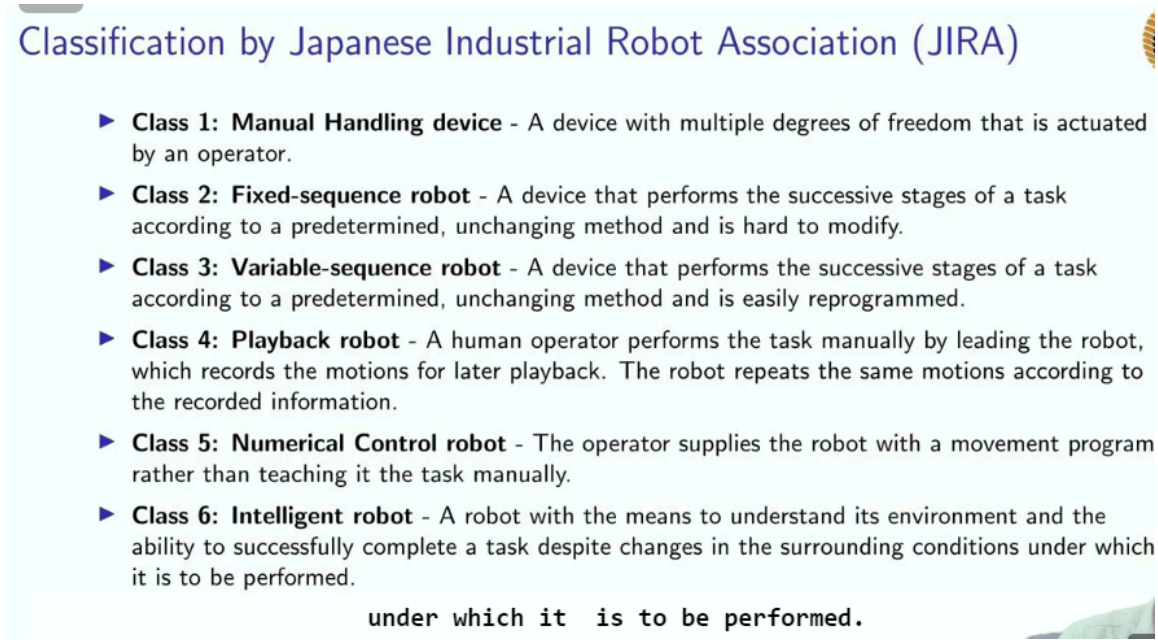
NPTEL Online Certification Course
Industrial Robotics: Theories for Implementation
Dr Arun Dayal Udai
Department of Mechanical Engineering
Indian Institute of Technology (ISM) Dhanbad
Week: 01
Lecture: 04

Classification of Robots

Classification by the Japanese Industrial Robot Association(JIRA)



Welcome back. So, in the last class, I included the technical specification sheet the manufacturer provides for a given robot in my lecture. So, we covered some specific parameters necessary to define a robot's performance. How is my robot going to perform? What is the capacity of my robot? What parameters should I look for to use a robot for a particular application? For example, I discussed payload, mounting flange dimensions, repeatability, joint angle limits, working envelope, etc. So apart from that, I also discussed the mandatory requirement of ISO 9946, which also states some of these required parameters to be included in any specification sheet to be called an Industrial Robot. Suppose the data sheet is for an Industrial Robot, and they want their robot to qualify to be compared against any other available Industrial Robots. In that case, they should be using ISO 9946 directives.

In today's class, we will extend further on this and see how Industrial Robots are classified. So, let us start. In today's lecture, I will cover mostly existing Internationally

approved classifications - JIRA and AFR. You can further classify a given robot based on the Power Source, workspace geometry, degrees of freedom, kinematic structure, movement, and application types.

So, yes, the Japanese Industrial Robot Association JIRA has a special way of classifying industrial robots that is one of the pioneers in organizing and giving definitions for classifying industrial robots. It says class 1, it has divided classes into six different courses. One of them is a manual handling robot that is class 1, a device with multiple degrees of freedom that an operator actuates. It means it is purely a manual robot with no automation. It may include something other than electronics or, sometimes, any computational software behind it.

So that is class 1 of types of robots. Class 2 says it is a fixed sequence robot that performs a task's stages according to a predetermined unchanging method and is hard to modify. It is like a CNC machine, but the way it differs from a CNC machine is the type of mechanism and the task it can perform. Class 3 says a variable sequence robot, in this one, is actually, a device that performs successive stages of a job according to a predetermined unchanging method and can be easily reprogrammed. So here comes the picture of some programming aspects of a robot, and now it fits well into our definition of the robot.

So, as we have defined earlier in our first class, the playback robot human operator performs the task manually by leading the robot to a place that records the motion for later playback. So, teach and repeat functionality is now added to this type of robot. The robot repeats the same action according to the recorded information. To do this, you also need to have some program that can store the data, and they can reproduce the same data. They have some playback sequences that can regenerate.

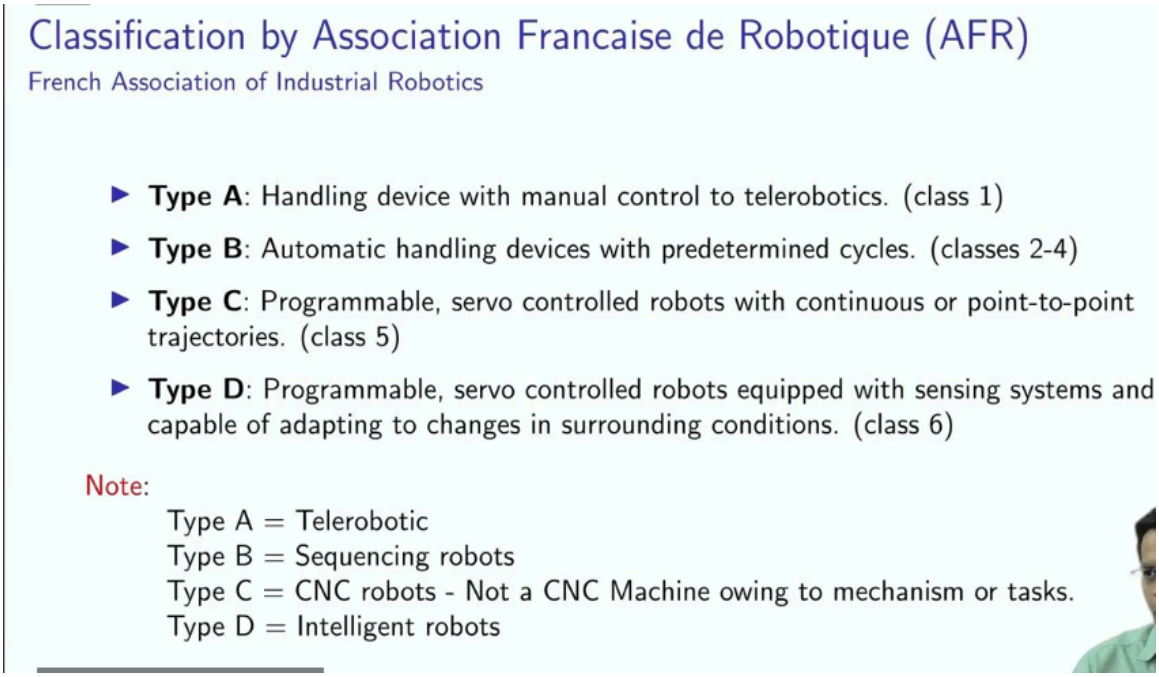
And then the class 5 is a numerically controlled robot. The operator supplies the robot with the movement program rather than teaching it the task manually. This excludes the other classes like playback robot class 4; it is not included. And this one is, rather than teaching, can be done manually. It means you can program for a specific type of motion, and the robot can repeat what is being programmed.

I have programmed my robot to follow a profile, and it will observe that profile several times. And the sixth one is the most intelligent. You see, it is the most intelligent robot. This says the robot has the means to understand its environment and the ability to complete a task despite changes in the surrounding condition under which it is to be performed. So, in this case, the picture of the brilliant robot has come in.

It must do more than just the task for which it is programmed. It can understand the environment and realize any changes and is rugged to work despite any surrounding differences. So that is class 6, 6 classes of these robots. So, as I told the first two definitions, at least the manual handling robot and fixed sequence robot do not fit into the standard definition of industrial robot, or in general, any robot. So Robotics Institute of America, R.

I only consider classes 3 to 6 to be robots. However, they are being classified as a robot, but they are not robotic cells.

Classification by Association Francaise de Robotique (AFR)



So again, AFR gave the second essential classification, the French Association for Industrial Robotics.

This has defined four different types of robots. It includes the the first one, the handling device with a manual control of telerobotics. Telerobotics means an operator is sitting somewhere on the remote, and he can control the robot remotely, as a master-slave system may be.

This is also similar to the one defined in class 1 of JIRA. Now, type B, automatic handling devices with predetermined cycles, just like classes 2 to 4 of the earlier definition of JIRA, mechanical handling devices with predetermined cycles, and then type C includes the programming aspect, programming servo control robots with continuous or point-to-point trajectories. So now, it can be programmed to go from an

end to a different point in a given course. This is the class 5 of JIRA. Type D is an intelligent robot.

It is also a programmable—servo-controlled robot equipped with sensing systems. So now it is sensitive to the environment. It may be doing its job based on climate changes, or it may be programmed to be rugged against environmental changes and capable of adapting to changes in the surrounding conditions. This is as good as having a class 6 definition as it was there.

So type A is a teleoperation robot, a master-slave kind of thing, or a sequencing robot is given by type B. Type C is a CNC robot. It is different from a CNC machine owing to the type of mechanism it is made up of and the task that it can handle. Type D is an intelligent robot. So these are some of the standard internationally accepted classifications which are there.

Based on Power Source: As in ISO 9946

Now, we will look at some different ways of classifying industrial robots. Moving ahead based on the power source, how can we organize a robot as in ISO 9946? This is a mandatory requirement, as I have said. So, a robot can be classified with electrical actuators, electrical motors with which it is made, and hydraulic actuators; it can be pneumatic actuators or some non-conventional sources that can power it. We will see that now. So yes, most industrial robots are electrical in nature. As you know, electricity

is abundant, you can find it anywhere, it is readily available, it can be of two types AC or DC kind of electrical power which is available.

So, we will look at various features of AC and DC things. So, the DC motor typically can provide higher torque, mostly higher starting torque, which is very very helpful to making compact robots because a DC engine normally has carbon brushes within, we will see in detail the construction of the DC motor, AC motor, stepper, and various kind of motors in our next module. However, for completeness, you should understand yes, it has; it is made up of carbon brushes, and with our background, we know it most of the time. So carbon brushes go into it, armature with coils which has some commutator which is there, so few additional parts are there, so a number of parts are more, so maintenance is more in this case. BLDC motor is a brushless DC motor, is lighter, it bears almost similar type of features that a standard DC motor has, however the drivers are a little bit complicated, it does not have brushes or a commutator makes it even more compact and because it has less parts, no wearing off of brushes can occur, it has more life as well.

It is an AC or DC motor, normally it has geared, gearboxes that are attached to enhance the torque rating of the motor or sometimes to reduce the speed of the motor. So you can go for BLDC motor type of robot or a brush geared motor type of or stepper motor, so these are few of DC motor kind, they are used in mobile robots, why because you know you cannot have an AC motor on a mobile platform, it is very difficult to make AC portable, you need to have a generator or an alternator on board your robot, so that does not fit in on an aerial vehicle at least where you need your robot to be very lightweight, it has to be agile so that you can quickly manoeuvre in the air. So just like a quadrotor or a drone, you call it, for a similar reason even underwater robots have a DC-powered source, it can carry a battery on board, so that has stored energy. AC servo motors are normally suited for large capacity industrial robots because you know they are normally grouted to the ground and they are in the industry where you have a huge power supply that is readily available again and AC motors are again they are very very compact so that is the reason it is used. Mostly with synchronous AC servo motors, AC motors do not go all alone, many attachments make it fully controllable, one of them is having feedback, servo means feedback, so AC synchronous motors which are normally run by variable frequency drives, motors with a gearbox and many other attachments like encoder behind or optical encoder or a magnetic encoder, some sort of position and velocity feedback devices are there, we will look upon them very much in detail while we will be discussing actuators.

So another very important classification part that you can see here is a hydraulic motor, so few of the actuators can be hydraulic in nature like over here you see the figure you

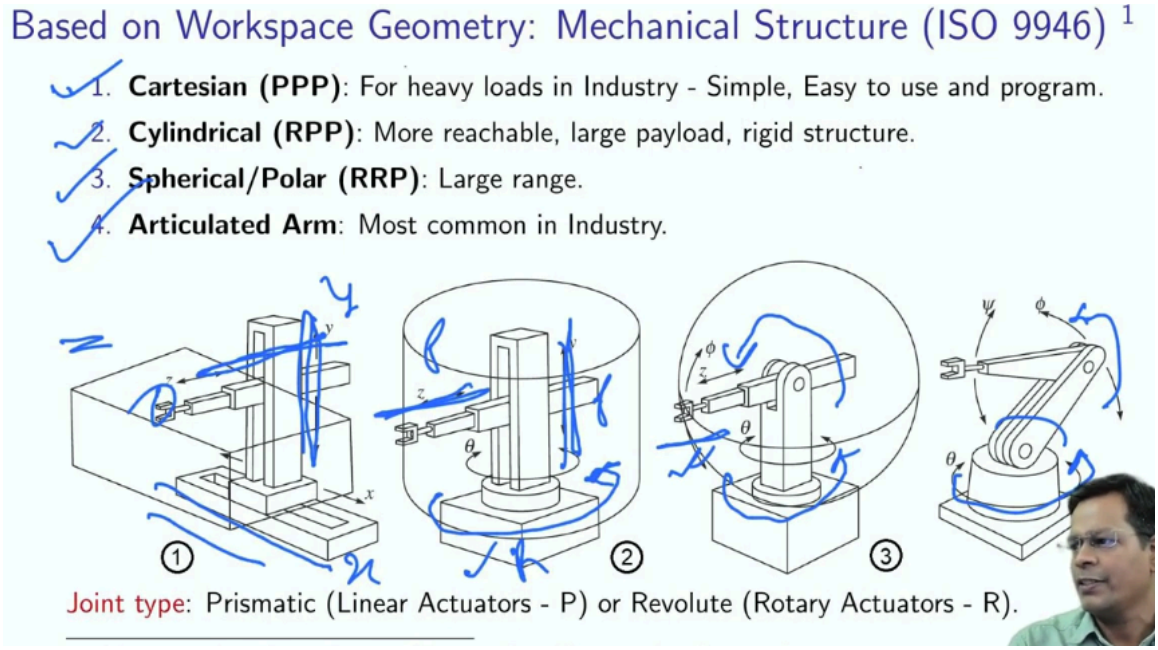
see this is usually a very large capacity robot, very very large capacity robot because hydraulic power packs are very difficult to fit in on board a robot or they are very very hugely expensive although hydraulic actuators can provide huge amount of power in a compact region of the robot so they are mostly used for large capacity robot. So that goes here in this, this is a rescue robot which is T5; which is manufactured by Tamsuk company which makes rescue robot of various kinds, so this is one of them you see it has linear actuators which are here which is hydraulic in nature which is here and which is here, so these are few places which you can at least see here, so this is just like an earth moving vehicle like bulldozers or JCBs that you find all around while construction works are going on it may be one of them which is automated through some remotely terry operated device so the things which you see down below is basically a suitcase kind of thing which robot operator can take it on the field where they have joystick for both the arms that you see here, this robot has two arms each one of them can be controlled using two different joysticks and user can see a live feedback, so you see this is the scale of this robot where it can do excavation task if at all there are some earthquake which has happened so it can remove the debris, rescue people and those kind of things can be done with this kind of robot.

So you see it is very very useful, however, it fits into a very different category of the robot which is run by hydraulic actuators and then everything comes at a cost, so even this one; because to generate hydraulic power, it has to have a hydraulic power pack that keeps the motor running continuously that keeps on developing the pressure for the actuators so it creates a lot of noise and it uses oil so, obviously there are some leaks which can happen and because oil fire hazard is there, it requires some sort of maintenance also. You see, let me just move here, yes maintenance is there because it has more number of parts. It needs a good amount of maintenance to be done and accumulated things; because of maintenance, there is manpower requirement, and so on

and so forth. So that is the hydraulic actuator-driven robot and then finally is the last one which is a pneumatic kind where it is like a soft cushion it is just like a pump if you have seen a cycle pump it is very similar to those kinds of actuator where instead of getting air out of it you push in air and your actuator will go out. If you pull out the air, it will come back. So that is the way it is driven. So this kind of robot can develop very high speed in a very short amount of time. It can be very very compact because no actuators are there but there is the compressed air bottle which is kept somewhere else and you see this kind of robot can also work but the only thing is you have to be a bit careful because air is compressible in nature; so what happens, because of compressibility it loses some sort of precision and over increases in some sort of temperature. What can happen? This air can expand. So that will create some sort of drift and those are the related issues with this kind of robot so yes pneumatic robots are there and there are some non-conventional sources like nuclear submarines. They use teleoperated robots sometimes to maintain the outer periphery of the skull hull of your vehicle. Sometimes, in space exploration, you have robots that go out into space and do some maintenance job to your vehicle, the solar panels of the space robots.

They are normally run by solar power, although all of these look like non-conventional robots, which run with different kinds of electrical power sources; but all of them are electrically actuated robots, why? because essentially all the robots are run by motors. Motors are driving power out of nuclear sources, solar panels, or some kind of other non-conventional energy source. Energy is different, otherwise, essentially they are all electrical actuators.

Based on Workspace Geometry: Mechanical Structure (ISO 9946)



So this is one of the broad classifications which is there and you see, based on the workspace geometry that also is a requirement of ISO 9946 that says to include this in the technical specification of the robot, that is as a name- they call it a mechanical structure of the robot. So it can go like this- a few of them will go into very much detail for each. Now let us begin with the Cartesian robot which is PPP type, what does it mean? It has three prismatic actuators if you see carefully this robot, this is the arm which has an actuator that can move in this direction. Another one can go in this vertical direction, third one can move in this direction so essentially it has an X axis, it has a Y axis, it can also move along the Z axis so, all three axes; this arm can go.

So effectively, it can go anywhere in space covered by a rectangular volume. So they are very good for heavy loads in the industry. They are simple, and easy to understand because you can judge if I am going two meters along X it is two meters along X, nothing else right? So that is very easy to understand, sometimes easy to program because of this reason also. Another very important kind of robot is a cylindrical robot. Only the first axis has changed, these two are the same.

So yes, you can change the height of your arm and the radius of the cylinder by changing the extension of your arm and the first axis, instead of having something like this. This time it can rotate. I will show you the video in the next slide, so this is essentially covering a cylindrical workspace denoted as RPP-Revolute Prismatic Prismatic, prismatic actuators are linear in nature, they can go back and forth whereas revolute axes are just like motors which can just rotate. So it has two kinds of motion - first is revolute, this is revolute, this is prismatic, this is prismatic. So yes, the third one is a kind of robot which

is RRP-Revolute Revolute Prismatic, So the first axis is a rotary one, the second axis is also a rotary one both the axes are orthogonal to each other and then you have an arm which can extend.

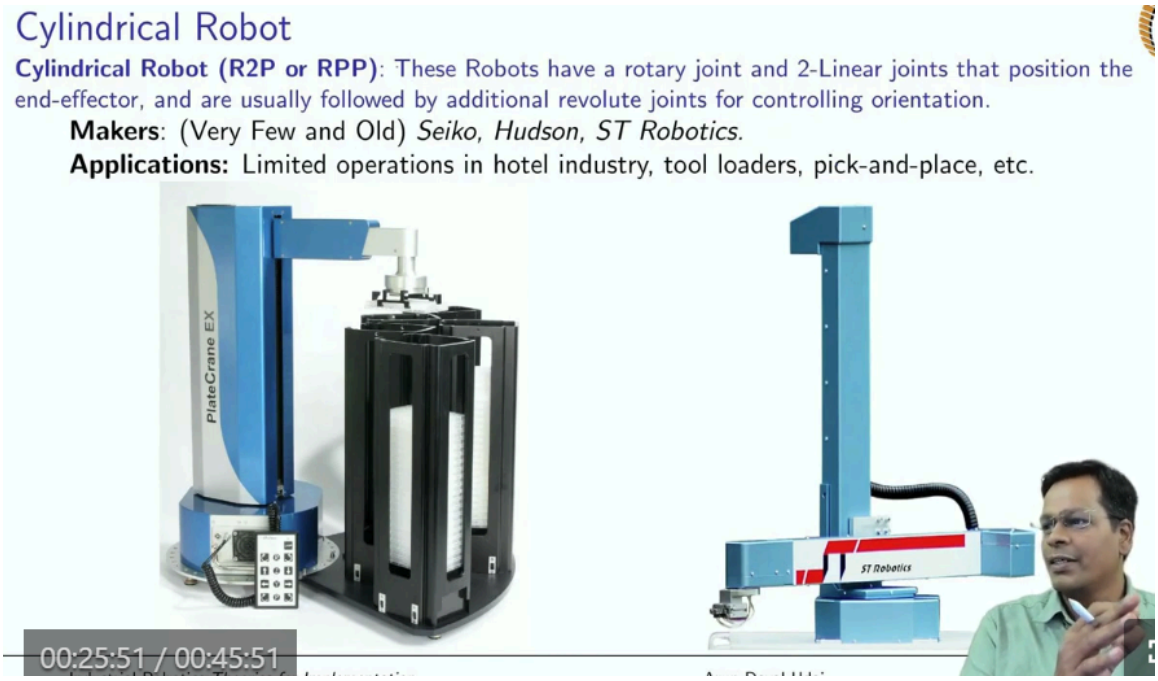
So this will change the radius of the sphere it can cover. So workspace is something like a sphere, So two revolute axes are one prismatic, it has a very large range but is very uncommon in the industry. Last but not least one that is the articulated arm robot which you have seen so far in our video, application video also where you have the first axis which goes like this you have multiple axes or and one of the other one after the other, just like our arm they are fitted. So you have multiple axes One you have a link, you have a joint, you have a link, you have a joint, you have a link, another joint; It forms a serial chain effectively, so that is what is articulated arm all about.

Cartesian Robot

You saw it just here, this one. You saw it just here, so this is the one. So it has three, these robots have three linear joints that position the end effector which are usually followed by an additionally revolute jointed joint for controlling the orientation it can go to any position X, Y, and Z so it can effectively go to any position in XYZ in a Cartesian volume. But yes now that you have reached there, you have to do something to do something, sometimes you need to orient. So, I will just show you one of the videos here just look carefully at this robot, and what it does. So it has an end effector that can orient, Orient, to make itself always normal to the surface where it works.

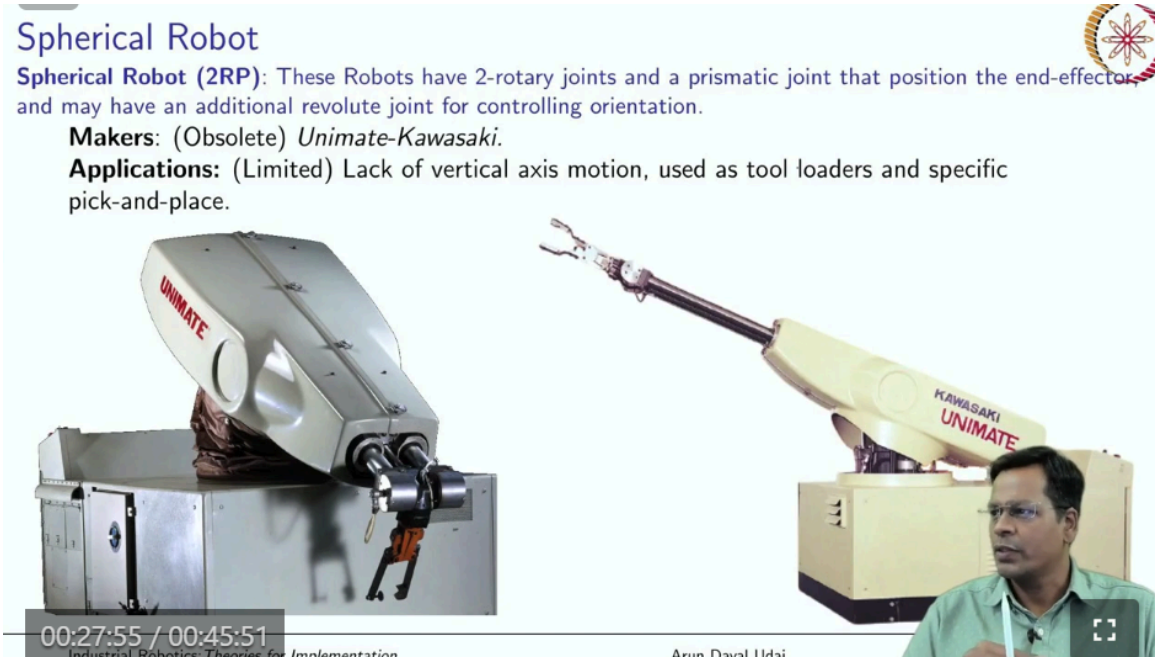
Let's say it is doing some spot welding operation it is doing some laser burning operation, applying glue, or anything similar, you see, the last one is just an orientation tool that is attached, which is to orient; Otherwise, it is just a gantry this is how it is operating. They are very common to do any sort of inspection CMM machining laser cutting, pick and place tasks, sometimes loaders and all there are many makers. I have just listed here which makes it. The one you saw here is of KUKA, but other companies are also making it. A few are - Bosch, Rexroth, at Motec Pro-Mart IAI fibro. These are a few manufacturers.

Cylindrical Robot



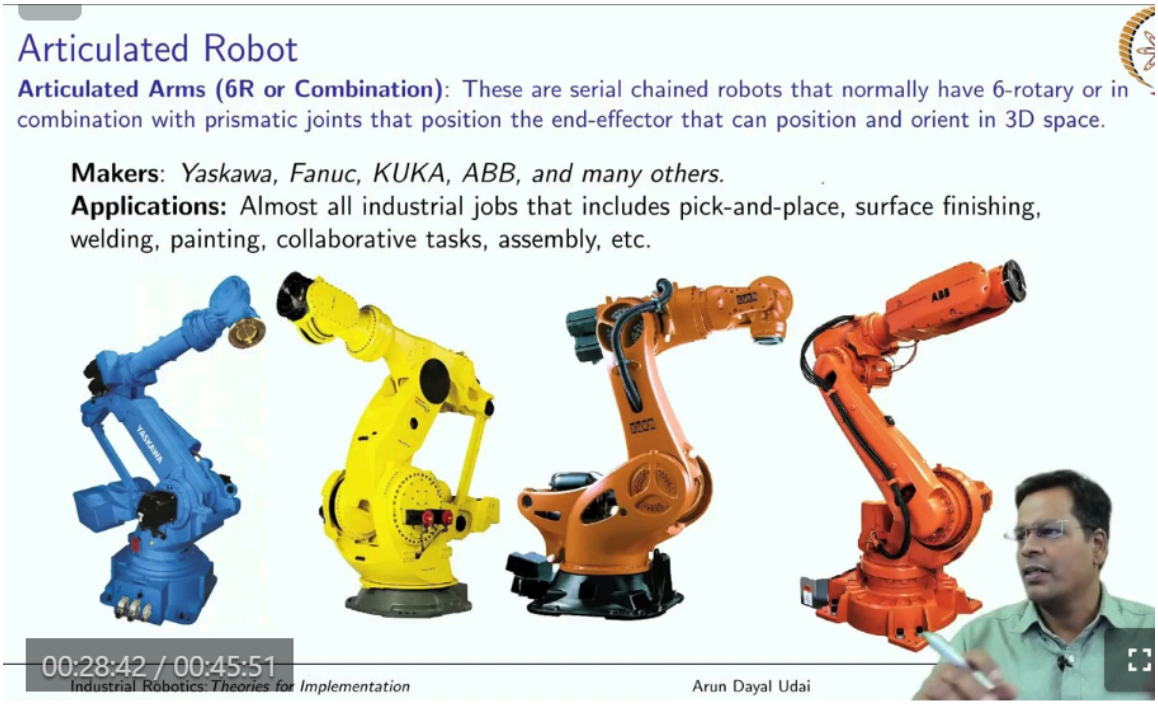
So, now this is the cylindrical robot, this looks like a physical robot like that was a cartoon of it like the simple line diagram of a similar robot that I have shown you so it is an RPP robot, in short form it can also be called as R2P so 2 times P these robots have a rotary joint and have two linear joints that position the end effector and usually followed again by additional revolute joint for controlling the orientation Again, a short video will suffice it, you just see how it works first axis is the rotary one, the second one is taking it up and down, the third one is the arm itself that can extend, goes back and forth. To increase the radius or decrease the radius. So essentially, it has a cylindrical workspace, but because the radius cannot go to a zero value, that is a hollow cylinder. This is how it works so very few makers are there Seeco, Hudson, ST Robotics and very limited operations are there, so it is used primarily in the goods industry, two loaders pick and place tasks can be done too, because it has just three plus one degrees of freedom; so it is very inexpensive to be used for those reasons got it. So yes, this is the oldest one this is already the robot which was the first robot which was there in the industrial category.

Spherical Robots



So this is a spherical robot 2-RP. These robots have two rotary joints and one prismatic joint that position the end effector and may have an additional revolute joint for controlling the orientation. Makers are Unimate-Kawashaki. This is already obsolete, you do not find this type of robot anymore in the industry, and applications are limited due to the lack of vertical axis motion. There is no axis that can make it go vertically up and down, so this type of robot is lacking; it is used as a tool loader and specific pick and place tasks. So, these are a few robots of its kind.

Articulated Robots



Finally, the articulated arm robot 6R has Six revolute joints or in combination with prismatic joints so you can have revolute revolute prismatic revolute so that could be there but most of the time in industry I have seen all revolute jointed robots are there these are serial chain robots and normally have six rotary or in combination with prismatic joint that can position the end effector as well as it can orient the end effector in a space. Major makers are Yaskawa, FANUC, ABB, KUKA, and many others, which are there. Applications are in almost all industrial jobs that include pick and place, surface finishing, welding, painting, collaborative tasks, grinding, polishing, assembly tasks, etc can be done with this kind of robot, so this is how it looks like, you need no video for this because in the first class, I have shown you plenty of these robots so we'll be working more, most of the time on this.

Based on Degrees of Freedom (DoF)/ Number of Axis^2

So, this is one broad classification again, which is based on the degrees of freedom or you may call it the number of axes; in the case of serial chain industrial robots, both are almost the same because very few times degrees of freedom are not matching with your number of axes, we will discuss this very much in detail, while we will be discussing kinematics of the robot. So, yes it can be a planar robot. Simply a planar robot is your engineering drafter. You should just think how many degrees of freedom it has. It can go

anywhere on your engineering board. It can go anywhere, so - any XY position, it can attain.

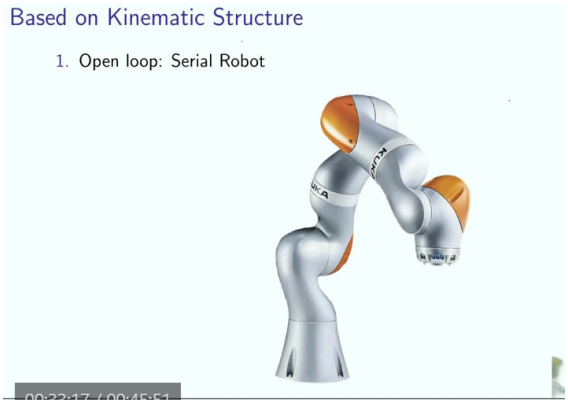
The third one you can do you have an angle set square kind of thing which can orient over there no once you reach there you can change the angle so that was the third degree of freedom which your engineering drafter can attain, So that is a planar robot, it can be two degrees if you just want to reach there or otherwise you may have an additional rotary revolute joint over there. Special robots: mostly they are of three degrees of freedom, pure translating, or a combination of translating and rotating joints. Six degrees of freedom can be three translations (+r orientation); a minimum of three degrees of freedom is required to make your robot go anywhere in space XYZ. Then, you need three more degrees of freedom to orient your robot. So, this is the requirement of having six degrees of freedom, and then you may have a redundant robot that can have more degrees of freedom essentially in space. Once you go into space, you can have six degrees of freedom, maximum. You can either move in all three directions or you can orient in all three directions so the maximum that you can obtain is six but on the input side, the number of joints can be more than six in that case it is a redundant robot there are few robots which are there, which has an infinite number of solution just to go to a place, So that is the advantage of having such robots, they are redundant robots. We will discuss them also, so there are a few special kinds of robots, which have just four degrees or five degrees of freedom. You don't need all the degrees of freedom for any kind of job. You may be just needing, like for your engineering drafter you just needed two degrees of freedom you don't want three degrees of freedom, you have to be on that plane all the time so you don't want to have more than four or five degrees of freedom. So that is the need for that. So yes, for limited degrees of freedom; robots are for special purposes like for the land of the electronics industry when you just need to pick and place vertically I see circuit components and you just have to place it on board; Kara is quite good enough; so this is one of them. You can further classify the open-loop serial chain robot based on the kinematic structure.

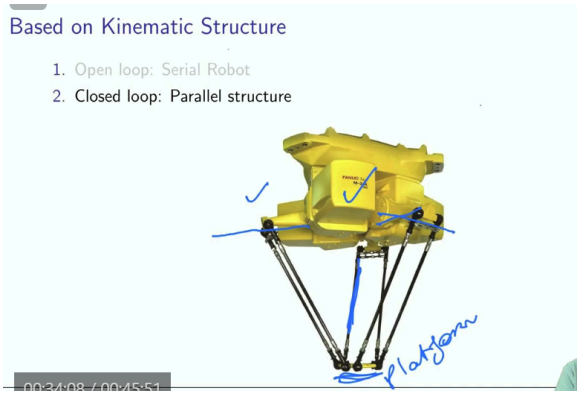
Serial chains are nothing, as I have just been told it is like your arm. You have a link, you have a joint again, you link another joint- you have a link and a joint; so on and so forth that makes and finally it terminates with a flange. Flange can have a gripper or any tool robot should have to perform a particular job. So that is a serial robot and you can have a closed-loop kind of robot, which is a parallel robot. Over here what you see has multiple actuators and a platform, so this is the platform that can move and then you have an actuator, which is over here. You have an actuator which is here, you have an actuator which is here, so all the levers all you can move and finally this can go up and down, this can move and that makes this platform go anywhere along X Y or Z directions, So this is a parallel robot when all the three are moving simultaneously, I will show this in

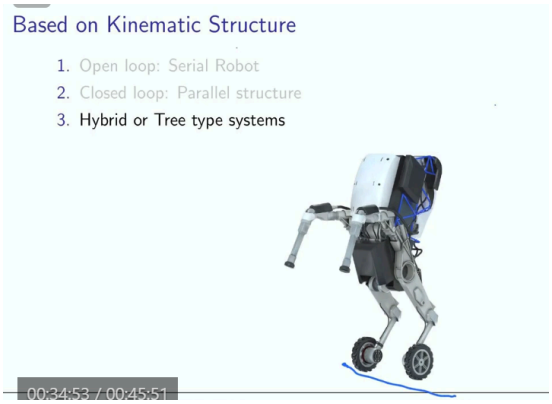
operation while I will be discussing serial and parallel robots in one of the lectures, just in this module. So this is a parallel robot and this is a kind of hybrid or a tree-type robot system, when you have a combination of all these as long as this robot is on the floor, this is Boston handle if you have seen the video. So it has wheels too, it can manoeuvre at very high speed on the floor if the surface is flat, so it can move at very high speed. That's why it takes advantage of that as long as both the legs so it can apply brakes to both wheels. Now it has become a legged robot, so that is what is making it a hybrid robot. So, it is a wheeled robot as well as a legged robot, and as long as both the legs are on the floor, you see it is like this; So, this is your floor, this is your torso where your joints are there, so this is a body and then you see what is it. Two serial robots are effectively connecting this platform; what is this? This is a kind of parallel robot as long as both the floor and both the legs are on the floor and then you have two serial chain robots which are open robots just like your arm and it looks like a tree. You have a trunk and branches that can move in it, so it is named like a hybrid or a tree-type system

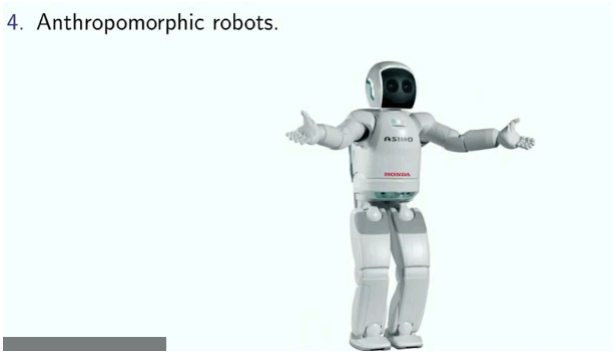
.

Based on the Kinematic Structure



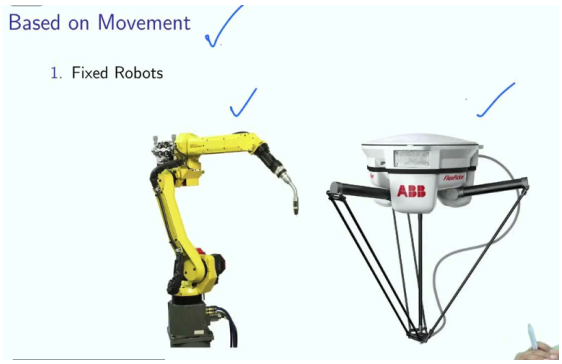


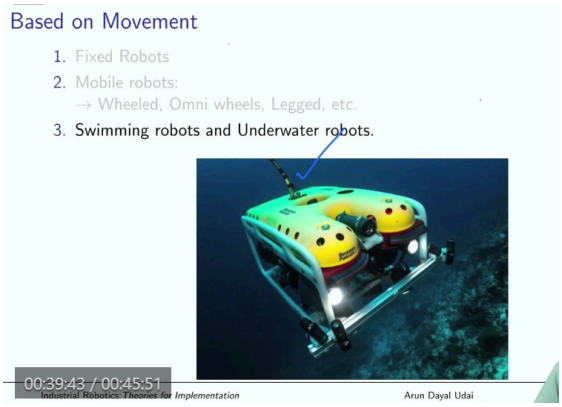




So this is based on the kinematic structure; you can further classify the robot as open or closed chains. Each has its advantages and disadvantages, two of which we will discuss in detail. At least serial and parallel robot in the next lecture and tree type system is beyond the scope of this syllabus but still, you may find plenty of videos for these kinds of robots. So there is a robot that fits into your imagination of having a robot in your home that looks very much like a human; you see it can do all kinds of jobs normally can be programmed what normal human can do. So it can take care of a child, it can look after some elderly people, it can serve you dinner. So, it can be programmed for various things: it has various types of sensors and arms very similar to your arm. It can be programmed for anything, but it is not right. So there are always facts. So these are some kind, so all together it goes like this.

Based on Movement

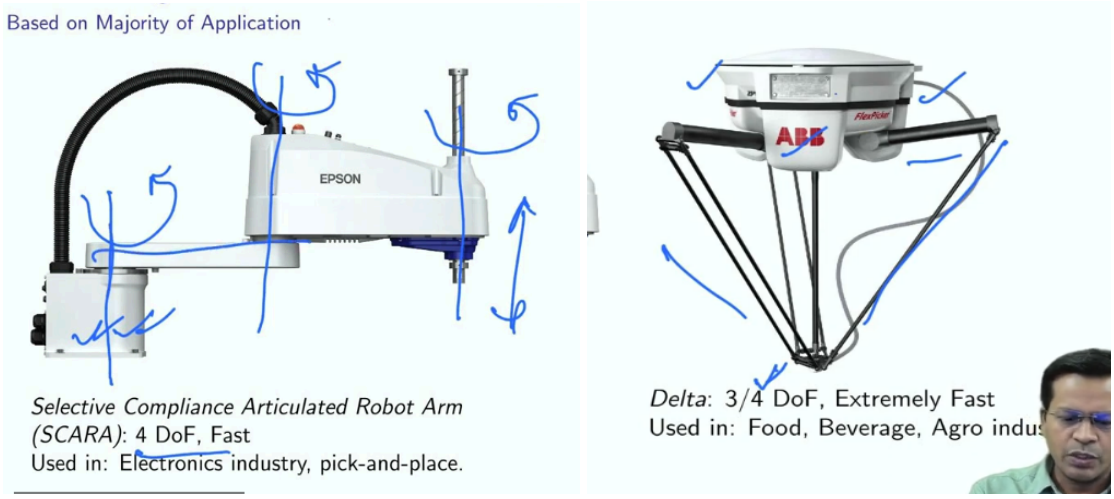




So that was based on the kinematic structure of the robot and then you have a fixed installation robot based on the movement. Based on the movement, I am classifying because these two robots fit into the.. see, one of them is a serial robot; one is a parallel robot. So they already fit into one category, but this category: when we start classifying based on the movement, these two robots are based robot; it is mounted on the floor, hanging from the ceiling. So both of them are fixed, the robot is not moving right. So that is why, that is there. Then you have mobile robots, which may have wheels; which may have been, the one here is a Mars Rover. It has wheels and even this one it has wheels. This is a KUKA OMNI robot, which has multiple OMNI wheels that make it move along the XY plane. This is again, a legged robot with a quadruped normally and it has an arm also, so it is a serial chain and it has legs, so it is a pedal robot; also you can say a quadruped. So it is a quadruped robot with four legs, all mobile robots. They are not fixed to any place and can move anywhere in your location. So yeah, another big classification is the Swimming robot. It can swim on the surface or it can go inside the water. Some exploration can be done, you might have seen on National Geographic or Discovery Channel that they are mostly teleoperated robots, which are connected from a base, which is floating on the top and that is a ship. From the ship, it is connected using a tethered cable like this. The cable connects and remotely operates from the top, so it may

not fit 100% like a robot. It hardly does few things only using autonomous mode; otherwise, it is mostly a teleoperated robot, but it can go into the wall inside the water. so it can move inside the water, so it fits into this classification. Another big one is aerial and flying robots. You must have seen nowadays at parties and all, these types of cameras are shooting you. So it has a camera, which is here. It can fly, it can manoeuvre, it can float anywhere in space XYZ, and it can carry some payload like a camera and some sensors. Nowadays, it can be used as a drone delivery of couriers or food packets. It is used for military surveillance and many other things, so this is your aerial robot with flight. Now based on the movement, you saw all these kinds. There are many other classifications that can also be formed one huge one is based on the application ISO 9946 also says your robot manual / your data sheet should mention the application for which this robot is designed. Based on the application, you also can classify your. It can be industrial, it can be domestic. If it is an industrial robot: it can be painting robot, it can be arc welding robot, spot welding robot, etc. We'll talk about mostly industrial robots from now on.

Broad categories of Articulated and Parallel Robot



You find, not just all kinds of robots in the industry, but there are a few broad categories of robots you see in the industry: Articulated armed robots and Parallel robots. So most applications are of this, that uses these kinds of robot. One is a selective compliance articulated robot arm carrying four degrees of freedom. In a robot, you see it has the first axis, which is like this; the second axis, which is like this; rotary rotary and the third one has two rotary as well as it can go up and down, so if it can take your robot anywhere in XYZ. It can rotate at that point of location where it can reach, It is used mostly in the electronic industry for any pick-and-place task. This is a four-degree-of-freedom robot, but it still suffices for that particular job. Why? you don't need to roll or you don't need a

pitch when you are doing the pick-and-place operation, you don't need to roll or you don't need to pitch. You just have to go vertically downwards and you have to go vertically upward and put it somewhere else. That is the reason it is used mostly and they are very very fast, most of the actuators are sitting here; so that is the reason, because actuators are one of the heaviest parts of the robot. If it is non-moving along with the arm, that can be very fast, so it is driven by belts if you can see. It has a belt, so it comes here finally. This also has a belt, so these two axes are driven from the same location, that is here and everything is because it has fewer degrees of freedom and fewer motors, so it is very light and fast again. The Big classification you know is a delta kind of robot I have shown earlier for fun. This is a trade-off Delta, but it can be a four degree of freedom if you attach a gripper, that can rotate its axis. You can go to any XYZ place and orient it vertically in the vertical axis. You can rotate these again, they are very very fast. It has all the actuators that are fitted, here it has three actuators commonly known as a Delta robot. They again are very very fast because the links are very very light. They are sometimes made up of composite fibres and are extremely fast, So they are used mostly in food and beverage and agro-industries. Yes, that's all for today in this class. So what you have seen? Now you can classify a robot based on the type of architecture, and its type of degrees of freedom. It has the way it is powered, so we discussed all those things today and a few of them were requirements of ISO 9946 to be mentioned in the industrial data sheet. A few of them are not like hybrid robots, there need not be specific rules for many such robots, at least for anthropomorphic robots and all. So what you should mention and what you should do is not a prerequisite, but yes, you have learned that now, and in the next class, we will discuss mostly serial and parallel robots, two broad classifications. The way you saw and this was serial, this is parallel. We will talk further about this kind of robot in the next lecture. That's all, thanks a lot.