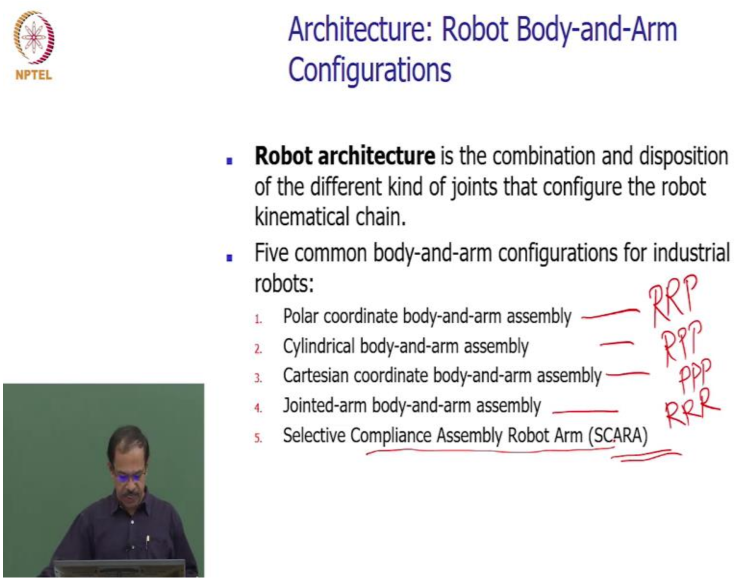
Introduction to Robotics
Professor T. Asokan
Indian Institute of Technology, Madras
Department of Engineering Design
Lecture 2.4
Robot Architectures

So in the last class we talked about various robot architectures. So robot architecture basically comes from the type of joints and the way the joints are arranged. And we saw that the first three degrees of freedom of the robot is used for positioning the wrist. And these positioning joints decide the architecture of the robot.

So we look at the way in which the first three joints can be arranged or the type of joints and the way it can be arranged. You will be able to get different configurations, different architectures for the robots, and we found that there can be five commonly used body arm architecture and they are basically the polar coordinates cylindrical body and arm, Cartesian coordinates jointed arm and selective compliance assembly robot arm.

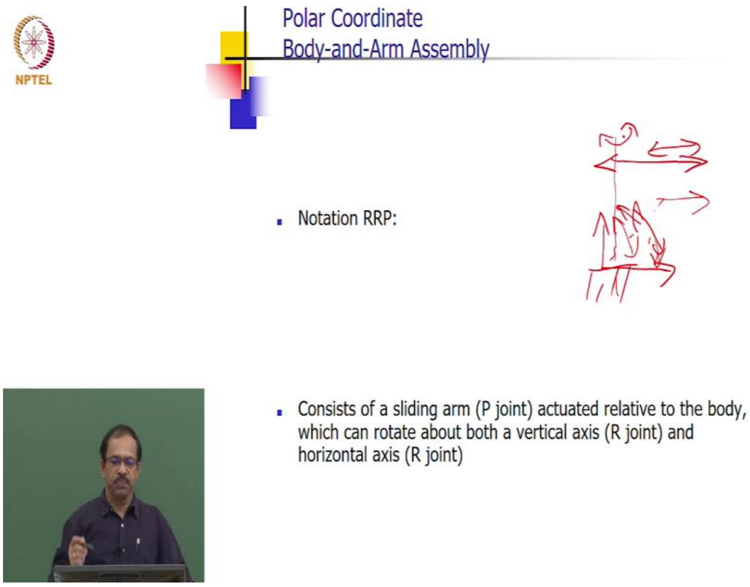
(Refer Slide Time 1:05)



So, these are the five commonly used architectures and we saw that these can actually be obtained by having two rotary joints and one prismatic joint, and then we can have the cylindrical body by having R, P and P. So, two prismatic joints and then one rotary joint will give you a cylindrical body arm architecture and then if you have all of them as P you will be getting a Cartesian coordinate body and arm assembly. So, this was what we saw in the last class and again jointed body arm architecture is RRR. So, if you have R joints, rotary joints, then we will get it as a jointed arm body and assembly architecture. And another variation of this is basically a SCARA again, 2 rotary joints and 1 prismatic joint, I will discuss it later.

So, you can get a different configuration known as selective compliance or simply robot arm. So, we look at these configurations and then look at their workspace and then little bit on whether the kinematics is simple or difficult or why it is difficult or why some configurations are preferred over the other by looking at these architectures.

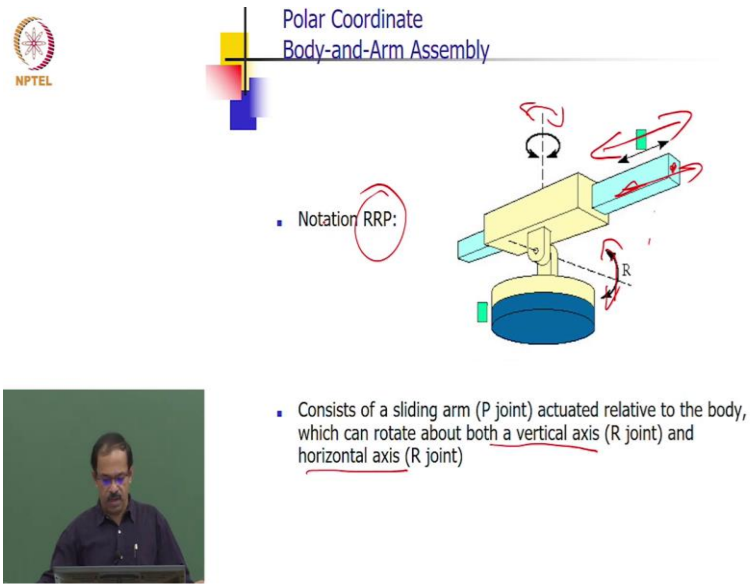
(Refer Slide Time 2:33)



So, first let us look at the polar coordinate body arm assembly. So, as we mentioned, it is a RR and P. So, you have a P which actually goes suppose this is the base and you have a coordinate frame like this. Then you have one joint which is the prismatic one which actually goes in this direction, and then we can actually have one axis which actually pertains with respect to this, that is it can actually go, suppose this is the one then it can actually go up and down this direction and then you can have it go like this also.

So, basically this is going like this and then in and out, so you can actually get R and theta or R and P like this and then if you rotate this with respect to the vertical axis, you will be able to cover the three dimensional space. So the first one will give you planar positioning, the this motion and this rotation will give you the planar positioning within a plane and out of line motion is possible because of the rotation with respect to the base, so this is the way how this RRP is arranged.

(Refer Slide Time 3:53)

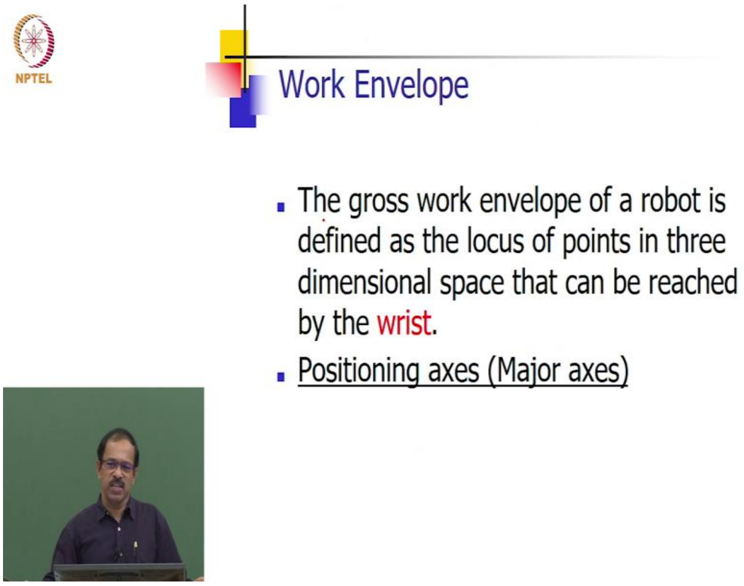


And the structure will look like this, so you have this motion, the prismatic joint going out of this or going inside, so you can actually get a motion like this and then the rotation about this axis, the horizontal axis. So, you have a vertical axis rotation and a horizontal axis rotation. So, the horizontal axis rotation gives you a planar motion with this and the vertical axis rotation gives you the out of plane motion also.

So, this way, you will be able to get a three dimensional workspace in polar coordinates. So, R theta will be the positioning that you can use and then phi will actually give you that y dimension I mean x y z coordinates can be obtained by these three joints.

So if this is the wrist point, so assume this as the wrist points. And we can see that the wrist point can actually be placed in a three dimensional space using the RRP configuration. So that is basically the polar coordinates body and arm assembly. Not a very popular configuration but for specific applications you may find this as useful, we will look at that.

(Refer Slide Time 5:08)

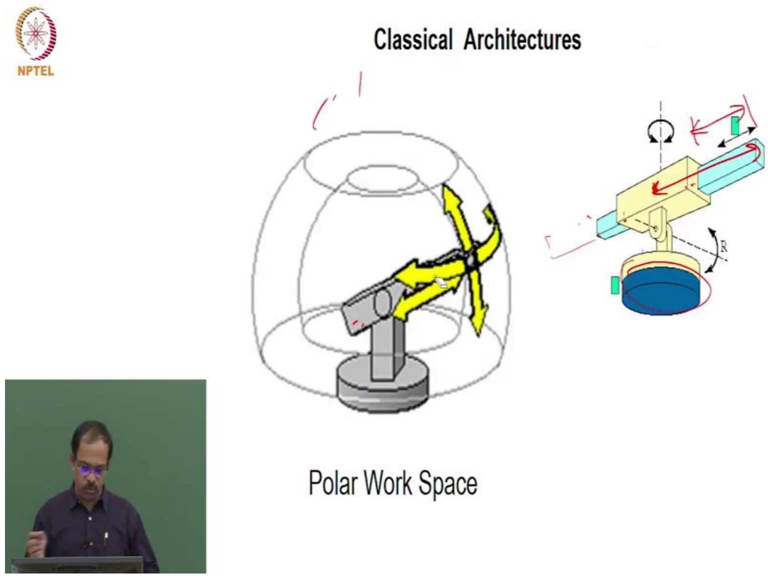


Now, the workspace or we call this as the work envelope of the robot because workspace has got a little bit more specific meaning, work envelope is the maximum envelope that the robot can actually reach that it basically known as the mark work envelope. So the gross work envelope of a robot is defined as the locus of points in 3 dimensional space that can be reached by the wrist.

So the points where the wrist can reach in three dimension space is generally known as the work envelope, sometimes work envelope and workspace are used in the same context. But in general, work envelope is the maximum that you can reach overall in the 3 dimensional space, work space may be a subset of the overall work envelope together depends on the joint limits and other things.

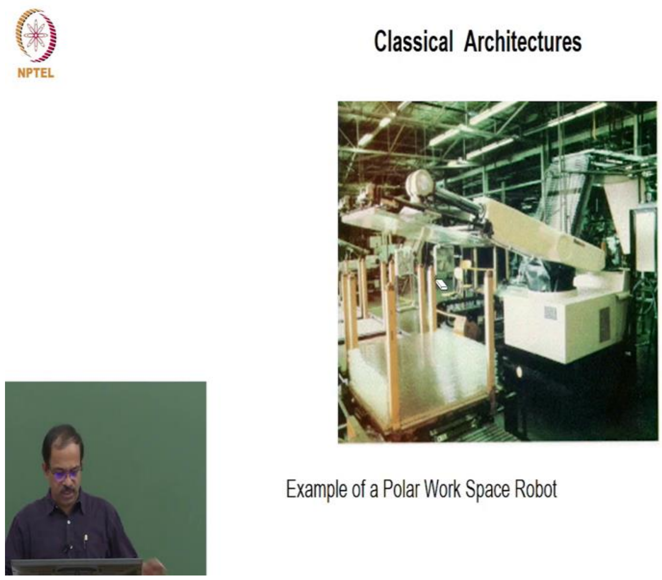
So without considering those joint limits, we can say this is the gross work envelope we can think of a robot. And this work envelope is basically depending on the positioning axis only because we are talking about the wrist and the wrist positioning is decided by the major axis and therefore, work envelope is decided by the major axis, I mean the type of joints in the axis, I mean type of joints available and the orientation or the way in which the joints are organized.

(Refer Slide Time 6:26)



So, it just shows the polar workspace that you can actually achieve this kind of robots.

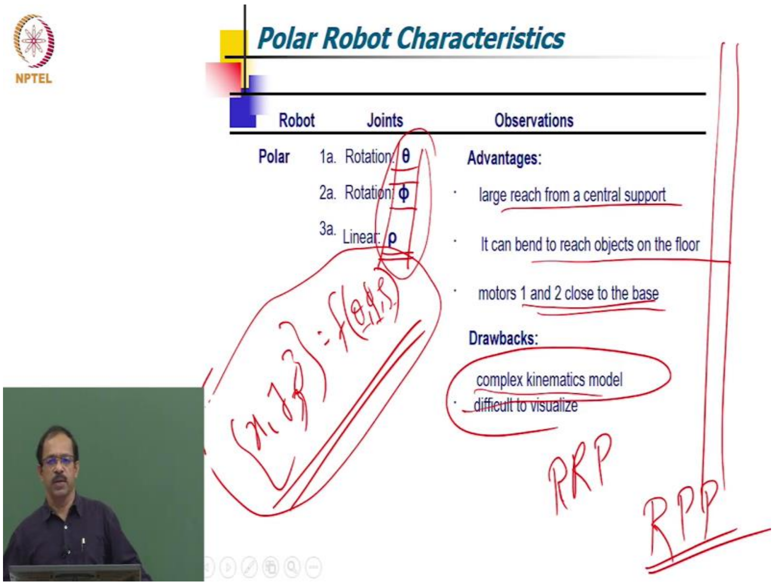
(Refer Slide Time 6:34)



Now, if you look at this is one of the commercial robots which actually uses a polar work space. So, you can see that all the motors will be somewhere at the base and even for this linear motion also the motor will be somewhere here, and this can actually reach the base also, the end can actually reach the base and then pick up something and then do some tasks.

So, that is why that is one of the advantages of this robots and since all the motors are somewhere at the base, you can actually have large payload also because these motors need not carry the load of other joints. So this is one example for a polar workspace robot, not very popular, you do not see them many in the industry.

(Refer Slide Time 7:22)

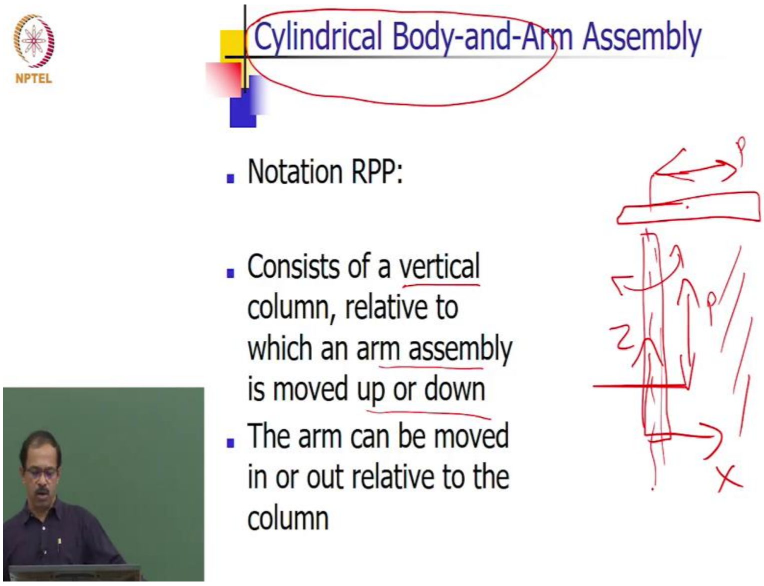


So these are the three parameters that actually defines the motion of the robots. So you have a linear motion, you have two rotations, theta and phi. So the x, y, z, the position that the wrist can reach is a function of these three parameters, Theta, Phi, and Rho. So this is the relationship that you can get in the Cartesian coordinates, and the joint parameters.

So we call this as joint parameters because these are the variables that actually changes the position of the wrist. And this relationship is not very straightforward compared to other robots, that is why I call this a little bit of complex kinematics, because you cannot directly tell what will be the x, y, z position when you change any one of these, you need to have a proper kinematic model for that one.

And other things like large reach from the central support, bend to reach objects on the floor, and motors 1 and 2 are very close to the base. So it can actually be positioned in a proper way you do not get too much of mechanical design issues with this kind of robots. So that is about the polar coordinate robots.

(Refer Slide Time 9:06)

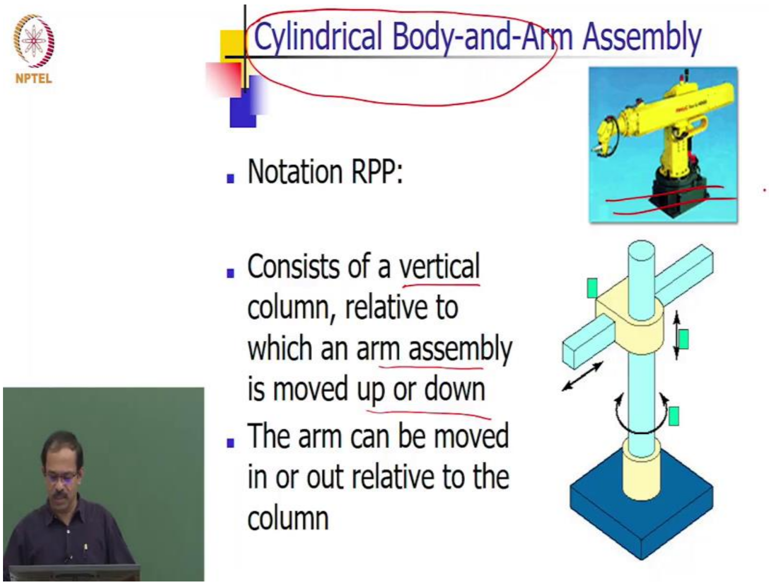


Now, so this was basically RRP. Now if you change this to RPP that is 2 prismatic joints and 1 rotary joint then you will be getting this as cylindrical coordinates or cylindrical body and arm robot or cylindrical coordinate robot or cylindrical body and arm assembly robot. So it consists of a vertical column and horizontal motion. So, you can actually have this kind of motion and this kind of a motion.

So, you have the arm which can be moved in and out and vertical column relative to which an assembly is moved up or down. So, you can have up and down motion and then in and out motion using this and then you can have a rotation with respect to this axis also. So, these two P will decide the motion in this plane, and the rotation will decide how it goes out of the plane also. So, that is the way how this cylindrical body arm assembly is organized.

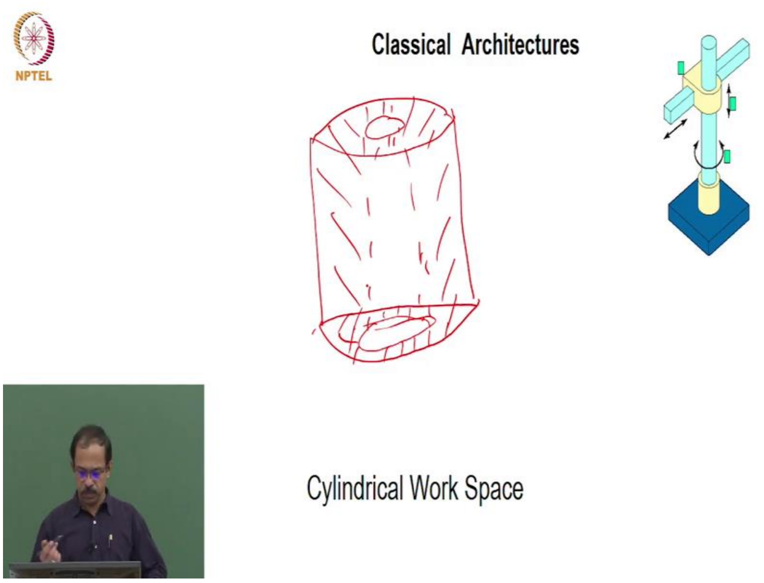
So, you have one rotary joint and two prismatic joints. So, this prismatic joint will take you in this, suppose this is the x and z axis so, the x plane motion is decided by these two and the y coordinate will be decided by the rotation with respect to this axis. So, this is the cylindrical coordinate.

(Refer Slide Time 10:38)



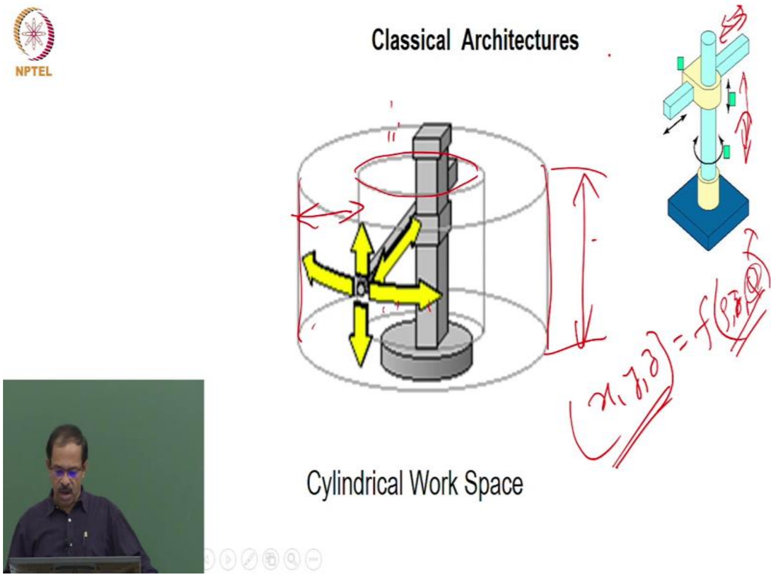
So, as the name suggests the workspace is cylinder, but of course, because of the mechanical requirements you would not be able to get the complete cylinder as a work space, the workspace will be having two concentric cylinders and in between the space will be the workspace of cylindrical body arm coordinate robot. So, can you draw the work envelope for this, what will be the work envelope for this robot? So, this is a typical cylindrical robots in industry what you can see.

(Refer Slide Time 11:10)



So the work space will be like a cylinder, so you will be having a cylindrical workspace, I mean outer envelope and then there will be a inner envelope because of the mechanical construction, you need to have joints so you cannot reach the center so it would be like this and this area will be the workspace or the envelope that you can have. And because of this space, it is known as a cylindrical robot.

(Refer Slide Time 12:03)

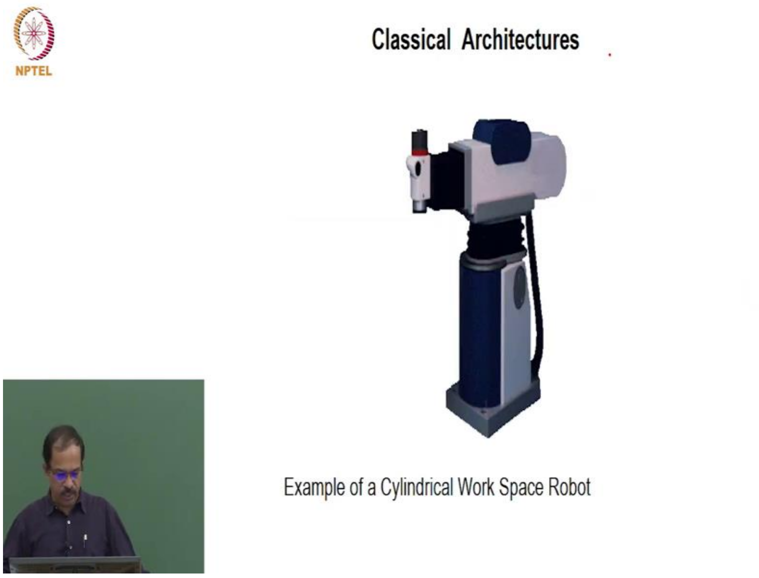


So, this will be the workspace that you can see. So, you will be having this here and then here because this distance is decided by this motion. So, what is the range that you can have that decides this, and this height is decided by the motion that you can have in this axis. So, these two are decided by these two prismatic joints and then assuming that it can go all the way 360 degrees, you will assume that, but not all the robots will be able to go 360 degrees, there will be joint limitations.

So, the actual workspace will be a subset of this space. So, what are the parameters that will decide the x, y, z here? Function of two linear motions, right? So, we call it as Rho and z and then an angle respect to this. So, these three parameters will decide the position of the wrist, again not a straightforward relationship, these two can be decided directly compared to the previous one, this is simple, because the x position and z position can be easily obtained by these two joints depending on how much this has moved you will be able to get this and then the angle will be decided by this one.

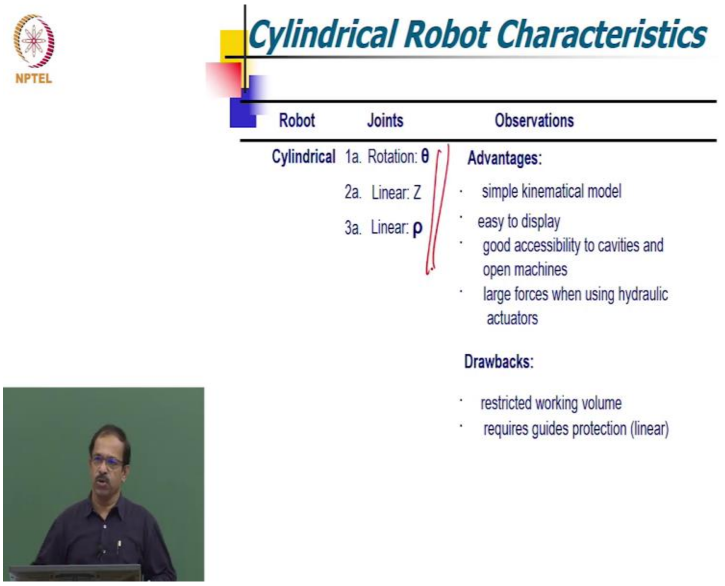
So, y will be decided by the rotation and x and z can be easily obtained, so that is the way how it is defined.

(Refer Slide Time 13:53)



So, this is an example for a cylindrical workspace robots.

(Refer Slide Time 14:01)

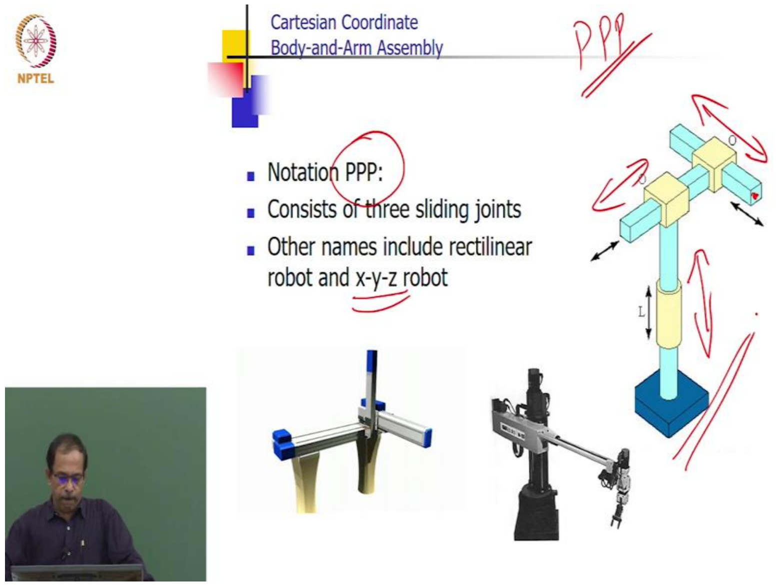


So, we have three parameters theta, Z and Rho and kinematic model is simple compared to the previous one. And of course when you are using hydraulic actuators you will be able to get large forces because it is our vertical and horizontal motions. And work volume is to be restricted, requires guides for protection because the linear joints are always a troublesome especially in industry environment may get corroded or get damaged easily, because you can see there will be protection on this surface.

(Refer Slide Time 14:34)

So, these are all provided with the bellows to protect the slides from getting jam due to some environmental pollutants or something like that. And they should be very smooth always, otherwise you will get a lot of motion difficulties so that is one of the difficulties with the prismatic joint, so you need to have proper protection for them otherwise it will get damaged.

(Refer Slide Time 15:04)



The next one is basically the Cartesian coordinate called as PP and P. So, this is the Cartesian robots, all the joints are prismatic so you can see there is a motion like this, a motion like this, and a motion like this. So all the coordinates, x, y and z directly related to the movement of these robots. So, it is really easy to find out the position of the wrist, suppose this is the wrist, we can easily find out the wrist by looking at the motion of each joint. So, it is a very simple kinematic model exactly and actually, there is not much of modeling here, the position of x is decided by one joint, y is decided by another joint that is defined inside by the other joint and therefore, we can very easily find out the position of the tool, so it is a very simple kinematic model.

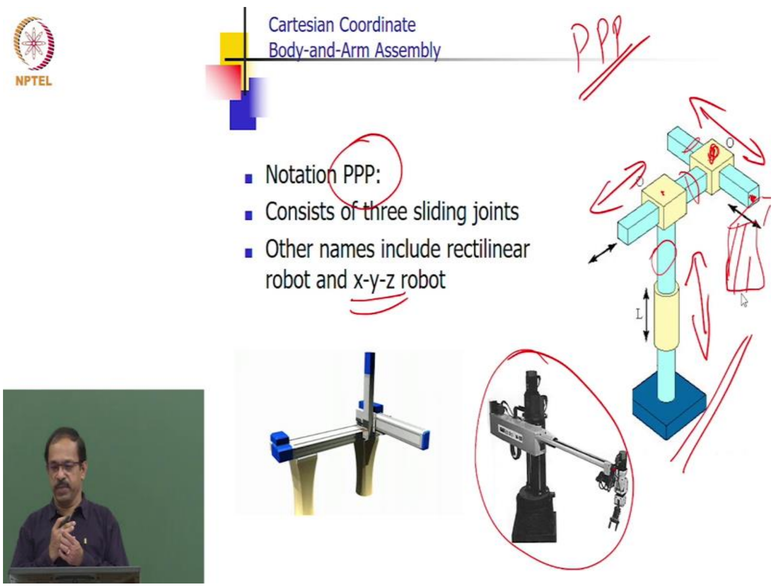
So this is an example for a industrial robot with all the three prismatic joints up to the positioning up to the wrist. Any questions? Chinmay you have some questions? Okay. Yeah. So, as you can see, it is a very simple design, because most of we use these kind of things very well.

Most of our x, y, z tables we use in many of the equipment, where you want to position it in the three dimensional space, go for this kind of mechanical striking configuration. So one advantage is that it is very easy to visualize and control, so control becomes very easy because you do not need to have any kinematic model, just control individual motors for whatever position you need.

There are disadvantages, one disadvantage is that as in the previous case, all these need to be protected, all the slides need to be protected otherwise it will actually get jammed or start malfunctioning, it would not be able to move because of some kind of pollutants or other debris getting into these slides.

Another disadvantage, okay, what will be another disadvantage of this one, can you tell me? Work space is discontinuous, why? Okay, we will see workspace later but any other thing? Loads, okay yeah load will be an issue because if you have a large reach, then you need to have bigger load carrying then this motor will be of larger weight it has to be held by these and it has to be held by this, that may be one reason okay.

(Refer Slide Time 18:46)



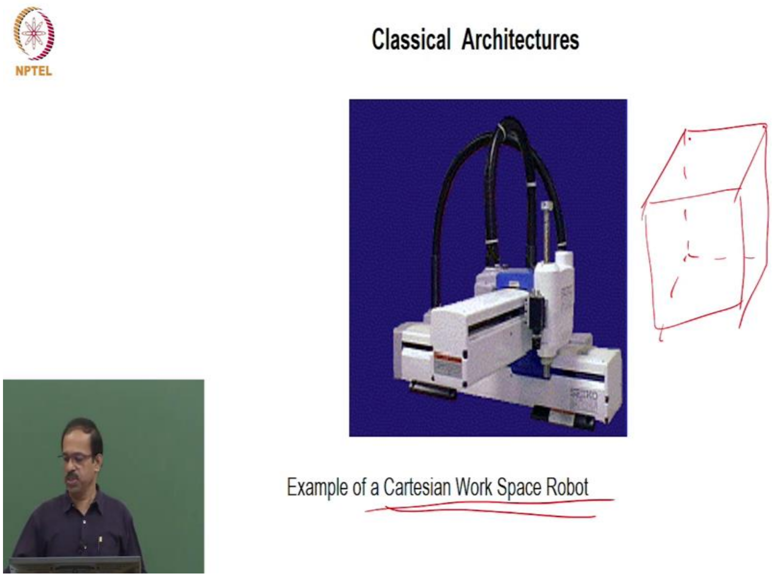
Another major problem with this that the actual workspace available or the work envelope available will be something like this, but the total robot says size will be much bigger than the size of the workspace that you can get, because each one has to move so you need to have a very larger size of the robots to get a smaller workspace or if we increase the workspace then the robot size also keeps on increasing.

So it is unlike other configurations, this one has got the largest size of the robot for a given workspace, so that is one disadvantage. So it is not commonly accepted unless you have a large space available. And if you can seen some Cartesian robot, the robot will be very big and the workspace will be somewhere in the center, a small area. If you can afford to that kind of a thing and you don not... Yeah.

that is what I am, in that case, the workspace available will be very small compared to the size of the robot. So that is the way how normally people make so they will be making a structure like this. And then you will be having the slides on this, one slide here and another slide here and then one up and down.

So the workspace will be somewhere in the center, you will be able to get a workspace here. In order to have full workspace you will be able to get so overall the size of the robot increases when you go for all prismatic joints. So that is why this is not preferred normally, most of the industrial robots wont go for this kind of configuration unless there is a specific requirement which warrants the use of this kind of construction.

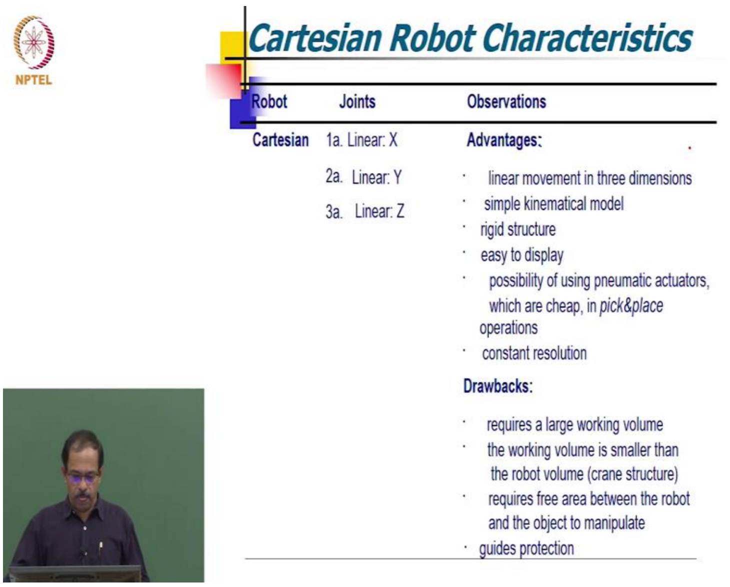
(Refer Slide Time 20:29)



So that is the prismatic robots, so it's a Cartesian workspace robot or a prismatic robots. So, the workspace is Cartesian. And you can actually find out the workspace will be something like this. And of course, there may be depending on the construction you will be having, the workspace will be within this and you can actually get the x, y, z position depending on the stroke length that is available for the work.

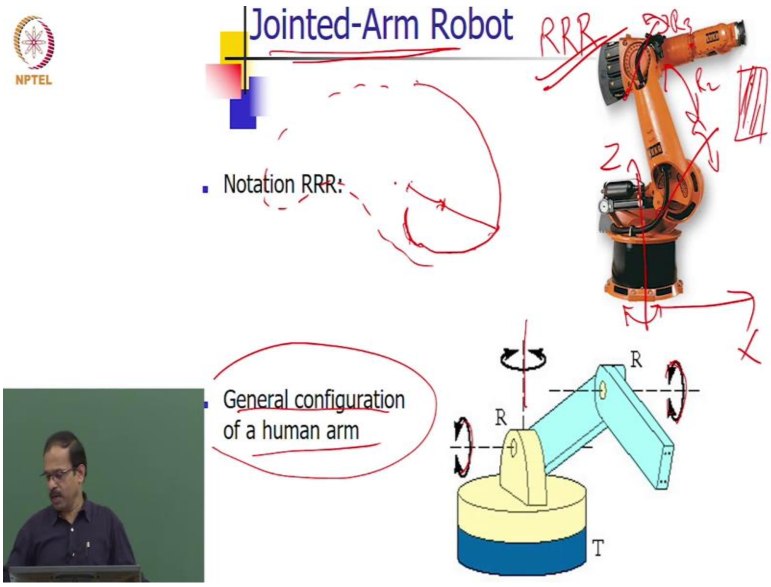
So depending on where actually you place the workspace, you will be able to get a variation of this as the workspace or the work environment of the robots.

(Refer Slide Time 21:03)



So x, y, z are directly so you do not need to have any other parameters here. So, the linear motion x, y depends that is actually the position of the wrist itself. So, you do not have any particular relationship here. So, simple kinematic model rigid structure and then robots with a large working volume, the working volume is smaller than the robot volume, requires free area between the robot and the object to manipulate, guide protection. So all those things are the disadvantages. Advantages are it is very easy to visualize and then program so that is the advantage.

(Refer Slide Time 21:47)



So the next one is the jointed Arm architecture, which is the most commonly used architecture where we have all joints as rotary joints. So this is the wrist point, if this is the wrist point, these are the wrist joints. So, you have one rotation here, another rotation here and another rotation here.

And so, we have three rotations, three rotary joints so the first two rotary joints, so these two rotary joints will decide about this plane motion within this plane, this one will decide and this one will decide out of the plane. So, if this is the x, z plain, x, z is decided by these two joints R 3 and R 2, the positioning within this plane is decided by this and then out of this plane the y coordinate is decided by the this rotation. So, this is the way how the robot joints are placed. So you will be able to get all the x y z coordinates within the work envelope.

And most of the industrial robots follow this kind of configuration, the first three joints, depending on the robot, the axis may be different, instead of this rotation, it can have a rotation here itself and then how rotational axis can be different orientations. But the first three will be rotary joints, so that you will be able to position the wrist in x y z.

So that is the jointed arm architecture, so there are many names, joined arm, anthropomorphic arm and etc, etc. But this is the configuration that we human also has got three joints, though we do not have the axis separated like this. So we can actually use these three joints to position the wrist in any plane.

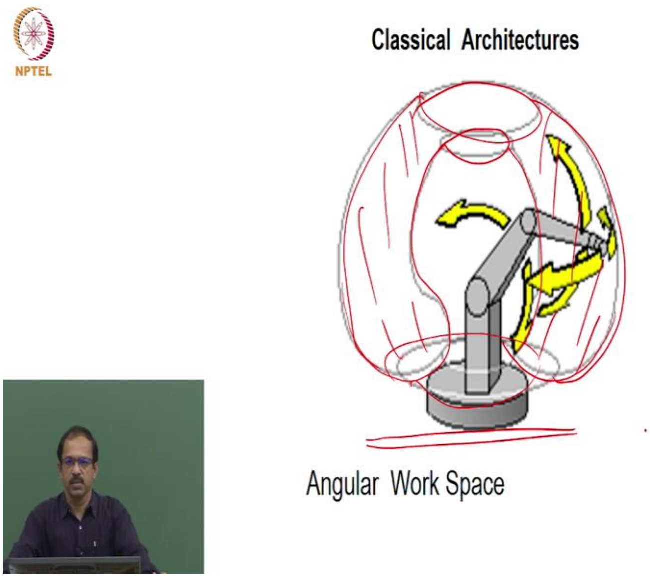
So I want to play in this plane or I want to move to this plane I will be able to use these three joints here to place my wrist in any coordinate in three dimensional space. So, the same configuration is used in the industrial robot also. So, this is the general architecture. So, rotational axis, rotational axis and rotation axis, so 3 rotary joints. So, what will be the workspace?

Pardon? Pardon?

Work envelope will intersect the robots, what do you mean by that? Okay. So, you can see this one actually can go up like this right. The first two joints can actually take a path like this, but then when the two joints are in this position, if you take these two, then only this can actually move or this has got its limit then it can actually move like this and then this can also move like this.

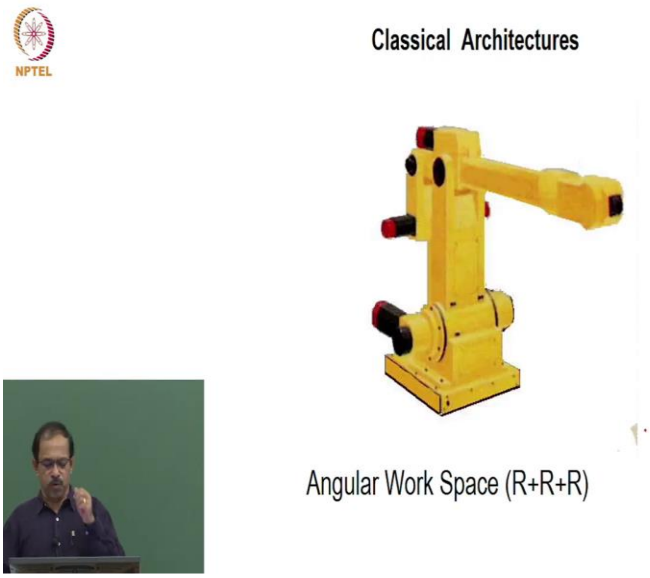
So, you will be getting a complex work envelope not exactly like a circular path here, arc you cannot get but it will be something like a complex one and then similarly you will be getting a complex arc path line. So, it not be something different from the previous configurations, do not define the exact shape, but it will be slightly complex work envelope we will be able to get.

(Refer Slide Time 25:36)



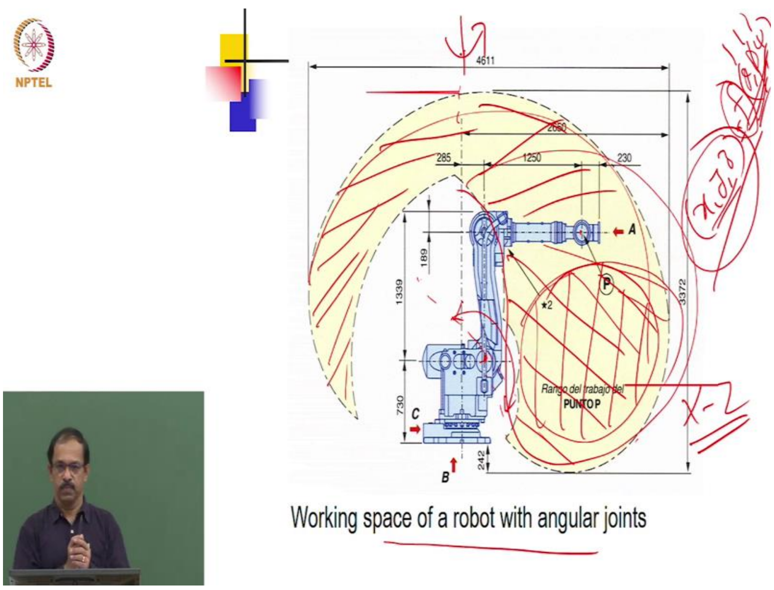
So, you can see here, so that to here and then it actually changes its configuration and then comes like this. Okay, the exact shape depends on again the limits and the mechanical structure it has, but in general we can say the work envelope will be in this region. Not all will be available for all the robots, most of the robots will be having a workspace in this area more and then back side it will be having a very limited work envelope. I will show you a typical work envelope of an industrial robot but this is the general shape that you can see for the RRR robots.

(Refer Slide Time 26:24)



So you will be able to see these kinds of robots we have in our lab also, so we have few robots with this kind of architecture.

(Refer Slide Time 26:33)



So, this shows the typical work envelope of, not the typical one but for a particular robots with the dimensions you can see this will become the actual workspace that the wrist can reach. As it comes up here, then it has reached one range of this join, then the next range will start here, then the next one like this, you will be able to see a work envelope which can actually reach. Now, most of the robots will be designed in such a way that they have the large workspace in the forward region, so that you can actually do operation. So behind not many operations will be carried out and therefore, these workspace will be somewhere like this only, again depending on the range that you decide, you will see that it can actually be less or more, but most of the time the workspace will be in this region, so that it can carry out some tasks.

Again, there may be pockets where it cannot reach because of the joint limits. So, the reachable workspace maybe again less but this region, every robot designer will try to make this region very accessible and without much of non accessible area. So, as long as you can get the good workspace over this region, then the robot design is considered to be the good one for a particular application.

So, though it can reach here, not always this work space will be used for any practical purpose except for some moving of some objects and all. We will see how we can identify the workspace of a robot later. So, once we know these joint limits, and the relationship between these coordinates, suppose we know the relationship between the coordinates and the joints.

So, we have three joints; theta, phi and psi, so I put this as three joint angles. So, if we know this relationship between the coordinates x y z and then the joint angles or the joint variables, then we will be able to find out for every value of theta and every value of a and every value of psi, you will be able to find out what is the position that you can reach and the set of all these points basically makes the workspace.

So the workspace points, all the points in workspace can be obtained by substituting the value of theta, phi and psi in this relationship and you will be able to get all the workspace. So, once we develop this relationship, then we can actually write a simple program looking at the minimum and maximum limit of Theta, Phi and Psi, you will be able to find out all the points in 3D space where the robot can reach that is that reachable workspace that we will be having.

Sorry, in this case, it is mentioned this in the fact that, no this is for the wrist.

P.

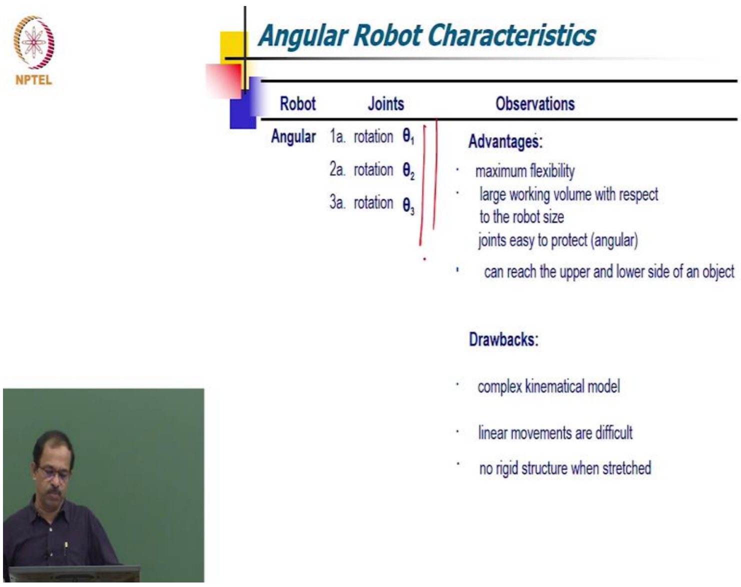
Symmetrical with respect to this you are telling?

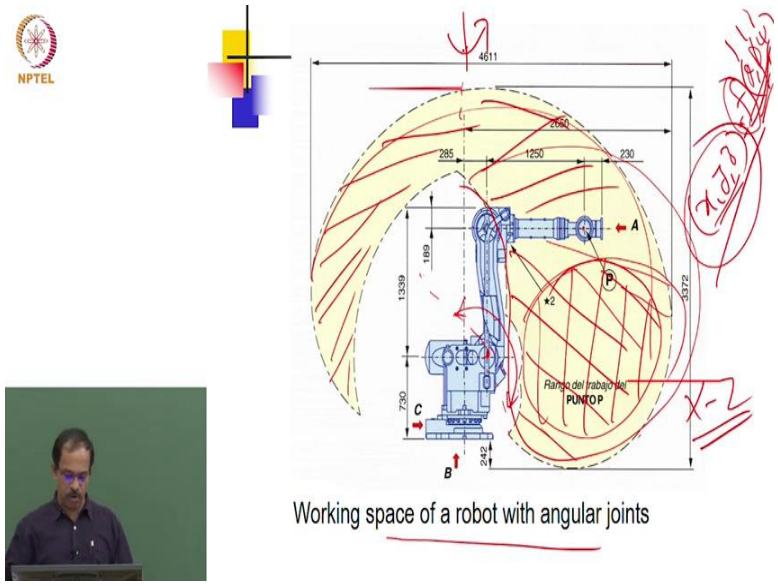
No, so the reason is that this joint or suppose if you take this joint, you can actually come up to here, means can have a limit like this, but here it is having a limit only up to here. So, this may be the joint limits that will be set for this joint.

No, this will be actually like a rotation how much you can rotate with respect to this axis that is with respect to the vertical axis. Now, this can actually be rotated that will be the volume. So, this is in this plane only, this is only in this plane, this is x-z plane. Now, how much it can get in, it depends on how much you can rotate with respect to this axis. So, the whole thing this workspace the whole this workspace can actually be rotated, you can sweep through this angle that will give you volume.

So, this is the area that you can get in one plane and then you sweep this. And again it need not be 360 degree, there will be a limit for this where actually it will stop.

(Refer Slide Time 31:15)



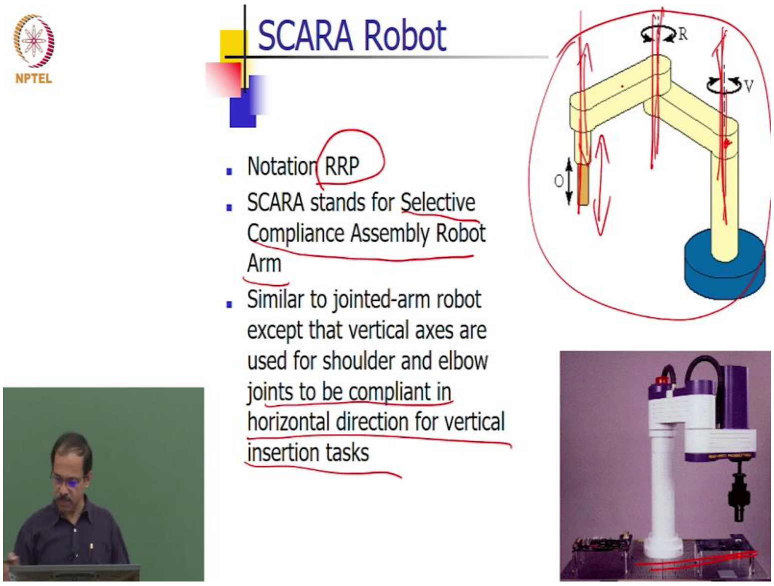


Alright, so these are the most popular configurations and it is a bit complex kinematic model. So it is very difficult for you to predict what will be the x y z position just by knowing the Theta, you need to calculate because it is not a direct relationship, and that is basically the kinematic model we talk. So, how the position of the tip is related to the joint angles we need to develop a relationship for that. And it can get the large working volume with respect to the robot size, for the given robot size the largest work volume can be obtained for the angular robot configuration and the least is for the prismatic configuration.

And it can reach the upper and lower side of an object that I will tell you later, so the complex kinematic model. So linear movements are difficult when I say difficult suppose you want to get a motion in like this, suppose I want the tip to move from this point to this point, I need to control all the three joints in this the planar motion, but in three dimensional space you want to get a straight line you need to control all the three joints and then move the robot to get the straight line motion.

So, compared to other robot configuration, this is a slightly complex to get linear motion. It is possible, but maybe a bit complex to get a straight line motion because all the three joints need to be controlled.

(Refer Slide Time 32:38)



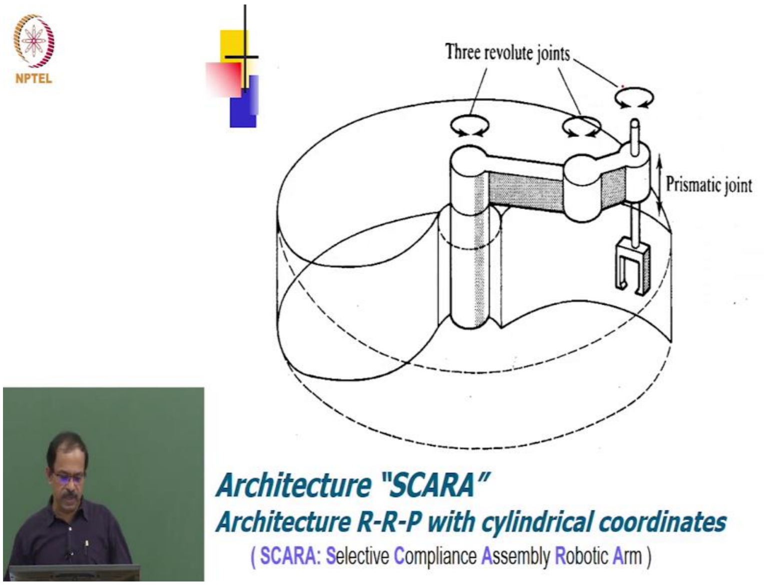
Okay, let me finish this also. So SCARA is basically a RRP robots. So you have two rotary joints, so two rotary joints and the prismatic joints. So this is the configuration of SCARA. It stands for Selective Compliance Assembly Robot Arm, it is a very common use robots because a lot of pick and place operations requires compliance in one direction that is, it should be able to move it in a particular plane so that you can get compliance and then insert some, like a peg in hole assembly problem, so you will be able to get into compliance using this kind of robots.

So, the peculiar design feature here is that all the axis are vertical. So, you can see all the joints are in vertical direction, all the axis of rotation are in vertical direction, there are no other joint axis, everything is in vertical direction and therefore it provides compliance in the other direction other plane so that is the advantage of this except that vertical axis are used for shoulder and elbow joints to compliance.

So, just to be compliant in horizontal direction for vertical insertion task. So, you are getting a compliance in the horizontal direction because all the joints are in vertical and that is the advantage of going for this configuration of robots. Other than that, it is like an RRP robot normal RRP robot. The only difference is that all the axis are in vertical direction.

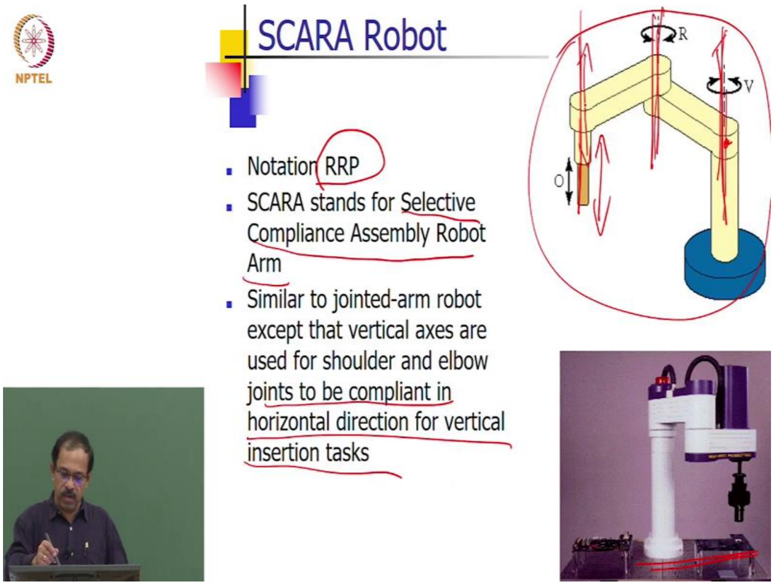
Again, since this is in vertical direction, the inertia of this arm is not actually reflected onto this, because it is moving this direction, the load is actually in the vertical direction so it is not reflected on this axis that is another advantage of this. Appart from the compliance actually this model need not take the load of these motors because it is vertically mounted.

(Refer Slide Time 34:36)



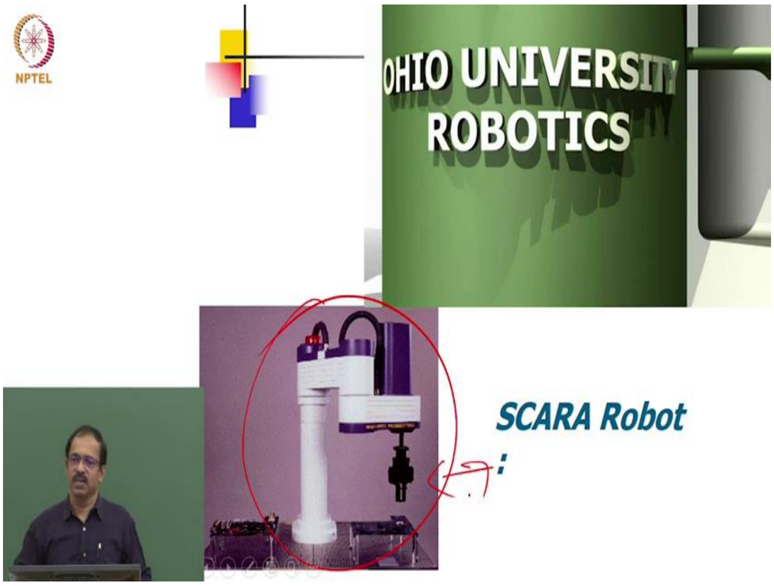
And the workspace will be something like this. It is almost like a cylindrical one, except that you will be having some kind of a depending on this because of this joint you will be having a small curve over here when it comes to the end of the work envelope. Other than that, it will be more like a cylindrical workspace. Yeah.

(Refer Slide Time 35:00)



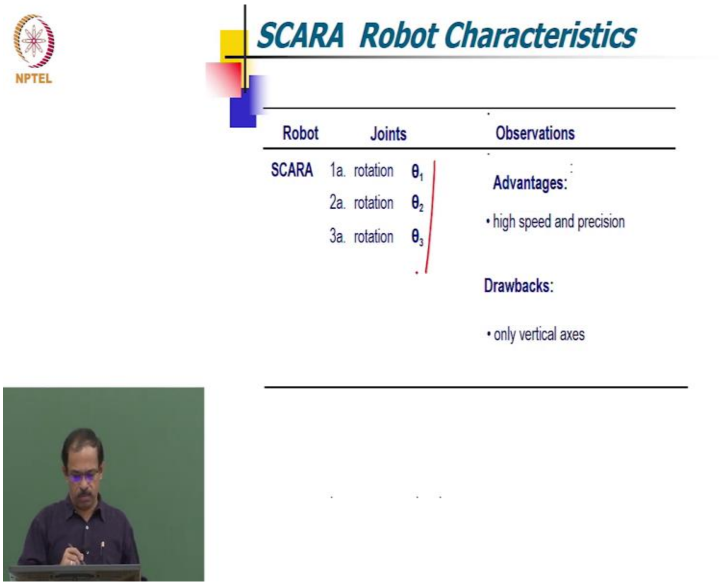
Advantage; so basically you have this vertical load here I mean the motors are here in the vertical direction, this is also vertical direction. So, this load is not reflected on the this motor, because this motor is actually moving in this direction. So, the vertical load is not actually reflected onto this motor, compared to the other kind of robot this load will be reflected onto this when you have to move like this, right? So, in this case it is not reflected as a image.

(Refer Slide Time 35:30)



So, these are some of the typical robots that you can see, this is a video, it is not working, but you can actually get lots of examples from the literature. There are lot of such robots available in the markets. And we also have one robot, we will show you, we will demonstrate this robot to you in the next class or one of the classes.

(Refer Slide Time 35:56)



So, sorry there is something wrong here. Dont take this, Theta 1, Theta 2 and D, so it is a P. So, by mistake it is given, I will correct it, it is not rotation. No, see that what I am saying is that the gravity load will not be acting on it, only the acceleration load will be coming. So if you want to accelerate it, it will be having a load, but the weight of the motor will not reflect onto this just that is taken by the structure itself.

that will be taken by the structure. So you design the structure in such a way that it can take the load, so the motor need not take the gravitational load of the other motors that is what I am saying. So it can have very high speed, so very high speed assembly robots are made using this kind of an architecture. And you have only a vertical axis. Okay, so we will stop here. And we will just talk briefly about the wrist configurations also, so how the wrist can be assembled, and then we move to the kinematic relationship in the next class. Thank you.