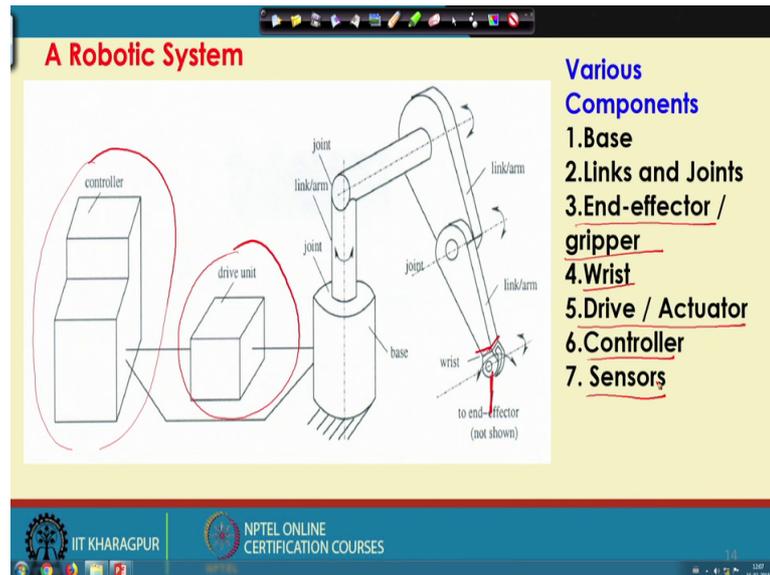


**Robotics**  
**Prof. Dilip Kumar Pratihari**  
**Department of Mechanical Engineering**  
**Indian Institute of Technology, Kharagpur**

**Lecture - 02**  
**Introduction to Robot and Robotics (Contd.)**

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So, we are discussing the different components of a Robotic System. And we have seen that, the robot is having base, links and joints. And the next is we have got some set of end-effector or the gripper. Now, this end-effector or the gripper, the purpose of using the end-effector is to gripe that particular object, which I am going to manipulate. And this particular end-effector or the gripper, so that will be connected here, not shown here in this particular the sketch, so the gripper will be connected here.

The next is this gripper or the end-effector, I will be discussing in much more details after sometime. The wrist joint, so this particular joint is nothing but the wrist joint, where I am just going to gripe, so this particular end-effector with the last link of the robot. Next is your the drive system or the actuator. Now, this drive system or the actuator, if you see, now let me see, what type of drive system we have in our body like we human being or we are dependent on both the mechanical drive system, that is with the help of your muscles. And we also take the help of hydraulic system that is with the help of blood, and the blood is pumped with the help of heart.

So, now all such things have been copied in robotics also. And in robotics we will find we have got the pure mechanical drive. Now, mechanical drive means, in the form of the gears, gear and pinions, in the form of chain drives, belt drive and so on. Now, supposing that the load requirement is more or the power requirement is more, so what we will have to do is, we will have to take the help of some set of hydraulic drive. We also take the help of pneumatic drive, using some set of compressed air, we use electrical drive also. And sometimes we combine, that means, use electro hydraulic, electron pneumatic drives. So, different types of drive unit we generally use here in the robots.

The next is actually the controller. Now, this controller is nothing but the brain of this particular the robot. So, just like our head. So, this controller contains this particular brain or the intelligence. And here in the controller, there will be software, there will be hardware also. Now, these actually constitute one robotic system all such components. Now, here if I want to make it intelligent, the robot will have to collect information of the environment with the help of some senses.

And that is why we use some sensors along with the robot, just to collect information of the environment and just to operate the drive units, so that we can make these particular robots intelligent. This is once again has been copied from human being, because we have got a few senses like we have got eyes, ears, nose, skin and all such things. We collect information with the help of these senses, take the decision on our head, the same thing is done by an intelligent robot. The information collected with the help of these particular senses, will be processed in the controller, then the decision will be taken, and that particular decision will be executed. This is the way actually one intelligent robot will be working. All such things will be discussed in much more details after some time.

So, the different types of sensors, we generally used in the robots, those things will be a discussed in details after some time. In fact, in robots, we use both internal sensors as well as external sensors. Internal sensors are used to operate the drive units. For example, say we have got the position sensor, velocity sensor, acceleration sensor, pores or the moment sensor and so on. On the other hand, we have got a few external sensors, which are used to collect information of the environment. For example, say we have got some sort of rain sensor, proximity sensor, and all such things will be discussed after some time in much more details.

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**Interdisciplinary Areas in Robotics**

**Mechanical Engineering**

- ❖ **Kinematics**: Motion of robot arm without considering the forces and /or moments
- ❖ **Dynamics**: Study of the forces and/or moments
- ❖ **Sensing**: Collecting information of the environment

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Now, I am just going to see; what are the different areas in robotics. As I told that in robotics, there are four distinct modules. Like these modules are coming under the purview of different disciplines. For example, say we have got the kinematics, dynamics, and sensing, which are coming under the umbrella of this mechanical engineering.

Now, in kinematics actually what we do is, we try to consider the motion, the relative motion of the different joints, different links ok, but we generally do not try to find out the reason behind this particular the movement or this relative movement, and that is actually done in dynamics. So, in dynamics, we try to find out, how much is the force required? If it is a linear joint, how much is that moment or the torque required, if it is a rotary joint. So, all such things are mathematically determined in dynamics. And in sensing, we try to collect information of the environment with the help of sensors. So, all such things are coming under the umbrella of mechanical engineering.

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The slide is titled "Interdisciplinary Areas in Robotics (Cont.)" and is divided into three main sections. The first section, "Computer Science", includes "Motion Planning: Planning the course of action" and "Artificial Intelligence: To design and develop suitable brain for the robots". The second section, "Electrical and Electronics Engg.", includes "Control schemes and hardware implementations". The third section, "General Sciences", includes "Physics" and "Mathematics". The slide footer contains the IIT Kharagpur logo, the NPTEL Online Certification Courses logo, and the number 16.

**Interdisciplinary Areas in Robotics (Cont.)**

**Computer Science**

- ❖ **Motion Planning:** Planning the course of action
- ❖ **Artificial Intelligence:** To design and develop suitable brain for the robots

**Electrical and Electronics Engg.**

- ❖ **Control schemes and hardware implementations**

**General Sciences**

- ❖ **Physics**
- ❖ **Mathematics**

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And then comes the motion planning. So, what we do is, if you want to intelligent, make intelligent these particular robots. So, what you will have to do is, you will have to make some planning. We will have to plan the course of action, and we take the help of a few motion planning algorithm

Now, if you see the literature, a huge literature is available on robot motion planning using, both traditional as well as soft computing based approaches. So, here in this course, basically I will concentrate only on the traditional approaches of motion planning, and those things will be discussed in much more details after some time. But, the purpose of using motion planning is to decide the course of action that means, depending on the input situation. So, what should be the output, how to decide that, that is the purpose of the motion planning.

Now, then comes the artificial intelligence. So, as we told that, we try to copy the human brain in the artificial way, using the principle of the artificial intelligence. Now, to design and develop the suitable brain for the robots, we will have to model the human brain the human intelligence in the artificial way, using the principle of artificial intelligence. And once again, this artificial intelligence is a very big area of research. And distinctly there are two groups of algorithms, one are called one is called the traditional AI techniques, and we have got the non-traditional AI techniques, that is called the computational intelligence, that is the artificial intelligence using the principle of soft computing.

So, using this principle actually, we can make a plan depending on the requirement. So, that the robot can be made intelligent, and it can take the decision and execute that particular task depending on the requirement. Now, all such things are coming under the umbrella of computer science.

Now, next comes the control scheme. Now, supposing that to perform a particular task. So, my motion planning algorithm has given some decision, which has to be executed. So, how to execute? So, what you do is at each of the robotic joint, we use some motor. Generally, we use DC motor, and to control these motors actually there should be controller. So, definitely the robot should have one control architecture, and one control scheme has to be used to control this particular robot in a very efficient way. And these control schemes, and its harder implementation are coming under the purview of your electrical engineering, and the electronics engineering.

Now, here actually to develop the robots are definitely, we will have to have very good knowledge of the general science like physics, mathematics, because we will have to use the principle of physics and mathematics very frequently to design and develop the robots. Particularly if I want to design from kinematic point of view, dynamics point of view, so lot of mathematics, lot of physics I will have to use. Similarly, if I want to design and develop suitable sensors for these particular robots, we will have to use the basic principles of physics, all such things I will be discussing after some time in much more details.

Now, that means, your if somebody wants to become a true expert of robotics, so he or she should have at least some basic fundamental knowledge of all these particular the pills. And that is why, the robotics is little bit difficult, and it is bit difficult to become a true robot assist.

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**Connectivity / Degrees of Freedom of a Joint**  
It indicates the number of rigid (bodies) that can be connected to a fixed rigid body through the said joint

*Joint angle*

**Joints with One dof  
Revolute Joint (R)**

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Now, I am just going to concentrate on once again the different types of joints, which is generally used in robots. I have already mentioned that basically we use two types of joints, one is called the linear joint, and another is called the rotary joints. Once again, the linear joint we have got basically two types, one is called the sliding joint, another is called the prismatic joint. Similarly, the rotary joint we have got the revolute joint, and twisting joint. Now, each of these particular joints is having the degree of freedom or connectivity. So, by connectivity we mean, how many rigid link can be connected to one fixed link through that particular the joint.

Supposing that this is the input link, and I have got one output link here, now if I want to join this output link with the input link, so I will have to put one joint. Now, if I can join only one output link to the in fixed input link with the help of that particular joint, so this particular joint is having one connectivity; connectivity one or degree of freedom one.

Now, here I am just going to discuss or in details, the joint like the revolute joint. Now, this revolute joint as I told, that it has got only one connectivity, and one degree of freedom, because I can connect only one output link with the input with the help of this particular the joint.

Now, one very simple example of this type of joint, this type of revolute joint is this particular joint, so this is a revolute joint. Now, here you can see, that if this is the input side, this is the output link, so this particular output link can be connected to the input

link with the help of this particular joint. So, this joint is nothing but similar to a revolute joint.

Now, here in this particular sketch if you see. So, this is the input link, denoted by  $i j$ . And this is the output link denoted by  $j k$ . And in between the input link  $i j$ , and the output link  $j k$ , we have got a joint, and that is nothing but the  $j$ -th joint. So, this is nothing but the  $j$ -th joint.

Now, here if you see, so this is the axis about which I am taking this particular the rotation. And the axis of the output link is nothing but this and they are at 90 degree. And that is why, so this is a typical example of the revolute joint. Now, let us see, how does it work, to explain its working principle. So, this is the input link that is the output link.

And here, I have got a fixed offset that is denoted by  $d_j$  fixed, so this is the fixed quantity. And, so this particular output link can only rotate with respect to the input in this particular direction  $ok$ . And this rotation is given by, so this particular  $\theta_j$ . And this  $\theta_j$  is nothing but a variable. So, here so  $\theta_j$  is known as the joint angle, so this is known as the joint angle. And this joint angle is nothing but a variable here for this particular the revolute joint.

Now, one second if I take this particular example, as I told that this particular joint is a revolute joint. Now, this angle the included angle, the moment I rotate this input link with respect to my output link. So, this particular angle is going to vary, and this angle is nothing but the joint angle. So, this is the variable for this revolute joint. So, this is the example of this particular the revolute joint.

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**Connectivity / Degrees of Freedom of a Joint**  
It indicates the number of rigid (bodies) that can be connected to a fixed rigid body through the said joint

The diagram shows a revolute joint with a vertical joint axis. A link is attached to the joint, with a unit vector  $a_{ij}$  and a variable angle  $\theta_j$  relative to the axis. The distance from the joint axis to the link is labeled  $d_j$ , fixed. The link is labeled 'link  $i$ ' and the joint is labeled '(a)'. A hand-drawn sketch on the right shows a revolute joint with a red pencil and a red box, with a red arrow indicating rotation.

**Joints with One dof**  
**Revolute Joint (R)**

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Now, then comes the Prismatic joint. Now, before I go once again for this particular this prismatic joint let me just tell let me tell you one more thing. Now, here I did not discuss the twisting joint that is another type of the rotary joint. Now, I am just going to show you one very practical example with the help of which you can find out the difference between, so this particular the revolute joint, and the twisting joint.

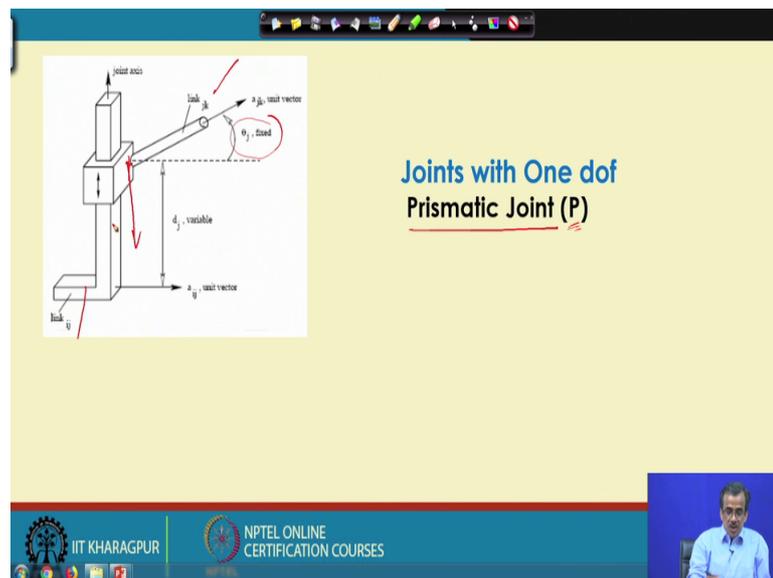
Now, I am just going to take one very simple example. Let us concentrate on the joint which you have at this particular neck, our neck. Now, with the help of this particular joint, I can rotate my head in two different ways. For example, say this is nothing but my fixed link. And supposing that, I am just going to rotate the head, so this is actually the axis about which I am rotating my head, and this is something like this. So, I am just rotating my head something like this. And, here in this particular rotation, this is the axis about which I am rotating my head ok, so this is one rotation.

And I am just going to rotate my head in another way. So, this indicates the axis about which I am taking the rotation. So, here in this particular rotation, so I am able to rotate my head like this. So, if I rotate my head like this. So, my output axis of the head is here, and this is the axis about which I am taking the rotation, so this angle is nothing but 90 degree. So, the moment I am rotating my head like this, so this particular joint is nothing but the revolute joint. But, the moment I am rotating my head like this. So, this particular

joint will act like the twisting joint, so this is the practical example, just to find out the difference between your the revolute joint, and the twisting joint.

Now, here if I just draw one revolute joint and the twisting joint on the same manipulator, I can draw very easily. So, I can draw very easily, one manipulator with one twisting joint, and one revolute joint. So, let me let me try to prepare one sketch. So, this is actually a robot with fixed base. So, this is a very simple robot. So, with respect to the fixed base; so here I have got a joint, and it can rotate something like this, so this joint is nothing but a twisting joint; it is a rotary joint. But, here I have got another joint with the help of which I can rotate, and this is nothing but a revolute joint. So, this is the difference between the twisting joint, and this revolute joint.

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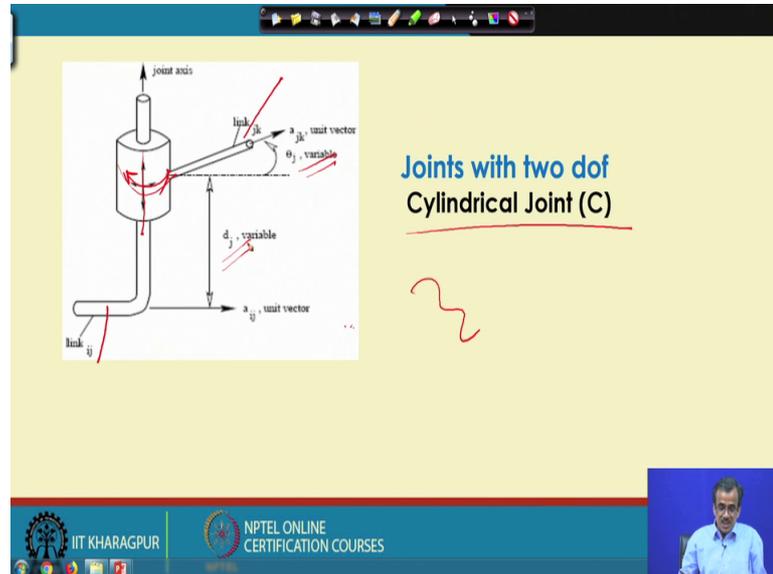


Now, I am just going to start with the Prismatic joint, which is nothing but which is nothing but a linear joint. And this particular the prismatic joint is having only one connectivity or one degree of freedom; now, here on this particular sketch. So, this is the input link  $i j$ . So, this is actually the input link  $i j$ . And the output link is nothing but the link  $j k$ . And here, we have got the  $j$ -th joint. Now, you can see that, so this particular  $\theta_j$  that is the joint angle is kept fixed.

Now, this block, so it can move up and down, so it can slide, it will have only the linear movement, only one connectivity, one only one degree of freedom, and there could be only linear movement. So, this particular the Prismatic joint, which is denoted by P, will

have only one connectivity or one degree of freedom. So, this particular your the prismatic joint or is having one connectivity or one degree of freedom.

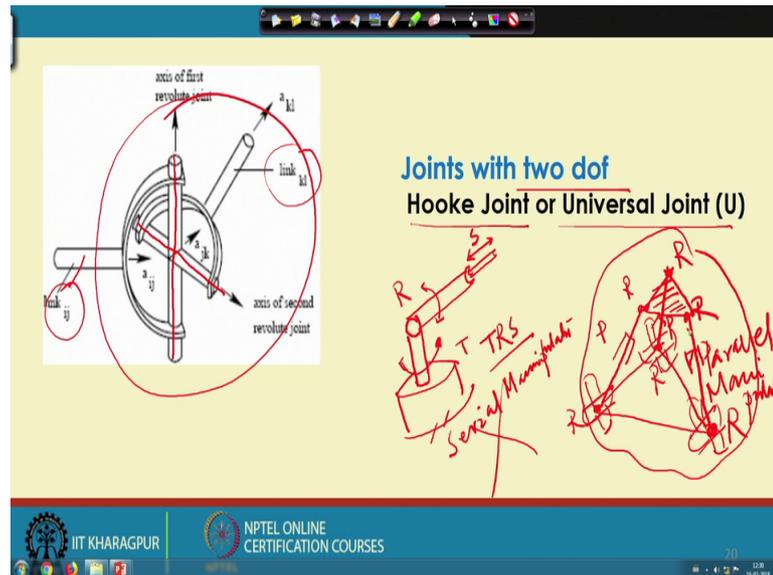
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Now, then comes the cylindrical joint. Now, this particular cylindrical joint is having, in fact, two degrees of freedom. So, cylindrical joint has got two degrees of freedom; this is the input link  $i j$ , the output link is  $j k$ . Now, this particular block, can slide up and down. And at the same time, it can also rotate something like this. And this is called the cylindrical joint.

So, here we have got one linear joint, and we have got the rotary and this is a combination, and it has got two degrees of freedom. And that is why both  $\theta_j$  as well as this particular  $d_j$  are kept variable. So, this is a typical example of this particular cylindrical joint, which has got two degrees of freedom or two connectivities.

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Now, then comes the concept of your the Hooke joint or the Universal Joint. So, this Hooke joint or the Universal Joint, this is actually a combination of two rotary joints. In fact, here we are going to combine, two such revolute joint. And this particular Hooke joint or the universal joint has got two degrees of freedom.

Now, let us try to understand the principle of this particular the Hooke joint. Now, here the input link is input link is  $ij$ , and the output link is nothing but  $kl$ . Now, here you can see that we have got one revolute joint here. So, this is the axis for this is the axis for the first revolute joint. And this is the axis for the second revolute joint ok. Now, I am just going to show you the physical concept of these particular, this Hooke joint or the universal joint.

Now, let me consider that this is a joint this is a revolute joint. So, this is the axis about which I am taking the rotation, and with respect to this particular axis. So, the joint can be rotated something like this. So, it has got some theta variation here, similarly with respect to this. So, I can have another revolute joint like this. So, here with respect to this the axis I can I can rotate something like this. So, this is another revolute joint.

Now, these two revolute joint if I just connect, so this is one revolute joint, this is another revolute joint another revolute joint. So, these two revolute joint if I connect, then it will form the Hooke joint or the universal joint. Supposing that this is actually my input side, and this is my output side. So, with respect to the input, the output will have two degrees

of freedom. And this type of joint is generally not used in serial manipulator, but this is used in parallel manipulator. Now, the concept of serial manipulator and parallel manipulator, I am not yet discussed. But, I am just going to give a very rough sketch for this serial manipulator and a very rough sketch for the parallel manipulator. Just to find out the difference.

Now, if you see the manipulator, which I just drew a few minutes ago, that is nothing but a serial manipulator. Now, in serial manipulator, actually all the links, all the joints are in series. For example, say the same picture I can consider for the serial manipulator, so this is nothing but a serial manipulator. So, this is another joint. And here, I can put one linear joint also. So, let me put one linear joint here. So, there is a twisting joint here, denoted by T, there is a revolute joint here, denoted by R, and there is a sliding joint here, say denoted by S, that is a linear joint. And this is actually known as, TRS manipulator, this is nothing but a serial manipulator. So, this is a serial manipulator.

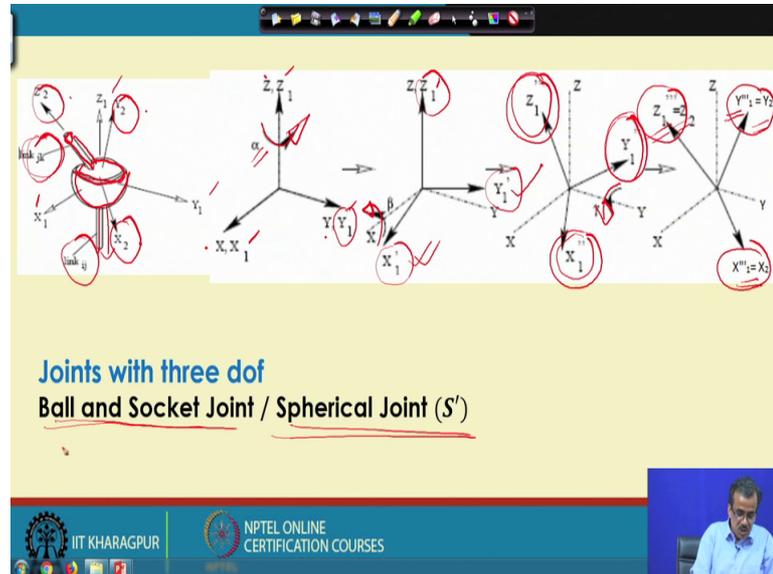
And now, I am just going to draw a rough sketch for one parallel manipulator. Very simple parallel manipulator if I just draw. So, very simple sketch, very simple design, I am just going to make. So, this is the parallel manipulator, this is the top plate for the parallel manipulator. And here, we have got a few joints.

For example, say I can put one revolute joint here, I can put one revolute joint here, I can put one linear joint here, say one prismatic joint I can put. Similarly, at each of these particular legs; so I have got one revolute joint here, I have got one linear joint here, this is a revolute joint ok. Similarly, I have got a revolute joint here, I have got another revolute joint here, I have got one prismatic joint or the linear joint here, so this is nothing but a parallel manipulator. So, this is actually a parallel manipulator.

Now, the reason why I am just trying to find out the difference between the serial and parallel manipulator here is as follows. So, these types of joint are generally not used in serial manipulator. But, there is a possibility that in some of the parallel manipulator, this is a very simple parallel manipulator. But, in some of the complicated parallel manipulator, we use this type of the Hooke joint. For example, in place of this rotary joint, I can put one Hooke joint here, I can put one Hooke joint here, I can put one Hooke joint here, I can put one Hooke joint here.

So, these type of joints are generally used in parallel manipulator, but not in serial manipulator. Those things I will be discussing after sometime in much more details.

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Now, then comes the concept of the ball and socket joint or the spherical joint. Now, this ball and socket joint or the spherical joint is having actually the three degrees of freedom, and all three are rotations. Now, here actually what we do is, the input link and output link is connected to so one carbon cone type of this thing arrangement. So, the input link that is link i j is having the coordinates X 1, Y 1, and Z 1, and input link is connected here, so this is actually connected to the input link ok. And the output link, whose coordinates are nothing but whose coordinates are nothing but X 2, Y 2 and Z 2 that is connected to your, so this part, and this is nothing but is your the output link, and this is a link j k.

Now, starting from input link i j, if I want to go to this link j k, how many rotations are required. Now, if I can start from X 1, Y 1 and Z 1, and if I can reach X 2, Y 2, Z 2, through some minimum number of rotation, that will be the degrees of freedom or connectivity of this type of ball and socket joint or the spherical joint. Now, let us try to find out what should be the degrees of freedom of this ball and socket joint or the spherical joint. And before I do that, let me once again mention that this type of joint is generally used only in the parallel manipulator, but not in serial manipulator.

Now, let us try to understand, why does it have three degrees of freedom. Now, this  $X_1$ ,  $Y_1$ ,  $Z_1$  initially that is coinciding with the universal coordinate system  $X$ ,  $Y$  and  $Z$ . And here, I am just going to give some rotation about  $Z$  by an angle  $\alpha$  in the anti clockwise sense. Now, if I give rotation about  $Z$ , my  $Z$  will remain same as  $Z$ . So, this will become  $Z_1$  prime. So, this will remain this will become  $Z_1$  prime. But,  $X_1$  will become  $X_1$  prime that will be different from  $X_1$ . And  $Y_1$  will become  $Y_1$  prime. And  $Y_1$  prime will be different from  $Y_1$ , but  $Z_1$  prime will remain same as  $Z_1$ .

Now, I am just going to give some rotation about  $X$  by an angle  $\beta$  in the anti clockwise sense. So, if I give rotation about  $X$  the original  $X$  or the universal  $X$  by an angle  $\beta$ . So, I will be getting change in all  $X$   $Y$  and  $Z$  that means your  $X_1$  double prime will be different from  $X_1$  prime;  $Y_1$  double prime will be different from  $Y_1$  prime; and  $Z_1$  double prime will be different from your  $Z_1$  prime.

And now, I am just going to give rotation about the universal  $Y$  by an angle  $\gamma$  in the anti clockwise sense. So, all three rotations will come that means your  $X_1$  triple prime,  $X_1$  triple prime will be different from your  $X_1$  double prime; then  $Y_1$  triple prime will be different from  $Y_1$  double prime; and  $Z_1$  triple prime will be different from  $Z_1$  double prime. And now,  $X_1$  triple prime is nothing but  $X_2$ .  $Y_1$  triple prime is nothing but  $Y_2$ . And  $Z_1$  triple prime is nothing but  $Z_2$ .

Now, here so this  $X_2$  is nothing but this particular  $X_2$ . This  $Y_2$  is nothing but this particular  $Y_2$ . And this particular  $Z_2$  is nothing but this particular  $Z_2$  that means, starting from the input link that is  $X_1$   $Y_1$  and  $Z_1$ . I am able to reach the output link that is  $X_2$   $Y_2$   $Z_2$ . And to reach that, I need to take the help of three rotations. And all three rotations were taken we with respect to the universal coordinate system that means I need three rotations. That means, you are this ball and socket type of joint or the spherical joint is having the 3 degrees of freedom or the mobility level 3.

Thank you.