I know him.” So, if you, means any one condition, for example, you straight away, you say that he has moved IIT Indore to IIT Palakkad, then it is not sufficient.

Because there are 2 or 3 faculty who moved from IIT Indore to IIT Palakkad. Similarly, simply you can say he is Robotic expert that is also not sufficient, in the sense, in order to understand or in order to recognize me you have thrown a minimum number of variables to

recognize me. So, or minimum description so, that is what we are going to call as a general degree of freedom. What that mean?

When you want to describe the system what are the minimum number of variables to, you can say variables required to describe the system in a unique sense. So that is what you call minimum number what you called degree of freedom. This minimum number of variables even you can call as independent variables, both are same, so in that sense I will just give a simple example, it is a planner manipulator, so this point I need to define.

So, only this point, so then what are the ways I can do? I can draw the x, y axis, I can draw this point and I can say x and y or other way around I can draw this. So, l or r theta, like that I can define. For example, now if I want to define this point how many variables required? So, I need to have l theta or x, y or even I say this l1 and the l2 are known, I said that this is phi1 and this is phi2, so you can see phi1 and phi2. In the sense what you can see it, so the minimum number of variables to describe the system is 2.

So, this is what the case. So, now you can look at the other way around. You take a simple pendulum, so now I want to know this position. I give this l, so now you say that this is P, so x, y. So now, do you think that there are two variables required to define this. No, if I know this angle theta, so I know l, l is constant, so, I can easily find this position. So, now there may be one question, sir, so l also required why you are mentioning that?

So, this is the independent variable, this l is constant throughout. What is the variable? The variable is theta, in the sense for defining this particular system you need one variable which is theta. So, in the sense what would be the degree of freedom here, it is 1, the same thing in mechanics we can try to understand. If you are looking in a motion system, so if you take any free body in space, so how many variables you need to require to or describe the system?

It required 3 translations and 3 orientations. In the sense it required 6, so if you have a n number of bodies, how many degrees of freedom would be there or how many variables required, it would be n into 6 or 6n, so now, I am taking one body and constraint with another body, this is a ground, I am confined this as a pin joint. So, now how many degrees are there? So, ground 1 and this is another 1, there are 2, so in the sense 6 plus 6, 12, but this can move only 1 body.

So, in the sense 6, another 6 is subtracted, further what happen this particular pin joint who is allow only 1 rotation. It cannot, it is proper collar, it cannot come out, it cannot go out, it cannot go this way and it cannot rotate this or rotate independently. It can rotate only vertical axis in the sense it is 1 DOF of system, this is what you have seen here, so in the sense, so degree of freedom is nothing but minimum number of variables to describe the system.

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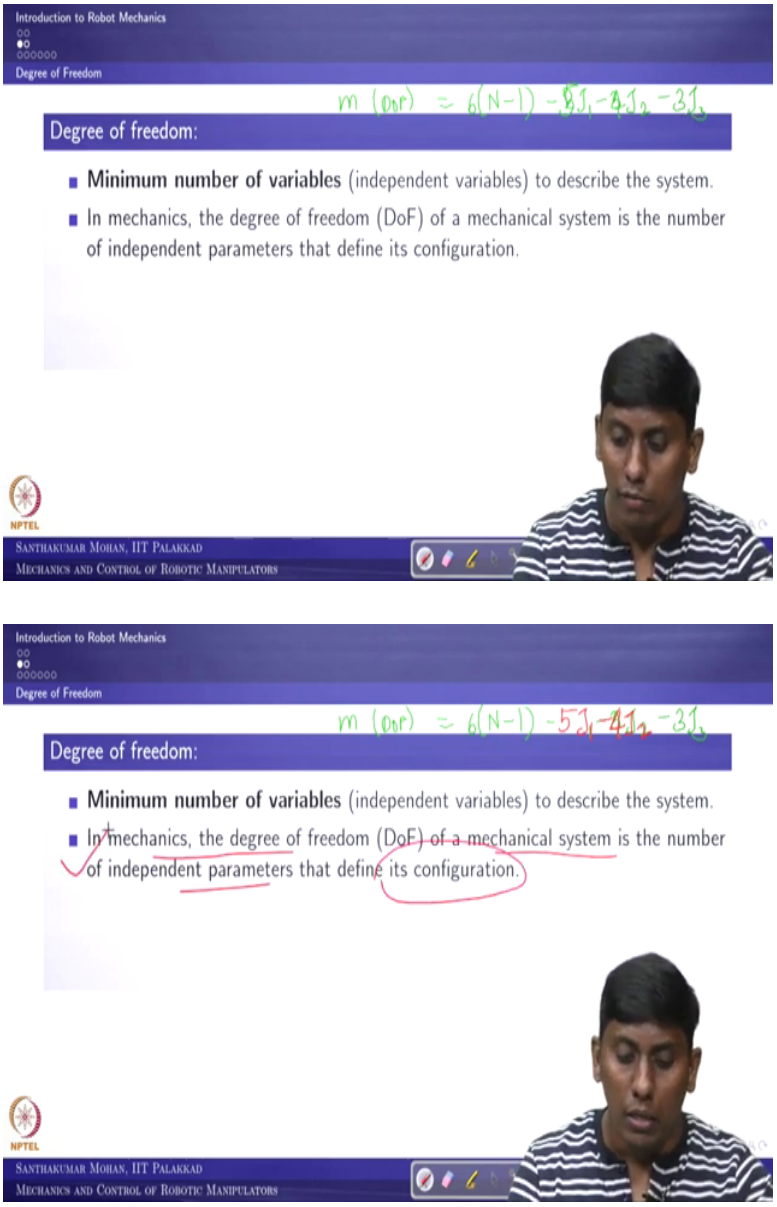

So, now I hope you would have already studied your, what you call a Grubler's criteria and the Chebyshev equations and all, so I am not talking that, but you can recall the degree of mobility or degree of freedom in general can be written as based on the number of bodies. So, I have it is in 3-Dimensional space, so N minus 1, N is the number of body and this is the number of 1 DOF joints and this is 5. And this is a number of 2 degrees of freedom joint and this is the number of 3 degrees of freedom joint.

In real there is no such 4-degree, 5-degree joints and all, so we can restrict these. This is 5. So, this is 5 J 1 minus 4 J 2 minus 3 J 3, which is going to give. I hope this equation you

would have studied in your you can say mechanics, but right not what mechanic says that the degree of freedom of a mechanical system is the number of independent parameters that define its configuration. Configuration means how the body is arranged 1 to another that is what you called the degree of freedom.

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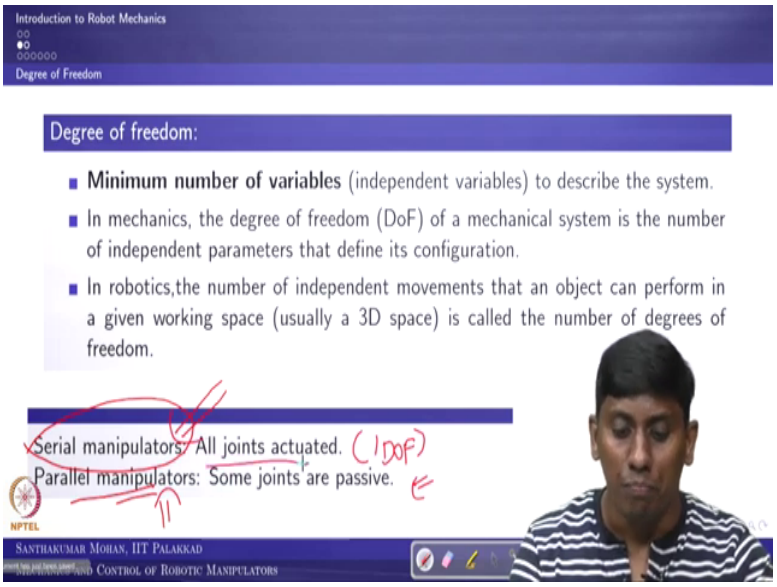

Now, in that connection what we are seeing in the Robotics, so Robotics is number of independent movements that and object can perform in a given workspace. Usually what it is a 3D workspace is call the number of degrees of freedom. So, in that sense now you are clear what is degree of freedom. There is another factor we suppose to know. So, before that I will talk, the serial manipulator, all joints are actuated in addition these all are 1 DOF, degree of freedom joints, so either rotary or translation joint.

So, even you have spherical joint that actuation would be independent. Whereas the parallel manipulator, some of the joints would be passive, further these joints can be having multiple degrees of freedom joints. For example, you have a universal joint, spherical joint, these all can come in the parallel manipulator whereas the serial manipulator it cannot come directly why because this is all joints are actuated.

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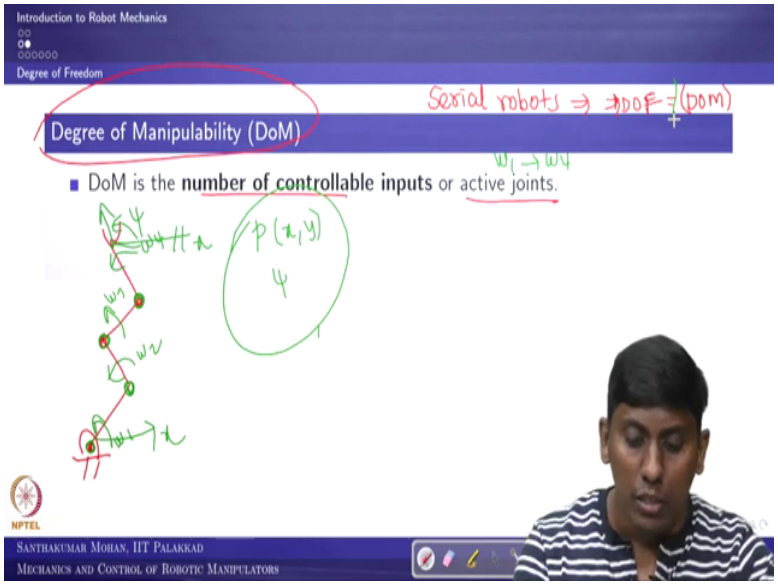

So, let us move further, we said one additional parameter you should know, what is that called degree of manipulability. So, what is manipulability? So, it is basically nothing but number of controllable inputs or active joints. By the name itself you can see if it is a serial Robot, if it is a serial manipulator or serial Robot, simply the serial Robot would be so the degree of freedom and degree of freedom and degree of mobility are same.

But whereas, if it is parallel manipulator then it is not so same. So, that is what I wanted you to understand so the controllable inputs are a different and degree of manipulability is different. For example, even you want to understand. So, I am just giving, it is a planar manipulator, it is a planar manipulator. It is having you can say 4 motors, so each motor can rotate, so omega 2, omega 3, and omega 4.

So, now, so how many variable to describe the system, since it is in a plane it required even this orientation all include, so P(x,y) and the orientation I call this is with respect to x-axis, this is parallel to x, so this angle called phi, in the sense these are the 3 which is the minimum number of variables to describe the system but how many controllable inputs, so omega1 to omega 4 in the sense 4.

Now, we can see even though it is a serial but, it is not having this match degree of freedom to degree of manipulability, but most of the case these are same but, you can see even one simple instant this is not same. Now, you are clear what is manipulability?

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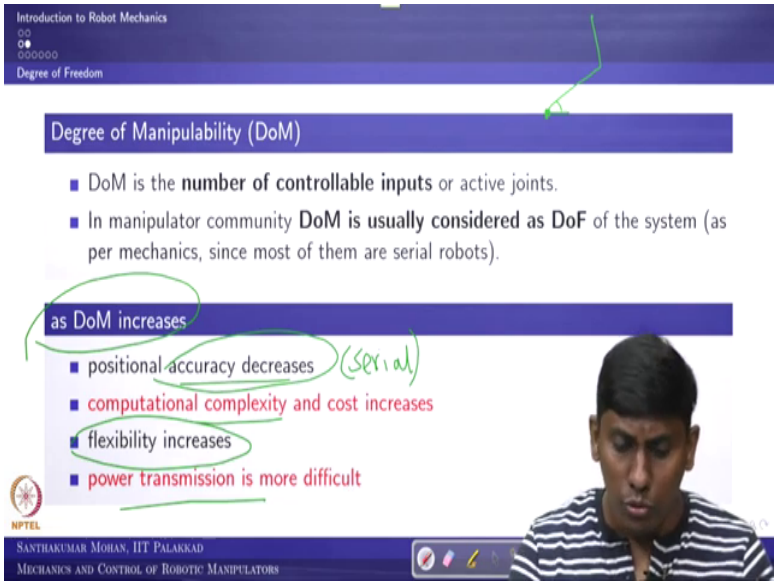

So, further you can see this manipulability is already I said usually consider as degrees of freedom because, as per mechanics most of them are serial and that to number of degrees of freedom is less than 6 or equal to 6, in the sense controllable axes would be maximum 6. If you have a redundant Robot, so then you cannot call it is 7D of system strictly speaking.

But commonly we use the system is 7 DOF system, 8 DOF system, but we need to describe in space only 6 variables required, but you have 7 inputs in the sense it is redundant so that we see further on. We will classify even Robot, Holonomic Robot, redundant Robot and under actuated or under or non-holonomic Robots and all.

But that is not the scope in this particular content. So, let us move further, so if the degree of manipulability increases, in the sense what you are trying to do, you are trying to increase the number of actuators. What you can see, the positional accuracy decreases as per serial Robot because if one Robot or one chain, so for example, you have error here, this error would accumulate further.

So, that is why I say if you keep increasing the degree of, you can say manipulability the, you can say the positional accuracy decreases. Similarly, the computational complexity and cost increases because you are increasing the number of controllable inputs, so the complexity is definitely increases, and cost also increases because you are increasing number of actuators. This is number of additional components.

But what you get benefit, benefit is the flexibility. So, you will get hyper-redundant, in the sense you are having a flexible condition. For example, the conventional Robot, you call the holonomic Robot cannot do, but the flexible in the sense hyper-redundant or redundant Robot do it. So, for example, I showed right 4 DOF system in the previous slide.

That can do much, much higher. Further what happens in your keep on adding in serial so what happens you need to deploy the power connection; accordingly, in the sense you have a restriction in the power transmission. So, these are the cases let us move one slide further, so now you know what is manipulability?

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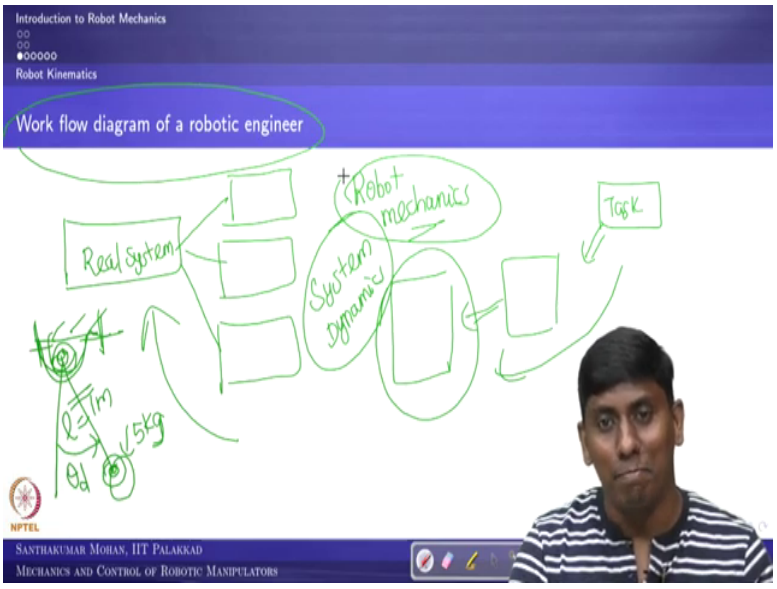

So, I just give this slide here. So, what would be the workflow of a Robotic engineer? So, you know all the engineers will give the task to be accomplish. So, the other side what you have, the task for example, I am saying that the Robotic assembly, so then you will see the real system, the real system would be, so what would be, the real system would be the manipulator. So, how will you choose the manipulator?

On shelf the manipulator will start from 2 lakhs to probably even 2 crores, so it is a very difficult, so from the task what one can get the desired specification you can get, so based on the desired specification what one can find, you can find the tentative configuration. So, the selection of configuration you can do but the real system required at least 3 inputs.

So, one would be the selection of actuator, the other would-be selection of the mechanical structure, the third one would be selection of you call control, or you can say sensors, because, you need to have a closed loop. So, now you can see the selection of configuration has come from one end, but selection of actuator, sensor and mechanical system is other side.

So, somebody has to fill here, so who would be filling, so, we are going to cover in this course is nothing but that we call system dynamics. So, simply you called in the Robotic the Robot mechanics is going to cover. So, in the sense what we are going to see here the Robot mechanics, so that is what we are going to see in this particular course.

So now, you got clarity what supposed to be required and what we are trying to do. Very simple example I will give and end this course. For example, I want you to make simple pendulum which has a 5kg as the bob weight, and the length is 1 meter, and this would be motorized in the sense it is a simple 1 R (rotary) actuator you can see.

So, what our angle I am giving that supposed to be keep as each with even 5kg load. So, then if I ask you to fabricate what you will see, so you cannot glue the metal rod with the metal bob. So, definitely, you have to see what to be done here. Similarly, this actuator you have to see what would be the minimum torque? and this support you cannot simply glue it. You have to see what would be the; you can say proper support so, that you can put a bearing and put a proper fastener and everything.

Similarly, this is supposed to be a proper cross section and material required. So, in this case, so you need to have a detail about each and everything. So, you need to fulfill your motion requirement, you should fulfill your structural requirement. So, both you require; in that sense you should know one of the important aspects is Robot mechanics.

When you talk about the Robot manipulator, so how they build, how they achieve the motion, so you need motion dynamics and structural dynamics. So, that is what we are going to cover in this particular course here after. So, with that, so I am saying thank you here, we will see next lecture, the Robot mechanics introduction, so until then see you! bye, take care.