**Robotics**
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**Lecture – 04**
**Introduction to Robot and Robotics (Contd.)**

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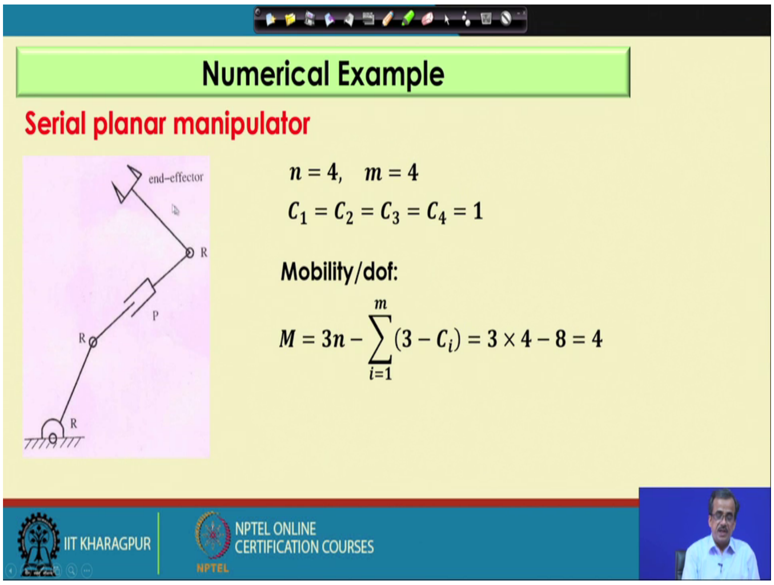


We are discussing how to use the principle of Grubler's criterion, to determine the degrees of freedom of different types of manipulator. Now, we have already seen for the serial planar manipulator. So, we got the degrees of freedom as 4. And here, this is a serial manipulator, because all the links are in series.

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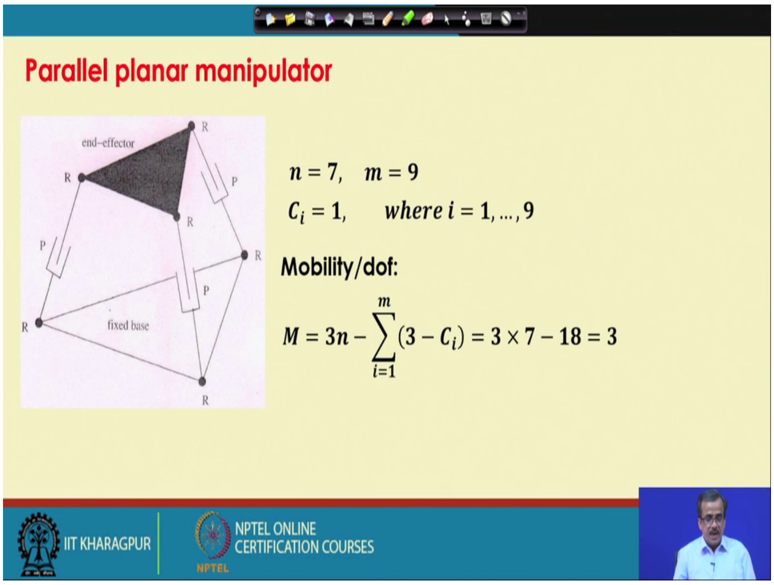


Now, for one very simple parallel manipulator, we also determined what should be the degrees of freedom. And we got for this particular parallel manipulator, the degrees of freedom as 3.

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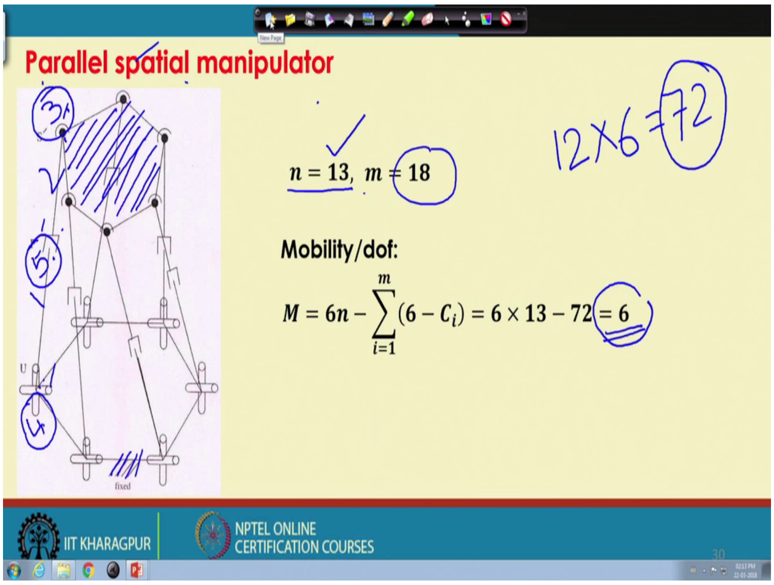


Now, I am just going to take the example of another more complicated parallel manipulator. And I am just trying to find out, what should be the degrees of freedom for this particular the parallel manipulator using Grubler’s criterion. Now, this is nothing but a parallel spatial manipulator. Now, here we have got like 6 legs, and each leg consists of one universal joint or the Hooke joint, and one prismatic joint, and we have got one spherical joint. And similarly, we have got 6 such legs. And the top plate is nothing but this, so this is nothing but the top plate for this particular manipulator. And the base plate is fixed to the ground.

Now, we will have to find out the degrees of freedom of this particular the manipulator. So, what we do is, for each leg, we try to find out, how many constraints it is going to put. Now, before that, let us try to find out, how many joints are there. In one leg, we have got 1, 2, 3. And similarly we have got 6 such legs. So, 6 multiplied by your the 3. So, 6 multiplied by 3, so we have got 18. So, we have got 18 such joints.

And the number of links we should try to find out, on one leg we have got 1, 2. So, similarly, we have got 6 legs. So, 6 multiplied by 12, and the top plate we will also be consider as one of the link, so you have got the number of links, the moving links that is equals to 12 plus 1, that is 13. So, we have got small n that is the number of moving link is equal to 13. And the number of joint that is m is equal to 18.

Now, here we will have to find out, how many constraints are put by one leg. So, this is the universal joint. Now, this universal joint has got 2 degrees of freedom, and this is a spatial manipulator, so this joint is going to put 6 minus 2, that is your 4 constraints. Similarly, so this particular joint is a prismatic joint is having only one degree of freedom, and it is going to put 6 minus 1, that is 5 constraints. And this particular joint is a spherical joint, which is having 3 degrees of freedom, and it is going to put 6 minus 3 that is nothing but 3 constraints.

So, the total number of constraints put in one leg that is nothing but 4 plus 5 that is 9 plus 3 that is 12. So, one leg is going to put 12 constraint. And similarly, we have got 6 such legs, so it is going to put 12 multiplied by 6, that is 32 constraints. Now, we have already discussed, that we have got 13 number of moving links. So, the mobility or the degrees of freedom is nothing but 6 n minus summation i equals to 1 to m 6 minus C i, C i is nothing but the connectivity. So, this will become equal to 6 multiplied by 13 that is 78 minus 72 and that is equals to 6.

So, this serial this parallel manipulator is having 6 degrees of freedom, and this is a spatial manipulator. So, this is nothing but an ideal parallel spatial manipulator having 6 degrees of freedom that means you have the top plate can have 3 translations, and there could be 3 rotation also with respect to the fixed ground. So, this is actually popularly known as the Stewart platform, which is generally used for the training purpose of the trainee pilot in aircraft. So, it has got other practical applications also. So, this is the way, actually we can use the Grubler's criteria to find out the degrees of freedom or the mobility of the robotic system.

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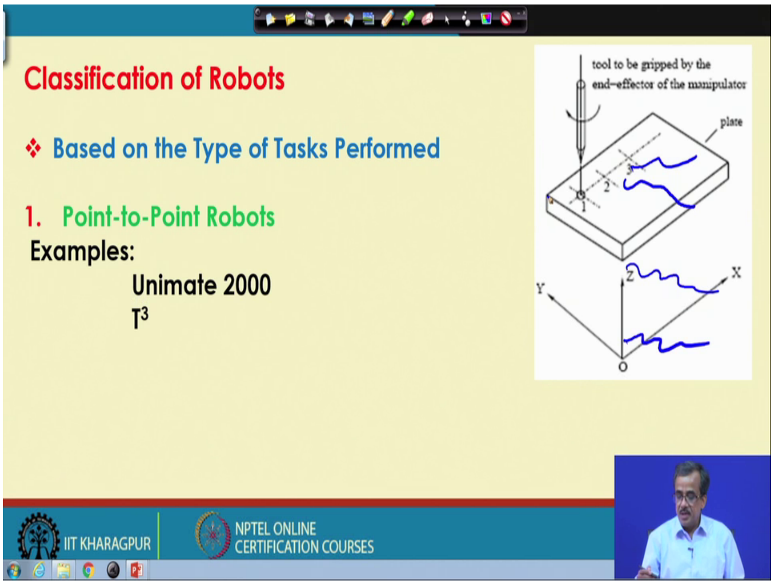


Now, I am just going to discuss, the classification. Now, the robots are classified in a number of ways, if you see the literature, we have got different types of robots. Now, based on the type of task, it performs the robots are classified into two parts, two groups, one is called the point-to-point robot, and we have got actually your the continuous path robot. So, point-to-point robot, and we have got the continuous path robot. And this is the continuous path robot. Now, I am just going to discuss, the working principle of this particular the point-to-point robot.

Now, let me take one example, very simple example. Supposing that, I have got a steel plate, and on this particular steel plate, so I will have to make some drilled hole at some pre specified location; say location 1, location 2, and location 3 with the help of say one cutter, that is the twisted drill bit. Now, this particular twisted drill bit will be gripped by the end-effector or the gripper of the manipulator.

Now, if I want to make the drilled hole at location 1, the tip of this twisted drill bit should be able to coincide with the center of this particular the hole. And once it is made coincident, now we can be rotate this particular the cutting tool, say either clockwise or anticlockwise. Supposing that, I am rotating it clockwise, so it is going to generate that particular drilled hole. And once that particular hole has been drilled, so what we do is, we rotate the cutter in the reverse direction, and the tool will be withdrawn from this particular the job.

Now, once the hole has been drilled at location 1, now we go to location 2, and repeat the process. And the same process we also repeat for the point 3. Now, here after this particular the hole has been drill at location 1, the tool is withdrawn from the job, and then we move to location 2, as the tool is withdrawn from the job, so the tool is not in touch with the job continuously, this is known as the point-to-point task.

So, for this point-to-point task, we use a special type of robot, and that is called the point-to-point robot. Now, this Unimate 2000, then T 3 that is the tomorrow tool, these are the typical example of this type of point-to-point robots.

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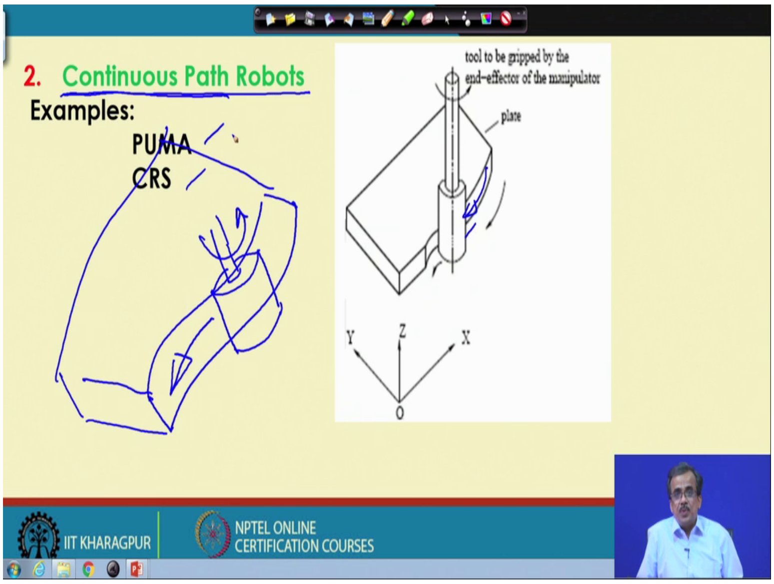


Now, let us try to explain the working principle of the continuous path robot. Now, here the tool will be in touch with the job continuously, and supposing that, so here I am just going to cut a complicated profile on say one side of a steel plate. Now, if I just draw this particular thing in a slightly different way, supposing that, I have got a profile, which is to be cut on one side of a steel plate. So, this is the steel plate say and here, so I will have to cut this particular the profile. The way we cut is, we use one milling cutter and this milling cutter, so this we will be gripped by the end-effector of this particular the manipulator.

Now, this milling cutter will have to rotate, and at the same time it should trace this particular the complicated profile. And here, we can use this type of milling cutter. Now, here what you can do is, this particular end, so we grip with the help of a gripper or the end-effector, and we generate the required motion that is the rotation as well as it will be able to trace this complicated profile while cutting.

Now, during this machining operation, so this particular tool is in touch with the job continuously, and that is why, this is known as continuous path task. And the robots, which are typically designed for this type of task is known as the continuous path robot. Now, the typical example for continuous path robot is your PUMA, CRS, so these are all continuous path robot. Now, here I just want to make one comment. Now, supposing that, I have got one continuous path robot, the same continuous path robot can also be used as a point-to-point robot, but the reverse is not true. And, so we have got both point-to-point robot as well as the continuous path robot.

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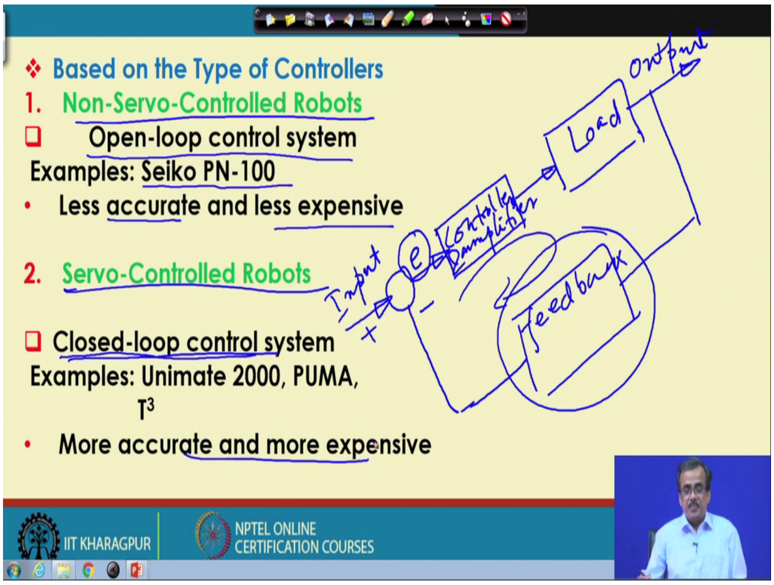


Now, another classification like based on your the type of controller, which is generally use. So, we divide this particular the robots into two groups; one is called the non-servo-controlled robots. So, we have got the non- servo-controlled robots, and servo-controlled robots. So, in non-servo-control robots, we use open loop control system. Now, in open-loop control system, we generally do not measure the output for the purpose of comparison, and just to find out the error. Now, this error is neither measured and not compared and nor feedback for the purpose of compensation of this particular the error.

On the other hand, in case of servo-control robots, we use some feedback device, and we use closed-loop control system. Now, here in closed-loop control system, actually what we do is, we measure the output for the purpose of comparison. We try to find out the error, and this particular error is fed back, and we try to minimize this particular error, and that is the principle of the closed-loop control system.

Now, here in robots, like if you want to use to perform some very precise tasks, so will have to go for the servo-controlled robot, and it has got the closed-loop control system. Now, regarding the closed-loop control system, the way it works is as follows. Supposing that, I have got the controller; say this is nothing but the controller, the block diagram for this controller. And here, I have got the mechanical load, so which I am just going to handle.

Now, what you do is, we try to give some sort of input here, through some error junction. So, here we have got the input and based on this particular input, so I will be getting some output here. Now, this particular output will be measured, and output will be fed back with the help of one feedback circuit, so this is nothing but the feedback. And this particular is compared here, so here we put minus this is plus, and we try to find out the error here, that is e. And in this particular summing junction, so we try to compare, and try to find out how much is this particular the error.

So, this error will pass through the controller and amplifier. So, generally we use amplifier also, and once again it will pass to the load, and we will be getting some output. And this particular cycle will go on and go on, and we will be getting very accurate movement. This is what we follow in closed-loop control system. But, in open-loop control system, so this feedback circuit is absent.

And, so we have got two types of robots, non-servo- controlled robots where we use open-loop control system the examples are Seiko PN-100. And as there is no error compensation, so it is less accurate and less expensive, because there is no such feedback device. On the other hand the servo- controlled robot like Unimate 2000, then PUMA, then T 3 are more accurate and more expensive.

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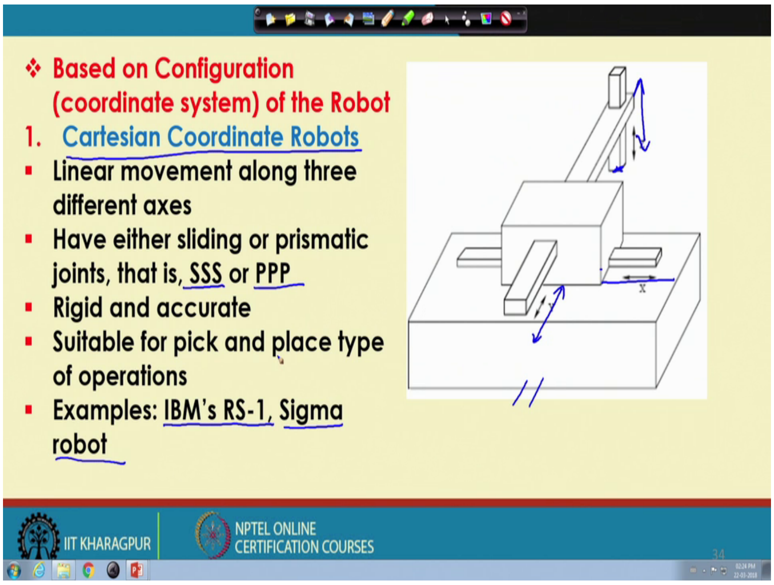


Now, the next classification is based on actually the type of the coordinate system, which is generally used. Now, based on the coordinate system we used in robots, the robots are classified into four sub groups; one is called the Cartesian coordinate robot, then we have got the cylindrical coordinate robot, then polar coordinate robot, and we have got the revolute coordinate robot.

Now, all such robots, I am just going to discuss one after another. So, based on the coordinate system as I told, there are four robots, the first one that is your the Cartesian coordinate robot. Now, here this schematic view shows a Cartesian coordinate robot. Now, for this type of robot we have got the linear movement along this particular X direction, the linear movement along the Y direction, and we have got the linear movement along this particular the Z direction. So, along X, Y and Z, we have got the three linear movement, and they are independent. And this type of robot is known as the Cartesian coordinate robot.

Now, this particular linear joint it could be either prismatic or sliding. Now, if I use all three are prismatic, so this is called PPP robot and if I use sliding joint, so that is called SSS robot. Sometimes we use a combination of P and S also. Now, here as this particular robot we use prismatic joint, so this robot is very rigid and very accurate. So, this is the end-effector. And this is the fixed base. So, if we want very accurate movement, so we can use this type of robot. And this is suitable for pick and place type of operation.

Now, a typical example for this type of Cartesian coordinate robot is IBM's RS-1, then Sigma robot from Olivetti. Olivetti is actually the name of the robot manufacturer. They manufacture one Cartesian coordinate robot, which is known as the Sigma robot. So, here in Cartesian coordinate system or Cartesian coordinate robot, so we get three linear movement. And this robot as I mentioned are very rigid and accurate. And for this type of robot, like if you want to use in the subfloor, so if something is lying on the floor, so with the help of this we will be able to pick that particular the object.

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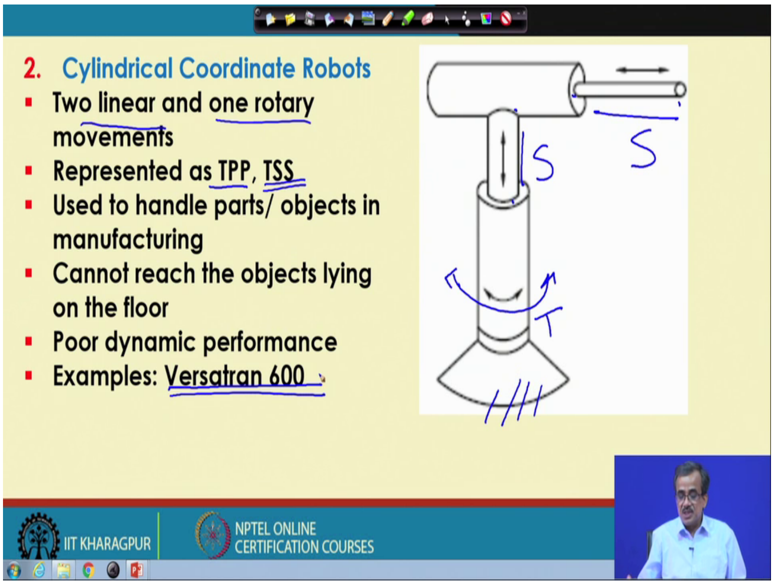


The next is your the cylindrical coordinate robot. Now, here we have got two linear, and one rotary joint. So, here we can see that we have got one linear joint, another linear joint, and we have got one rotary joint. Now, this rotary joint with respect to the fixed base is nothing but a twisting joint. And this is actually the linear joint, say it is a sliding joint. And this is another linear joint, say this is the sliding joint. So, this particular robot is known as TSS robot. Now, in place of sliding joint, I can also use the prismatic joint. Here also I can use the prismatic joint, then it will be called as TPP.

Now, if you see this particular robot. So, here actually there is one problem, the way it works. So, this particular the, with the help of the joint, so I will be getting the maximum horizontal reach, and the minimum horizontal reach. Similarly, here I will be getting the maximum vertical reach, and the minimum vertical reach. And for this type of robot like if something is lying on the subfloor, so it will not be able to pick that particular the object.

And it has got another problem, that problem is related to this rotary joint. And due to the presence of this particular rotary joint, the dynamic performance of this particular robot is poor, compared to your I should say that Cartesian coordinate robot. Now, here this Versatran 600 is a very typical example for this type of cylindrical coordinate robot. So, this is the way actually this particular the cylindrical coordinate robot is working.

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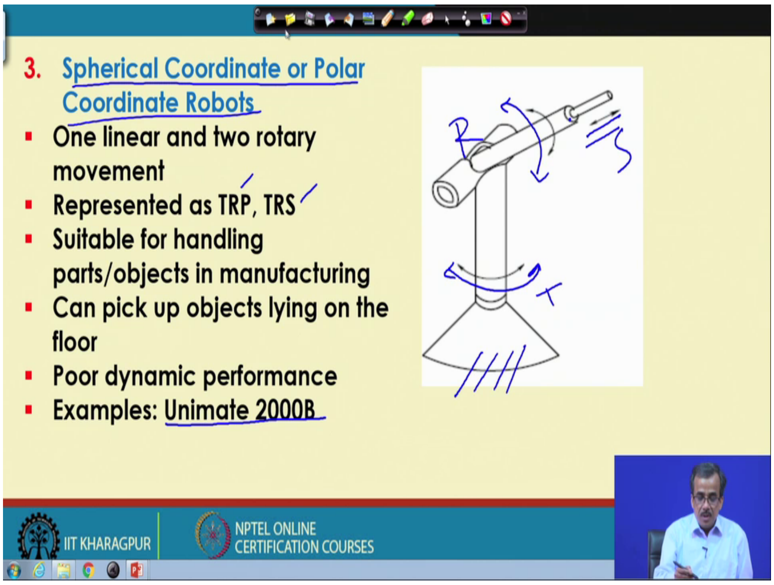


Now, then comes your the spherical coordinate robot or polar coordinate robot. So, spherical coordinate robot or the polar coordinate robot. Now, here we have got one linear joint. So, here we have got a linear joint and we have got two rotary joint, so this is nothing but a twisting joint. And we have got one revolute joint here with the help of which it can rotate something like this. Now, with the help of this linear joint, so I can represent what should be the maximum horizontal reach, and what should be the minimum horizontal reach.

Similarly, with the help of this particular the revolute joint, I can find out what should be the maximum vertical reach, and what should be the minimum vertical reach. And here, with the help of this particular twisting joint, so I can rotate with respect to the fixed base. Now, this robot if I use T here, R here, and say S here, so this is known as TRS robot. And if I use prismatic joint, so this is known as TRP joint. Now, this robot is suitable for picking some objects, which are lying on the subfloor. And, but here we have got another problem, the same problem like your poor dynamic performance due to this particular the rotary joint. Now a typical example for this type of spherical coordinate robot is Unimate 2000B.

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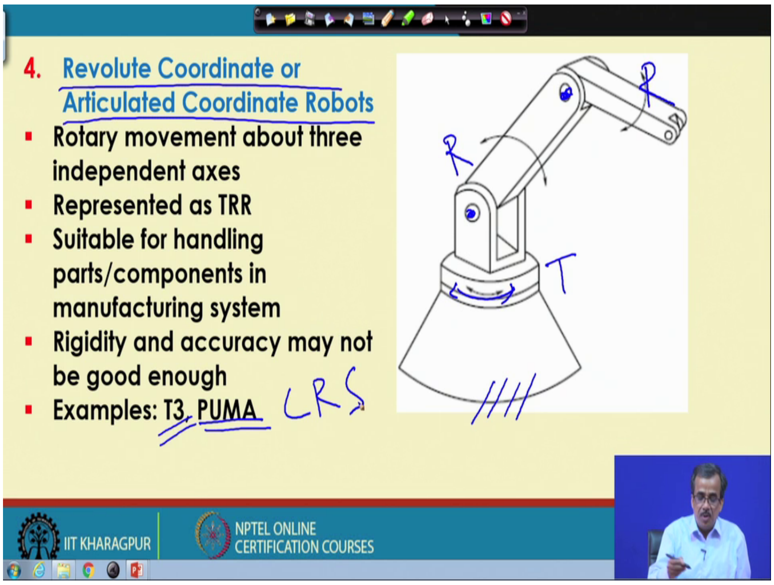


Now, I am just going to discuss another robot, which is also very frequently used, and that is called the revolute coordinate robot or articulated robot. So, this revolute coordinate robot we have got three rotary joints. For example, say this is the schematic view of the revolute coordinate robot, now this is the fixed base. So, with respect to the fixed base we have got a twisting joint here, similarly we have got a revolute joint here, and I have got another revolute joint here, so I have got a revolute here, revolute here, and we have got the twisting here, and this is known as actually TRR robot.

And this type of robot is actually very much used in industries. Nowadays to solve a variety of problem like pick and place type of operation or if you can do some sort of drilling, milling that type of operation, so this type of robot along with some more attachments are very frequently used. But, here once again, due to the presence of this particular the rotary joint its dynamic performance may not be so good.

Now, a typical example of this type of robot could be your PUMA that is Programmable Universal Machine Power Assembly, then T 3 the tomorrow tool, then comes CRS is another example of this type of revolute coordinate robot. Now, this particular robot as I told, that this is very frequently used in industries.

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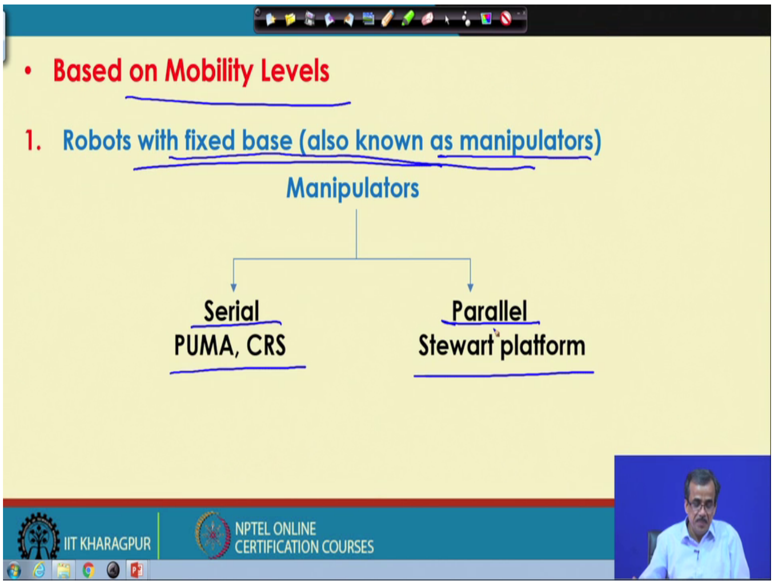


Now, another classification I am just going to discuss, and this is based on actually the mobility levels. Now, based on the mobility levels, the robots are classified into two groups, robot with fixed base, and the robot with moving base. Now, the robot with moving base, I am just going to discuss after some time.

Now, let me just concentrate on the robot with fixed base, and as I told these are also known as the manipulators. Now, these manipulators could be either serial manipulator like PUMA, CRS or it could be parallel manipulator like the Stewart platform. Now, both the things I have already discussed little bit. The serial manipulator the links should be in series, the joints are in series.

On the other hand for this parallel manipulator, the links will be in parallel and if I compare the load carrying capacity of this particular serial manipulator, and the parallel manipulator. The load carrying capacity of the parallel manipulator will be more compared to that of the the serial manipulator.

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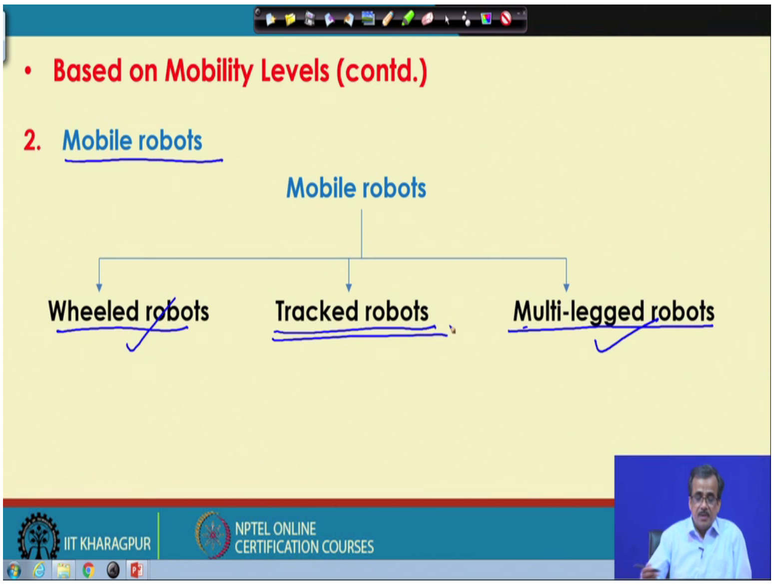


Now, I am just going to discuss the robot with moving base. Now, the robot with moving base, these are very popularly known as the mobile robots. Now, the mobile robots could be either the wheeled robots, there could be tracked robots, or the tracked vehicles, or there could be multi-legged robots. Now, supposing that, the terrain is perfectly smooth, now for the smooth terrain we can go for the wheeled robot. Now, if it is perfectly rough, there are many such ups and downs, staircases, so it is better to go for the multi-legged robots like 4-legged robot, 6-legged robot and so on. And if the terrain is in between that is neither very smooth nor very rough. So, we can go for some sort of tracked vehicle.

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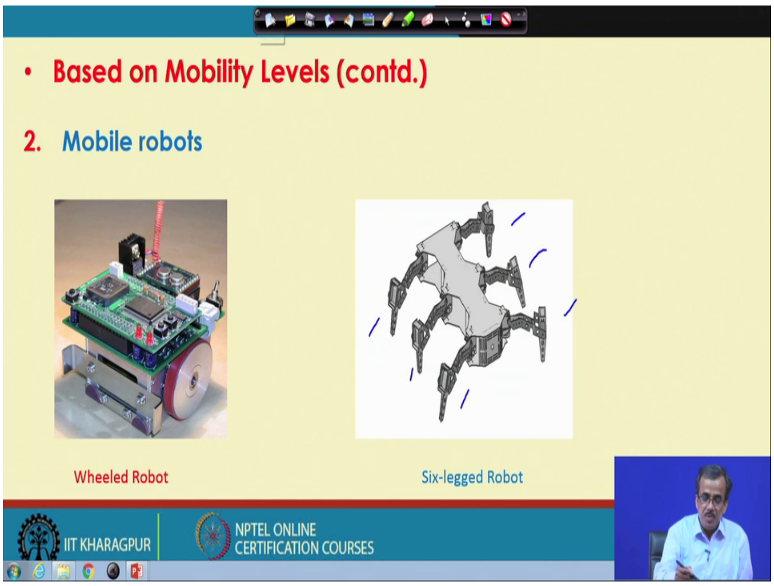

Now, here I am just going to take the example of one wheeled robot. So, this is one actually two wheeled one caster robot, it is a very simple wheeled robot. So, one wheel we can we can see here, the other wheel is on other side, and below that, there is one caster also, that is nothing but the support, so this is a typical the wheeled robot.

Now, similarly here I am just going to show the schematic view of a six-legged robot. Now, here you can see, we have got six- legs, and each of these particular legs are generally having 3 degrees of freedom, and this is actually the trunk for this particular the six-legged robot.

Now, depending on this particular duty factor sometimes like 4 out of 6 will be on ground; sometimes 3 out of 6 will be on ground and so on. So, these are actually you are the mobile robot. Similarly, we have got some other type of mobile robots also.

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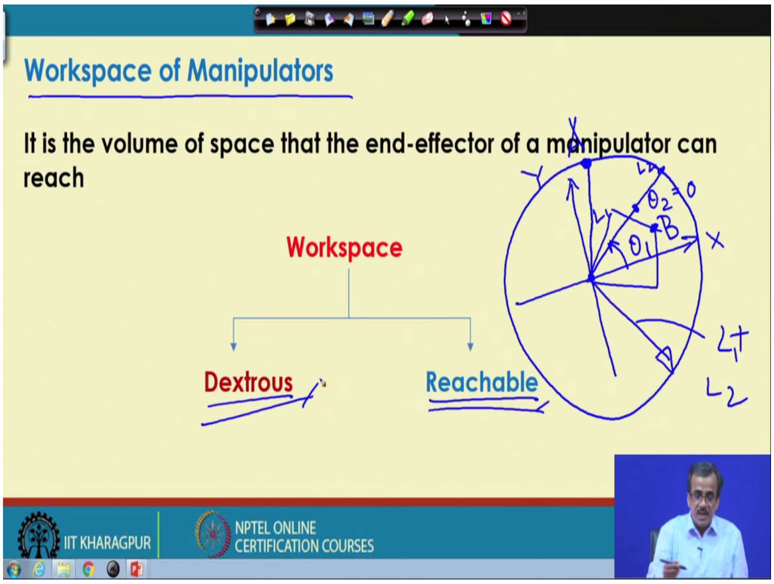


So, we have seen the classification of the robots. Now, if you see the literature, we have got the different types of robots. And as I discussed that these particular robots are are classified in different ways, and we get different types of robots. Now, I am just going to discuss with another topic, which is very important, and it is little bit difficult to understand also to imagine also. Now let us start with that, and let us try to see this particular the how to determine the workspace of a manipulator. So, by a workspace we mean the volume of space that the end-effector of a manipulator can reach.

Now, let me take a very simple example. Now, if I consider that my hand is nothing but a serial manipulator, and this is nothing but the end-effector of the serial manipulator, so this is the fixed base. So, with respect to the fixed base, so I can move this particular end-effector like this, so I can go to the top; I can go to this side; I can come to this side; I can go to bottom; I can go to up. So, this particular end-effector is having some locus, and it is going to maintain one volume of space. Now, this particular space has got a volume, and that that is actually the workspace of this particular the manipulator ok.

Now, if you see this particular workspace, workspace could be either dextrous workspace, or it could be the reachable workspace. Now, to define these two terms like the dextrous workspace and the reachable workspace. Let me take one very practical example.

Now, let me take the example of a very simple manipulator. For example, say I have got one serial manipulator having say 2 degrees of freedom. So, this is X direction, this is Y direction in Cartesian. And supposing that, the joints are such that, say this is my the first links say L 1, say L 1 is the length of the first link, and the L 2 is the length of the say second link, say this is L 2.

Now, let us consider here, the angle between L 1 and L 2 has been assumed to be equal to 0. So, as if this will act as a manipulator having only one degree of freedom, that means, there will be only one joint angle theta and supposing that, so this theta can vary through say 360. Now, if I vary through this particular theta 1 through 360 degree, and of course, I have got theta 2, but theta 2 I have taken equal to 0.

So, if I just rotate, then there is a possibility that I will be getting the work plane or is just like a circle sort of thing, whose radius is nothing but L 1 plus L 2. So, this L 1 plus L 2 will be the radius of this particular circle, and this is nothing but the work plane, because this is in 2-D plane for this particular the manipulator. Now, I am just going to take two points. Now, supposing that, I am just going to consider a point here, lying on the boundary of the circle. And that particular point is a denoted by A. And I am just going to take another point say point B, and that is inside that particular the circle.

Now, if I want to reach this particular point A, I need a particular configuration, that is your theta 1 and theta 2, will have some value and corresponding to one value for this particular theta 1 and theta 2. So, I will be this particular tip will be able to reach this particular point A. Whereas, to reach the point B, there could be two different configuration, one is this configuration, another could be your this particular the configuration. And now, I say that the point 1 is a point, which is lying on the reachable workspace for this particular manipulator. And point B is a point, which is lying on the dextrous workspace of this particular manipulator. Now, let us try to see the definition of this particular your dextrous workspace and the reachable workspace.

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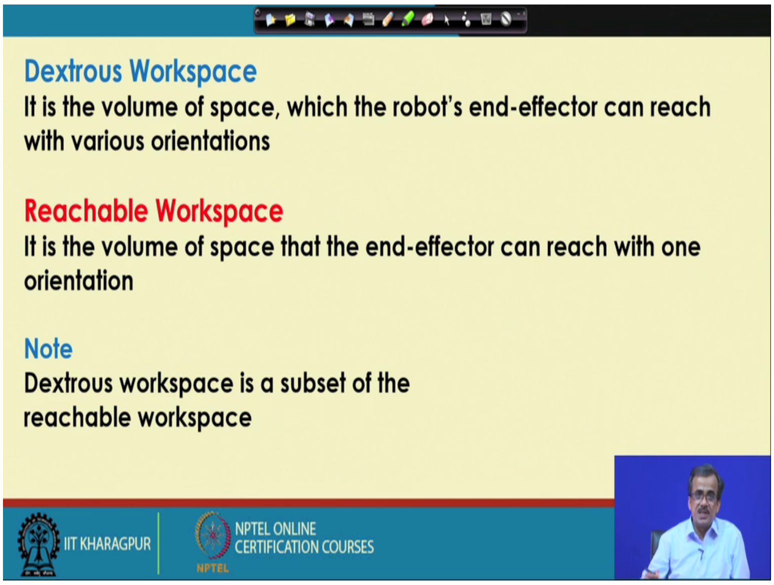


Now, if you see the dextrous workspace that is nothing but the volume of space that the robot's end-effector can reach with different combinations of the joint angles. On the other hand the reachable workspace is that volume of space that the end-effector can reach with one orientation. And this particular reachable point is was lying on the boundary of the circle.

On the other hand, the dextrous point it was lying on the inside that particular the circle. And here, I have got I have put one note, that dextrous workspace is a subset of the reachable workspace. So, the reachable workspace is the larger workspace, bigger workspace. And dextrous workspace is nothing but a smaller workspace, so dextrous workspace is nothing but the subset of a reachable workspace.

Thank you.