NPTEL Online Certification Course
Industrial Robotics: Theories for Implementation
Dr Arun Dayal Udai
Department of Mechanical Engineering
Indian Institute of Technology (ISM) Dhanbad
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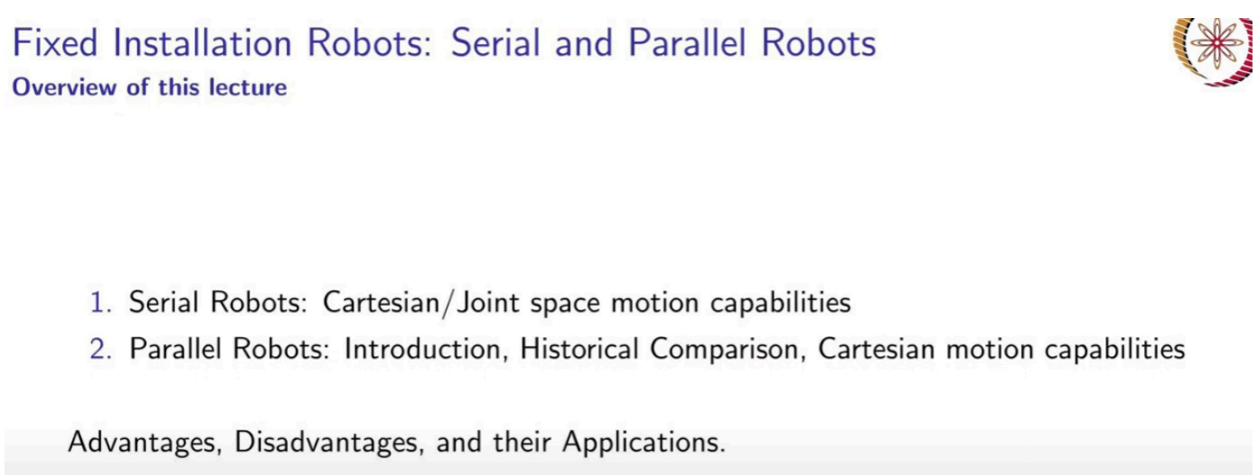
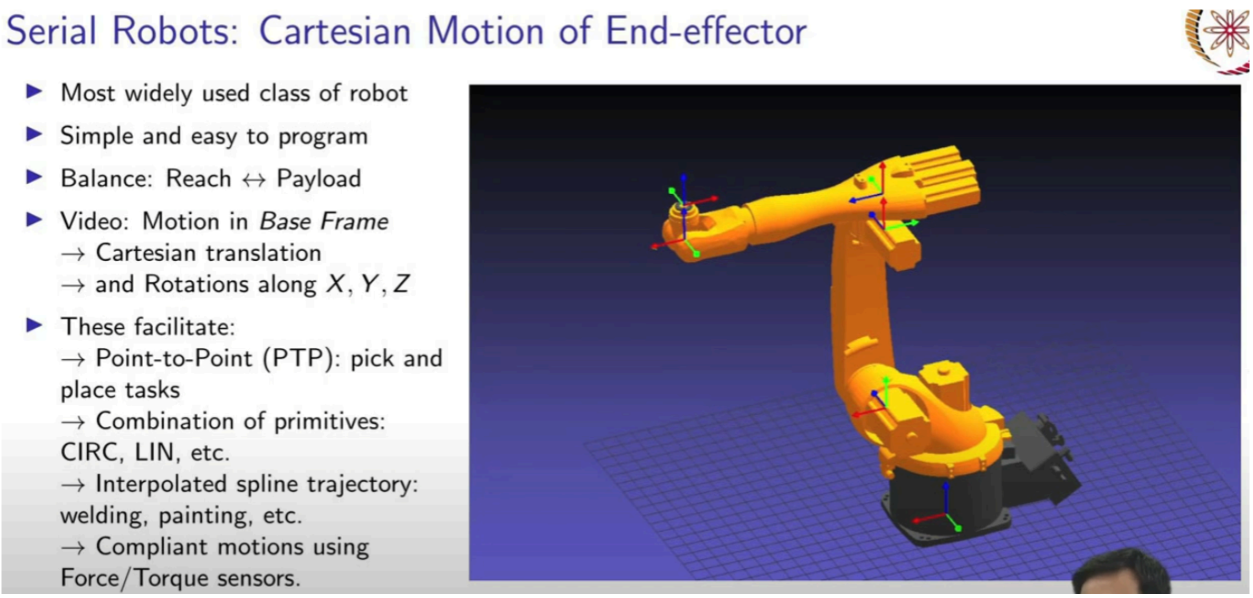
Fixed Installation Robots - Serial and Parallel Robots

Welcome back. So, in the last few lectures, you have learnt what Industrial Robots are? You got a glimpse of various types of robots when I discussed the classification of industrial robots in my last lecture. So, in today's class, I will cover two broad classifications of Industrial Robots which are popularly known as Serial Robot and Parallel Robot. So, let us begin.



In today's lecture, I will be covering serial robots: Cartesian and joint space motion capabilities; I will show you. We will discuss parallel robots also. I will introduce you to this special kind of robot, its historical comparison, cartesian motion capabilities, advantages, disadvantages, and applications. Why this special discussion is required? Because, you know, these two kinds of robots are most widely seen in the industry shop floor. Most of the applications which are there in the industry, which are made by robots are by these kinds of robots.



Let us begin with Serial Robots. First, before we begin, let me just start a small video that will run parallelly while I discuss serial robots. Let us start the Cartesian motion first. It is the most widely used class of this robot. It can make almost all kinds of motion. It can make motion in Cartesian space. Cartesian space is the motion, and you see this robot is moving with respect to its base frame, which is attached to the ground. That is the frame along different Cartesian directions of that frame. Now, this robot is moving, you see, moving along X, i.e. I would represent by red, along Y I will represent with green axis, and Z is blue axis if you can see.

In all three directions, you see the translational motion this robot is now making. And it can also make rotary motion along those axes as well. You see, it has all the six degrees of freedom in space, and the end effector can go. So, any object can manipulate in those directions. It is the most widely used class of robots.

Suppose you go to any industry, all the pick and place tasks, pelletising tasks, and welding tasks. So, it is a very, very powerful robot, and it is almost omnipresent on the industry shop floor. And why? Because you know, this robot you can clearly visualise by which direction it will go. If you have to program this robot, it is very easy to visualise the end effector. You can simply jog; they have a teach pendant attached, which you have seen in the anatomy class also. There is something known as a teach pendant. With the teach pendant, you can directly jog them in Cartesian space along X, along Y, along Z, and you can clearly visualise its motion, you can estimate the motion, and you can teach this robot quite easily. You are taking it to various places in the workspace. And they are very, very simply constructed. All the joints are very much analogous to the kinds of joints we have, the kinds of links we have.

So, even our arms, you see, it is of a similar kind, you have a link, you have a joint, you have a link, you have a joint, and finally, you have an end-effector, that is our palm, with some fingers.

So, we can hold something, and we can orient it in all three directions. We can move along all three directions. So, you see, it is very much similar to our arms. So, we are kind of brought up with these kinds of arms. It is very intuitive to handle this kind of robot, and you see, you can handle something which is very far beyond by stretching your arms. You can hold something, and you can hold powerfully at the centre region, and you can handle something. So you see, it has a very good balance between its reach. Okay? You can reach quite far, and you can handle a very heavy payload if you are in something around, near to your body. So, then you can handle a huge payload also.

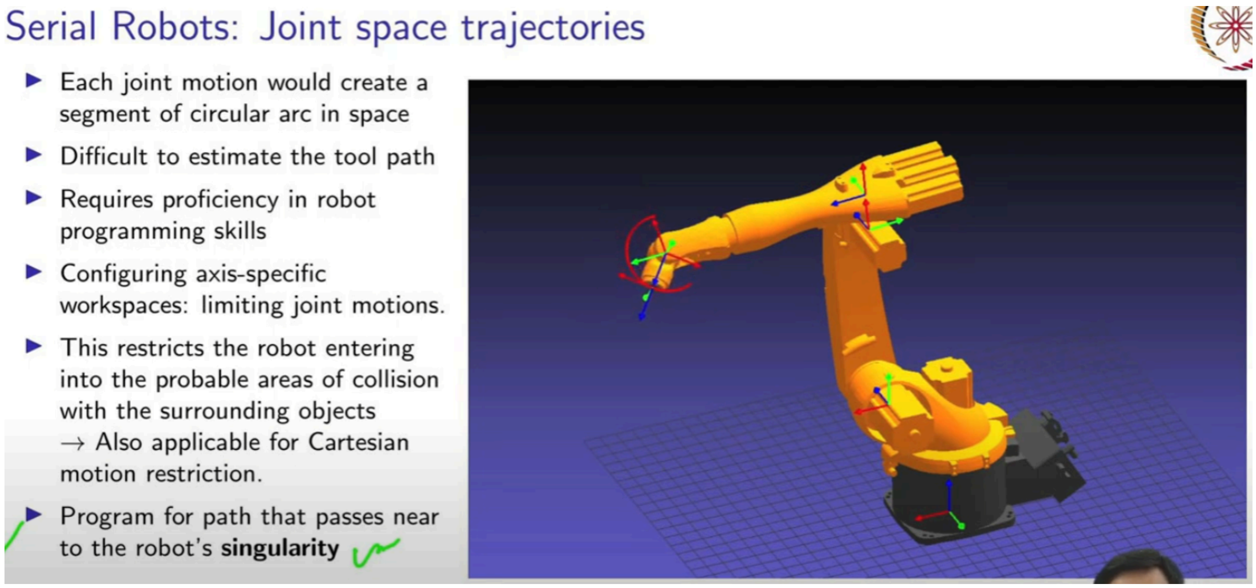
So yes, that is the beauty of this kind of robot. It has a very good balance. That is what makes it very much omnipresent in the industry. Now, it is making rotary motion. You see, it is rotating its end effector frame about the y-axis. That is the green one, and similarly, it has made rotation about the z-axis. So, now, it is moving (rotating) about the z-axis. You see, it is making almost all kinds of motions which are required normally to handle any object that all six degrees of freedom motion is possible, at least with this robot, so not all robots, which are serial can be of this capability. It is a six-degree-of-freedom robot, you now understand already. So, this type of motion can facilitate any kind of pick-and-place motion, a point-to-point trajectory. It can take you from a point and bring it to another programmed point.

That is not just the point. What I mean is a point in space; it is position and orientation in space to a position and orientation in space. So, it can gradually make itself grow from one pose to the other pose. So, pick and place tasks mostly require this kind of motion. We commonly call it PTP motion.

It can be a combination of primitive tasks. So, industrial robot controllers are pre-built with some kind of motion, which are like circular arcs. They can be defined in different ways, can be defined like two points and a centre point or radius and two points in the space or maybe just three points in the space that is easy to define a circle also. So, there are various ways you can make your robot go circularly. Your end effector will go in a circular trajectory, and similarly, a line in space can be defined by any two points in the space. So, those are a few standard motions that this kind of robot supports, and it can also do interpolated spline trajectory, which is mostly common when we do a painting, welding, glueing task, or laser cutting.

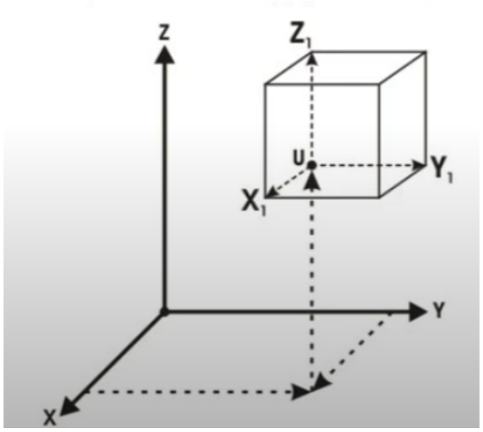
You have already seen various such kinds of motion where you require a robot to move in a free-form shape in the space. So, that can be programmed. So again, when we program, I don't just mean it can go point to point only in position. It will continuously gradually shift its orientation, which was taught at every location in the workspace. That is how it can be programmed. So, this kind of programming is already fitted into this kind of robot's controller and the compliant motion task. It can also do compliant motion tasks. Not all robots can do compliant motion. There are special kinds of robots which are known as collaborative robots or cobots, which are joint compliant. So, their joints are not very stiff, and you can make them go backwards. Also, that means they are all back-drivable. They are gravity-compensated; they can be controlled for impedance and can be controlled for stiffness at their joints even at their end-effector level.

So, those kinds of robots are soft robots, and they are compliant using force-torque sensors, it is made so. So, that is also possible with this kind of robot. There are many other capabilities this robot can see.

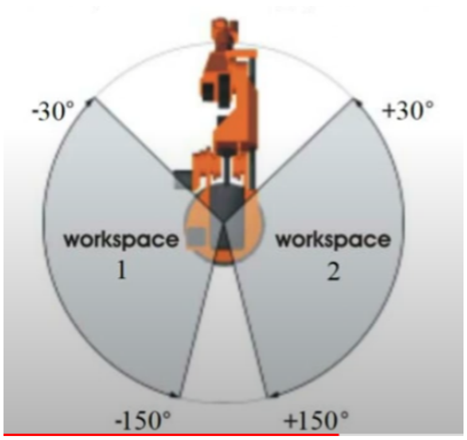


So, the next one is a joint motion capability. First, you see that axis one is moving, and it is making it go in a circular arc in space. Again, I will make the second joint move; the second joint is moving, and again, it is going in a circular arc. Now, I will make the third joint move. It is the third joint. Now I am moving, see again it is in a circular arc. From the axis of rotation, you have a centre, and then the end effector goes in a circular arc. This type of motion is known as a joint space motion trajectory, in which a robot is made to move about its joint only. So, one of the joints or a combination of joints is made to move, and then you can take your robot to go to a particular place. In this, we are not very specific about moving in special trajectories like linear displacement along any of the axes or rotary along any of the axes. So, each joint could create a segment of a circular arc in space, but it is very difficult to estimate the robot tool path; you know this is a complex robot with multiple links connected one after the other, so while moving one of the joints, you cannot estimate precisely where your robot will go. Whereas, when you were moving this robot in Cartesian space, what you saw, you know it will go down along the z-axis if you are just jogging it along the negative z-axis, you can clearly understand yes, it will go down, but in this case, you cannot predict where this robot will go, Yes, you have some estimate that it is going to make some circular trajectory in space, But using this kind of trajectory for programming is not at all advisable because it is very difficult to estimate the tool path, very experienced users can do it. So, it requires proficiency in robot programming skills. If you want to use it, you should be very familiar with this robot.

Now, configuring the axis-specific workspace is also there. So the way you could confine your workspace in the Cartesian robot, the cartesian motion of this robot, let's say you don't want your robot to go to a particular workspace, so you can definitely put that workspace out of the programming.

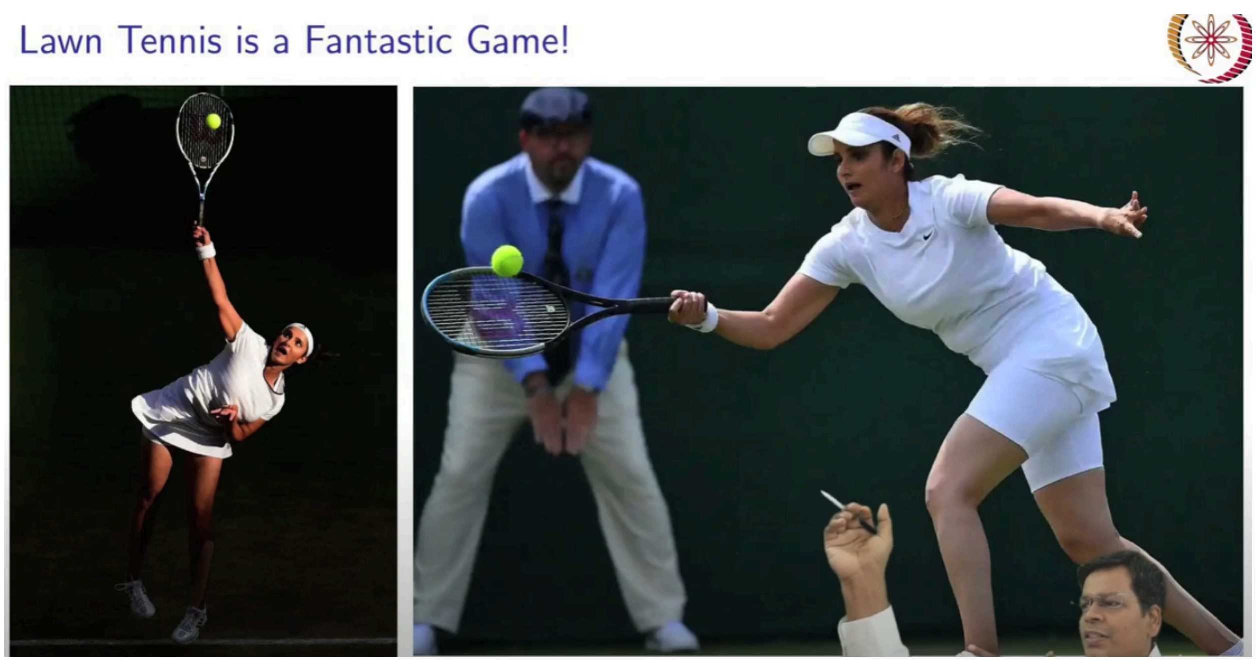


There are provisions in the robot's teach pendant where you can define x min, x max, minimum and maximum values of x, similarly minimum and maximum along y, and minimum and maximum along z also; so, that is what you can mention. And you can clearly say, okay, this is the cube within which I want to work, or this is the cube within which I don't want to go.

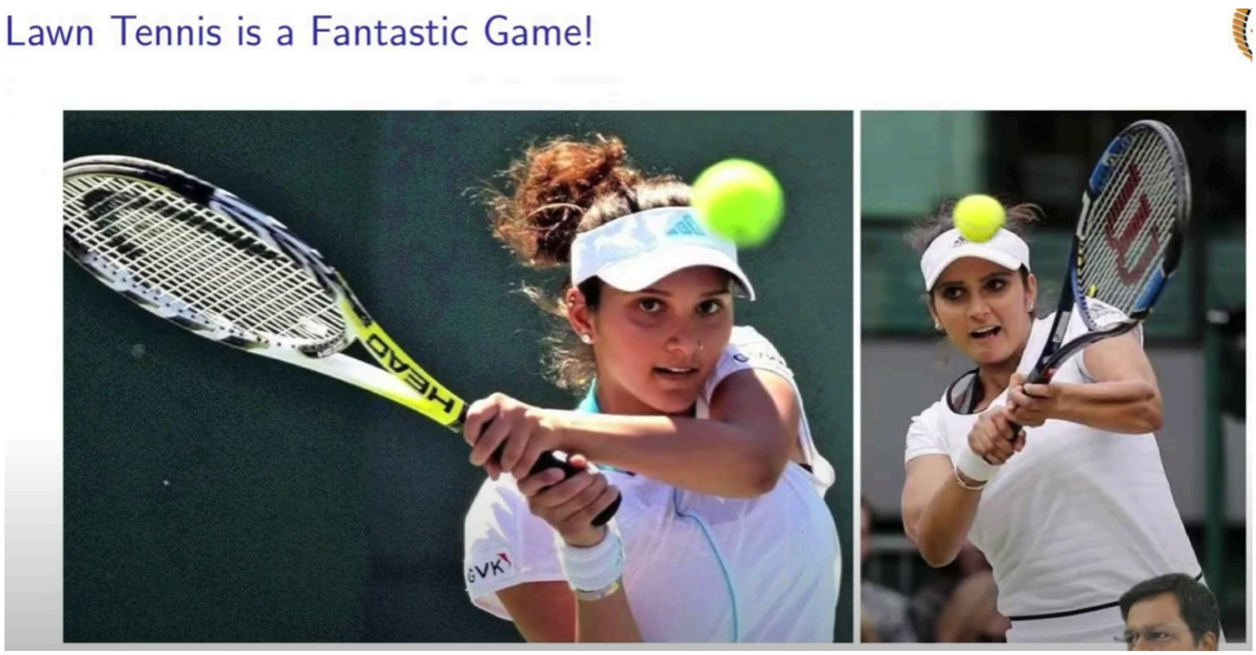


In the same way, when you are programming for axis-specific motion, you can also limit your joint motions, and your robot will not go to a particular joint segment of your robot. So, a whole of the rest of the space your robot joint will move, whereas it will simply exclude that space; while it is moving okay or it can do otherwise also, it will work only in that space, and it won't work in spaces which are not in that. That is what is also possible, then this restricts the robots from entering into possible areas of collision, so this is done in order to avoid collision with surrounding objects. You know you have an object in that particular location, so that is the reason why you should do this.

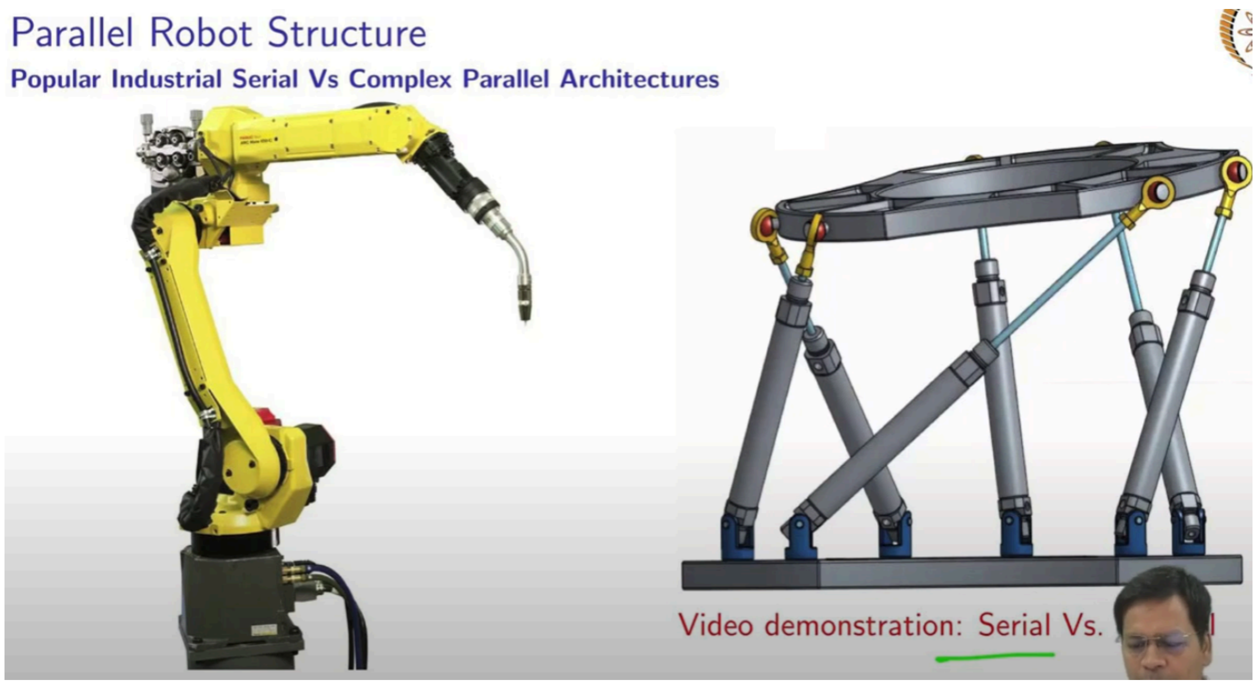
It is also applicable to Cartesian motion that I have just said something that I am doing for joint space similar analogy is there in Cartesian space also. Programming for a path that passes near the robot singularity. It is very much to be understood first. I'll show you in kinematics why a robot is singular. So, those are the places where you should avoid the robot going because that is the place where it is mathematically singular. You don't have solutions to get the joint velocity corresponding to any cartesian velocity. So, no relation exists, at least in those places, so going near to singular will make your robot move at, let's say, very high velocity in those cases, and your motor will draw a huge amount of current for that reason. So, your robot may just trip at a high current in that case. You should avoid going to those places, so a clear understanding of this will be given when I discuss singularity in robot kinematics, that is, the Jacobian relation, which is the relation between the velocities of the end-effector and the joint motions. So, programming a robot to go near robot singularity is a tough task when you actually do robot programming in Cartesian space. You don't know; if you have made it go from point to point, there may be a point in between through which your robot cannot go; maybe it is a singular phase, so in those cases, you have to use joint motion capability. So, that is the place when we normally program the robot to move just the joint and is still passed through the same workspace or same point. So, that is quite possible if you program your robot to go through the joint trajectories.



Now, let me introduce you to parallel robots. What are the capabilities? What are the applications? So, Lawn Tennis is a fantastic game. You just see what this player is doing. She is stretching her arms okay. She has a length and the joint a link, and a joint. You see, in the end, she is holding a racket and playing lawn tennis, right? So, that becomes her end-effector in which she is holding a tool and handling and manipulating an object which is floating in space, that is a ball. Hitting a ball requires all six-dimensional motion. She needs to orient her bat and as well as locate her bat anywhere in space; okay, so yes, forget about the additional motion that the whole of the body can do at least just by the arm; like table tennis also, one can make such a motion okay. It is one motion that looks like a serial arm.

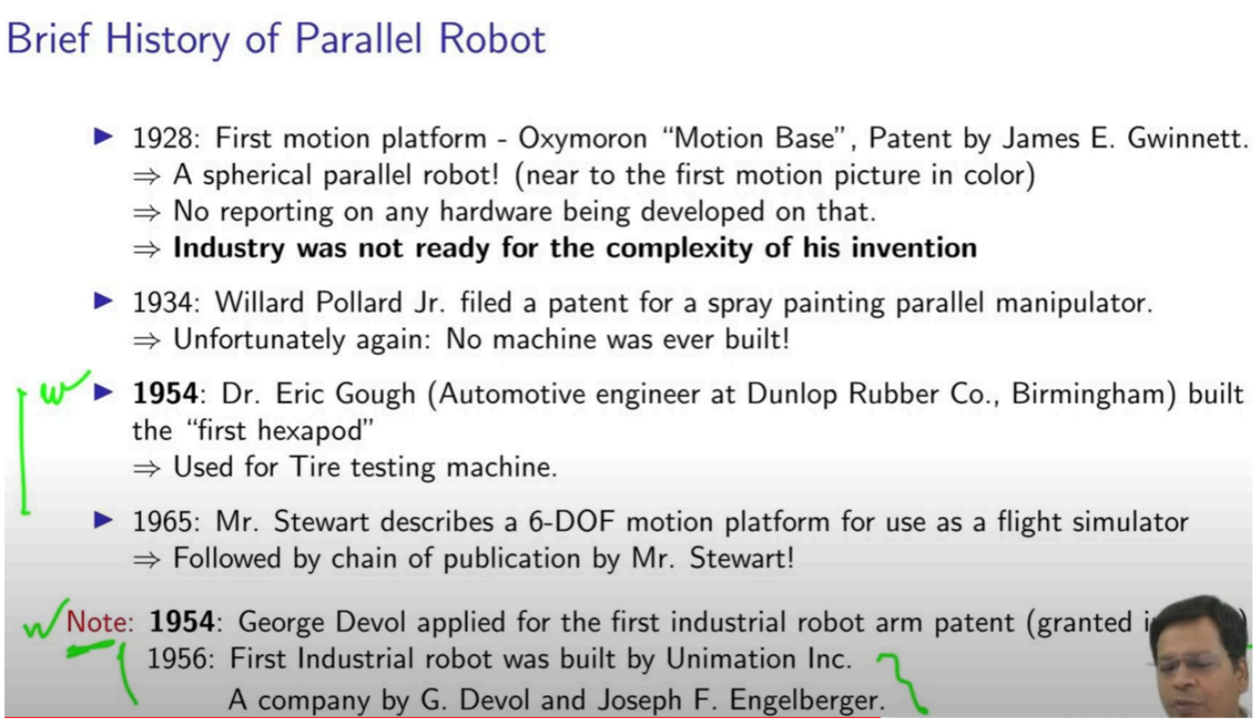


So, what difference do you see here now? Now, she is attempting to play a ball which is very close to her body, and maybe she needs a huge amount of power to do that. What now is she doing, she is holding her bat with both of her arms, so what is the difference now? So, just pause for a moment and think about what was in the last figure and what is in this figure. So, that was a fully stressed arm that is a serial arm. So, in this kind of motion, when you are holding two serial arms together and creating an end-effector for some manipulation task, you also have an end-effector over here with a tool that is your palms, a combination of palms that acts like a gripper in which you can hold a tool and do something; so, this kind of motion is known as a parallel kind of motion, so in the case of robot terminology we call it a Parallel Robot.



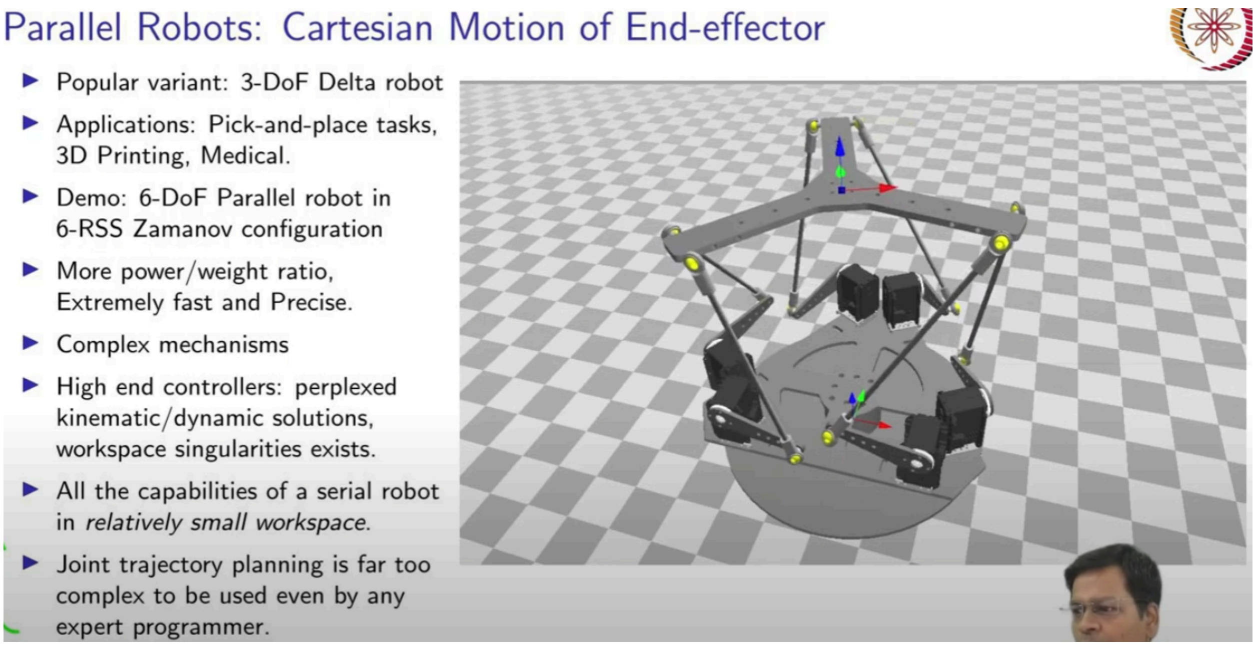
So, it is your serial robot. It has a fixed base. It is mounted at the base and founded on the ground. You have a joint, you have another joint and a link, a joint and a link, you have multiple joints, and the link finally reaches the end-effector frame. So, the second one is also a robot. It looks like a manipulator or a platform. It is very, very similar to the way the robot is defined; a manipulator can be a robot if it fits well in all those definitions. So, these are actuators; you see, it has one linear actuator that can make this kind of motion; it has another linear actuator, yet another one you have another one, so these are nothing, but this is a Stewart-Gough platform. So, it has six linear actuators that connect the bottom platform using a spherical joint and maybe a universal joint, or it can go otherwise. So, it is universal, prismatic and spherical; so it is known as a 6-UPS robot or a Gough Stewart platform. So, it is a parallel robot robot. You see, all six actuators are simultaneously moving the top platform to achieve any kind of motion. Those robots have limited workspace, but they are very, very powerful. To make any kind of motion, all the arms are the actuators also are moving simultaneously using their power to do that.

You have all the actuators themselves that become the links; okay, you don't have any additional links here. So, that is the the reason probably these robots are also maybe a little lighter as compared to similarly powered serial robots. So, we'll see a brief comparison now. You have already seen the video for the serial robot. Now, making it go in a cartesian workspace as well as a joint workspace. I'll show you some videos for parallel one also.



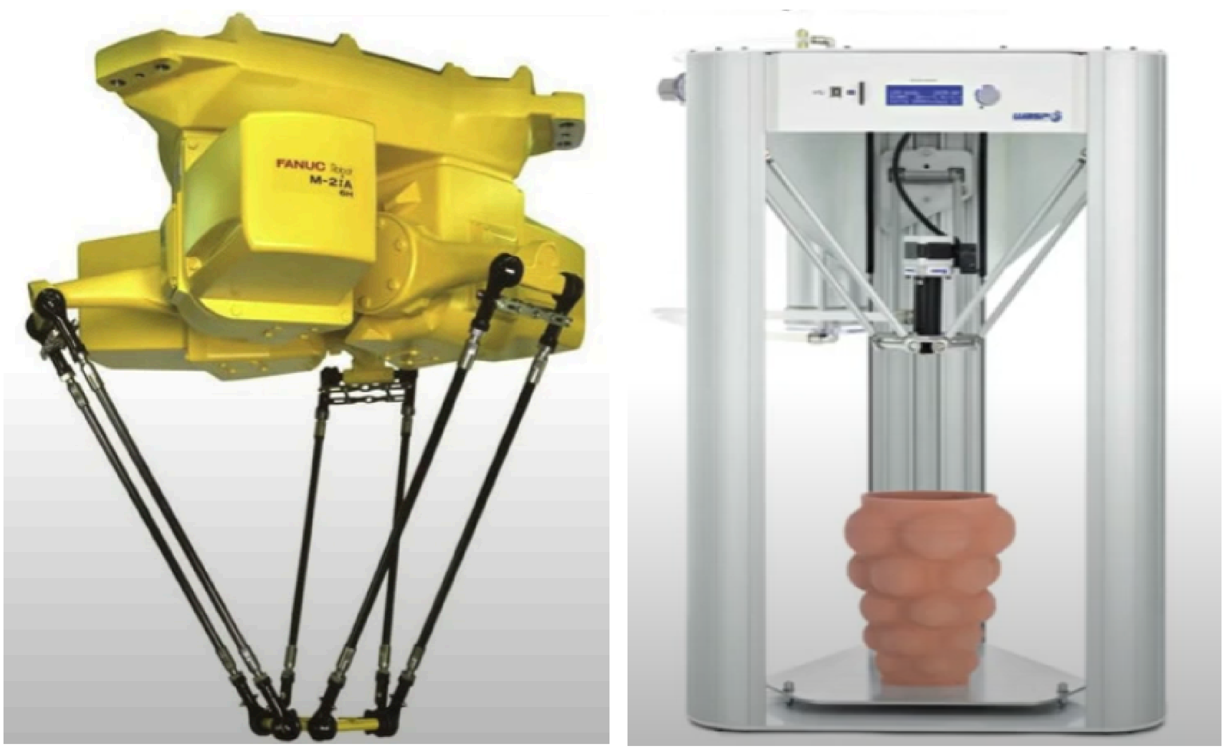
Now, let us discuss the brief history of parallel robots. So, you see, it is the first platform that came in, which was reported in 1928, which was known as Oxymoron, which was a motion-based platform patented by James E Gwinnett. It was nothing but a spherical parallel robot; this patent was filed almost near to the first motion picture, which came in a similar year. It is so age-old, you know, so even serial robot is reported quite early in those days. So, no reporting on any hardware being developed on that. Even after this patent, there was no hardware which actually came in. You see, this parallel robot is very, very complex; the mathematics is complex, computing the workspace is very complex, and estimating where it will go by moving just one joint is very difficult to visualise. So, the industry was not ready to handle this complexity mathematically, as well the kind of computational power that we had due to the kind of computers that existed in those days was not that good. So, this invention was on hold for quite a long time till we saw actual computers which could handle these mathematics came in. So, in 1934, Willard Pollard Jr came in with a new patent for a spray painting parallel manipulator. Unfortunately, again, no machine was ever built for that patent was filed, which claims that it can do some spray painting operation using a parallel manipulator, but no machine was built so this was in 1934, and then in 1954, you remember this is just one year near to the serial robot discovery; so, the serial robot patent by Dr Eric Gough came up. He was an automobile engineer at Dunlop Rubber Company in Birmingham, so he built the first hexapod, which was the first machine which was built on parallel architecture. Okay, that was used to test the tyre which they were manufacturing. So yes, in 1965, Mr Stewart, he came in, he described the sixth degree of freedom flight simulator, okay so he followed by a chain of publication by Mr Stewart so yes, after his coming in in 1965, he could publish a series of paper based on parallel architecture. So, this man Eric Gough and Stewart were the pioneers in this. So, in 1954, George

Devol applied for the first industrial robot arm patent. So, you see, the years are very, very close here, 1954 and 1954. You see, this parallel robot, because of its complexity, the kind of mathematics, and technical reportings which were there in those days, was on hold; it went a little slower for parallel robots although the applications you will find. Even parallel robots are most widely used nowadays, So, the first industrial robot was built by Unimation Inc. It is just for the comparison; I have just noted it here. So as to compare the years, you see both were patented in almost similar years, and both the discoveries started almost at the same time, but the whole of the development and seeing this platform in industry soft floor went at different speeds.



Now, I will show you the parallel robot: cartesian motion capability. So, this is the robot with six degrees of freedom. You see, there are six actuators all simultaneously they are moving. All are rotary joints. So one end can have a spherical joint other one can have a universal joint, but in this case, it is both spherical rod and bearings. So, it may be called six RSS. So, that is six Revolute Spherical Spherical joints. Again, it is six degrees of freedom robot. You see, it has made a translation motion along all the three cartesian directions with respect to its base, and you see this is the third one. So again, it can do all kinds of rotary motion also about each of the axes. So, you see, this is fully capable of the way your serial robot was moving; this also can move. The most popular variant in the industry is a 3-DoF Delta variant that you have seen in the kinds of robots that we have discussed in classification. This can do pick and place tasks also. This normal configuration in which this can do pick and the place is mounting this inverted, and you can put your end effector at the tip platform, and you can make it have a gripper and do some pick and place tasks also. These are very commonly used for 3D printing, in medical surgery when you need your end effector to be very, very stable and very, very precise and stiff. So, these are a few applications. So, the configuration which is shown here is a six degrees of freedom parallel robot in six RSS Zamanov configurations. So, these robots, you see, all the six actuators are moving simultaneously. There are no actuators which are mounted on the link. Your links can go very, very light in this case, right? So, that makes the whole of the structure very, very light, so that is the reason it is very, very fast, and that is the reason it doesn't have much inertia also as compared to the serial robots. So, they are very, very precise also. So, the fastest robots which are reported are parallel robots. It has a very good power-to-weight ratio. So, they are very complex. You see, they are solving for complex mathematics that is not that trivial, so high-end controllers are required because of their perplexed kinematics and dynamic solution; workspace singularities exist. So, it doesn't just have singularities at its boundaries. It also has singularity within the workspace, so finding out that similarity position is again a challenge.

All the capabilities that a serial robot has also has, okay, but you see, it has limited workspace. So, the only limitation it has is its small workspace, but the joint motion planning is far too complex. You cannot estimate where your end effector will go. It is even more complex as compared to your serial robot, so just moving one of the joints can make an arbitrary motion in the space that you cannot predict. Okay, even a very good programmer cannot understand that. So joint programming, in this case, is just excluded; okay, you cannot do that. It is far too complex to be used by any expert programmer.



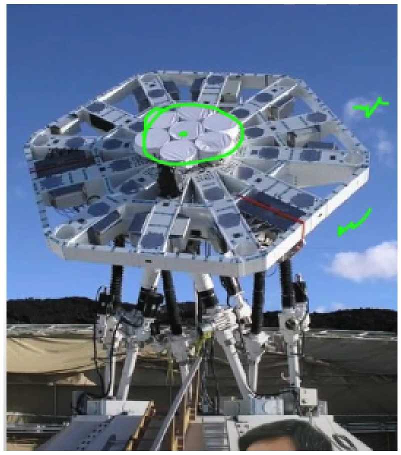
3-DoF Delta Robot

Applications of Parallel Robots in the Industry

Let me just discuss some of the applications of these robots in the industry.

You see flight simulators, a naval simulator mining or truck simulator, where you can train the drivers who will actually drive the real vehicle. So, this is just the cockpit of the flight, which is placed on top of a parallel platform. So, this looks like a Stewart-Gough platform only. So, you have a bottom base that is attached to the ground, and you have a top platform which can make motion. So, on top of that, you have a cockpit; so that a person can sit within this cockpit and this platform based on the graphics that are shown in front of the driver. So, he also sees the motion so that he can get a completely immersive feeling of the actual environment that he is going to face when he is riding on a real flight. So, that is what a simulator is, and so, it is used for that reason.

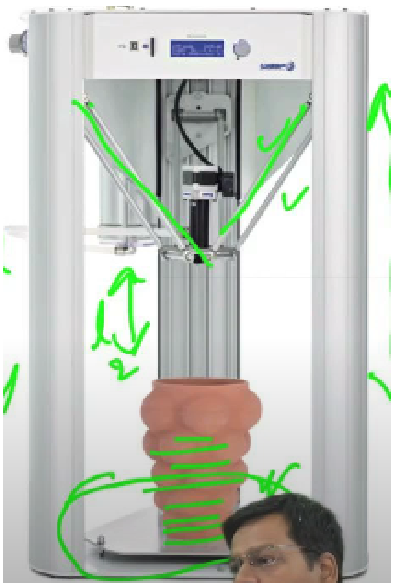
Now, moving giant telescopes: Telescopes require the very precise location of these top sensors. So, that is to be located very precisely, that is to be oriented very precisely because even having an error of a fraction degree over here can have used displacement when it actually sees any object in space because of the distance. So that is the reason it requires a very stiff base and is very precise and effective. So, that is the reason for mounting any giant telescopes or even solar panels, parallel platforms are used. Pick and place tasks in any industry you see; this is a standard delta robot, which is picking a moving object from a conveyor okay. So, that is most common in the food packaging industry, and agro-industry mainly 3- DoF Delta variant is popular in an industry that has only three translational degrees of freedom and can just pick and place.



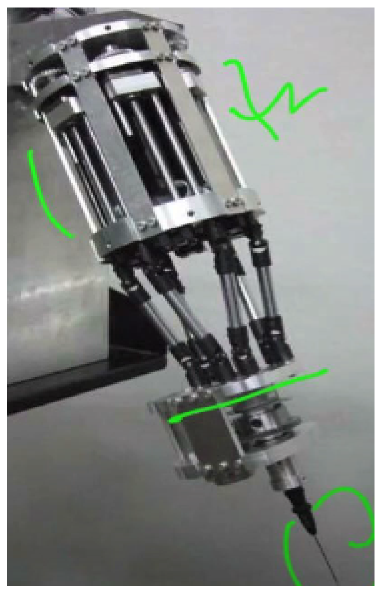
Moving Giant Telescopes, Solar Panel

Pick and Place: 3 DoF Delta Robot

Micr- manipulators



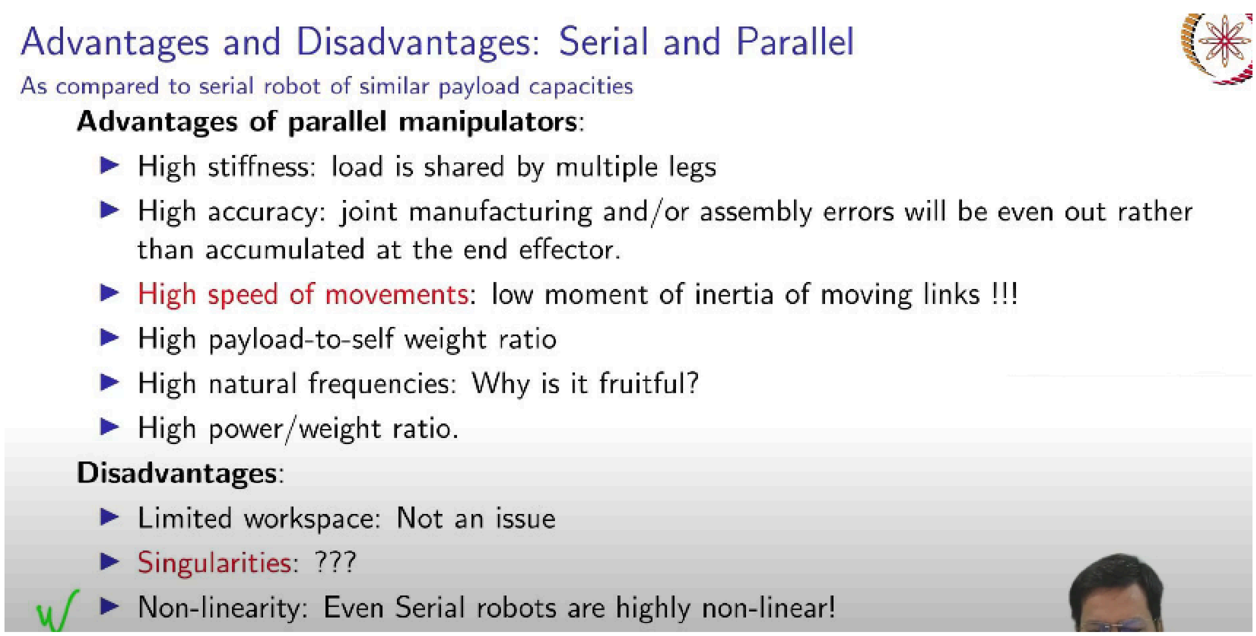
3D Printing, Milling (5D Printing)



Medical Robots for surgeries (serial with Parallel ends)

The da Vinci surgical Robot

For medical, robots are used for surgery. So, you have all the six actuators that are in it. So, this is not the only one, there are many other industrial robots which use this okay; even your Da-Vinci robot that you have seen in the classification also uses a kind of parallel architecture in the end. It has a serial to expand its reach, and it ends with a parallel architecture at the end. So, it is a serial-parallel system. So, this is just a parallel tip that is holding a kind of needle over here. Yes, so now you can see the needle also which is here. So, this is the needle which is mounted here at the top platform. This robot is mounted inverted. It is an application which uses a parallel robot in medical surgery; it can be a laparoscopy tool also, so again, it is used for 3D printing. It is one of the most popular variants of a 3D printer in which you have all three linear actuators which are mounted like this. It has three linear actuators that can take these links; these are the links that simultaneously go up and down while it builds up this object in 3D. So, as it is built layer over layer, so, all three links can go up, and it can by adjusting the lengths of all three links: L1, L2, and L3. These three links can extend and retract, so those are prismatic joints. Basically, that is attaching these permanent links okay and making it go anywhere in this region. so it can make xy motion like this anywhere and it can go up and down. It is a three-degree-of-freedom robot. So, you also have a parallel robot for 5D milling or 5D printing, which works similarly. You have a micro-manipulator to do any kind of, let's say, brain surgery, or this is just a mop, which I got from one of the literature available over the internet. So yes, you see, this is a parallel Stewart platform that is mounted with a needle that is working somewhere in the brain part of our body. So yes, this is your micro-manipulator kind of thing, so not just for this, it can be used for, let's say, assembling your wristwatches. So, that can be handled also. So, most of the applications where a serial robot can go with some exemptions, even a parallel robot, can go. So, the workspace can be very, very similar only limitation is in reach; otherwise, it can do everything. So, this is the Da-Vinci robot, which has a serial arm with a parallel end that has which goes over here. So, this is what I was talking about when I was talking about medical robots. So, these are the robots.



So Now there are many advantages of a parallel robot. You see it because it is mounted on top of all six actuators, which are very stiff, which means you don't see much of a jerk due to external load variations. So, it has a very high stiffness, and the load is shared by multiple legs. It has very high accuracy also as compared to serial robots; when you have a joint, if at all you have an error over any of the joints, it is felt at the top. So, all the joint errors are accumulated together, and you can see at the top it has a huge amount of errors that can go. So, in this case, you have all the actuators basically connecting the bottom and the top frame, so any error in one of the joints may be compensated by the other one. They don't need to be added together, okay? So, that is the reason they are very, very accurate in joint manufacturing, or the assembly errors will even out rather than getting accumulated at the end effector, as in the case of serial robots. It has very high-speed motion. You see, their links are the actuator itself, and you don't have any actuator which is mounted on top of the links. So, your links are very, very light, so that is making it a very low moment of inertia. So that is the reason why your links can move at a very high speed. So effectively whole of the robot can go at a very high speed, okay? So, high payload to self-weight because your links are lighter whole of the robot is lighter. For the same payload capacity, a parallel robot has a very good payload-to-self-weight ratio and high natural frequency. Why this is fruitful because, you see, they are very, very stiff, so that is the reason natural frequencies go very high. So, in the case of serial robots, it is very, very long. It may match with the working environment frequencies, and that can resonate with the system, so that cannot happen with this. If your frequency goes very, very high, the natural working of your robot cannot match the frequency of your cycle operation. So this is very, very fruitful. So, you can work at a very high speed also without getting worried about whether it will match your working cycle or not; whether it will match the natural frequency of the robot. So, that is the reason it is very, very useful, and you don't have any control in the case of the serial robot. Even if it happens that so you just have to skip that working frequency, working cycle, okay, that cycle frequency you have to just exclude from your programming system. So, it has, again, see high power-to-weight ratio, so it draws very little power for the same payload capacity robot as compared to the serial robot. It is different from payload to self-weight ratio, okay, so yes, you have already seen it has limited workspace, but it is not an issue if you plan your workspace properly; okay, you mount your robot in the proper location. You can very well create a very good workspace. Sometimes, it is preferable to put this robot inverted, and you have huge free space at its bottom, okay; at the base, you see it has a free space where you can manipulate its end effector, okay? So that free space is there. So that is not much of an issue here singularities. It is also there in the case of serial robots only thing is if you know it is very good. You just have to find out that it is a problem in the case of parallel robots. But at least with Delta, it is very well-known where the similarities are, and you can easily avoid that. And mostly in industrial robots, they work on a PTP base that is point-to-point programming in which you record a joint position and just replay that joint position in order to do any pick and place task because delta robot kind of parallel architecture, which is very, very popular in the industry. They are basically using a delta robot, and it doesn't face any singularity because it works in joint space, not in cartesian space. It doesn't have to relate the end effector motion to its joint motion, okay? So, Jacobian and getting singular is totally absent. We'll discuss more about this when we'll be discussing singularities and differential motions. So yes, they are non-linear; even serial robots are non-linear, so even that is not much of an issue. So yes, you've now seen the power of parallel robots also. You already know serial robots. They are very, very popular in the industry. So, with this, I'll end today. In the next module, we'll start with actuators. Actuators give powers to the joint different kinds of actuators. Mostly will focus on electrical actuators. So, that's all for today. Thanks a lot.