Computer Integrated Manufacturing
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Lecture – 32
Industrial Robotics

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Robotics is a very interesting topic. Today you see almost all the school going kids are fascinated in making a robot, and today there is a lot of advancements which are happening in robot and robotics technology. So, in this course also and in reality in computer integrated manufacturing, robots play a very important role. They play an important role in terms of assembly, in terms of painting. So, they can be robots can be used in a painting station, assembly station, cleaning station as well as material handling.

So, robots can be used for spot welding, robots can be used for painting, robots can be used for seamless painting, robots can be used for inspection also today. So, the robot plays a very important role, when we talk about computer integrated manufacturing.

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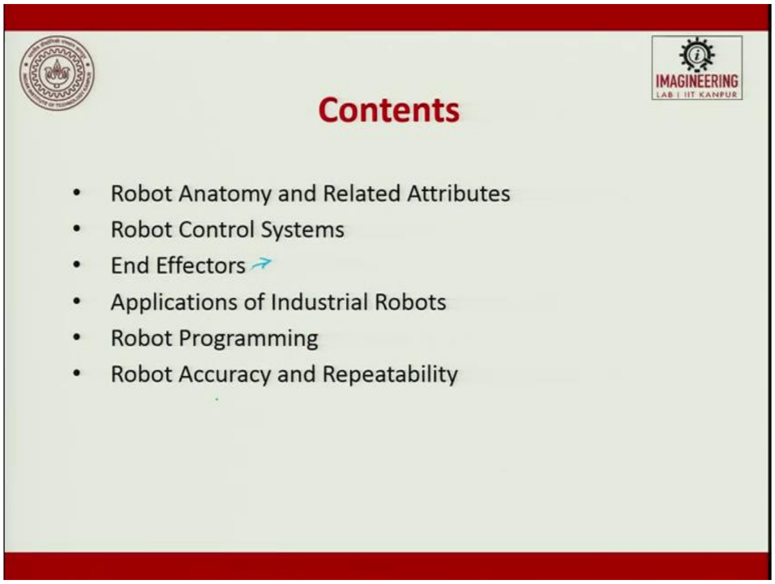

So, here the content of this lecture is going be; Robot anatomy and related attributes. We will talk about robot control systems and what are the different end effectors. These end effectors play a very important role. For example, we were just discussing about a tree cutting robot. So, you change the end effector.

You can use the same robot for multiple applications. So, next is the application of industrial robots, then robot programming a little bit, and then finally we will talk about robot accuracy and repeatability.

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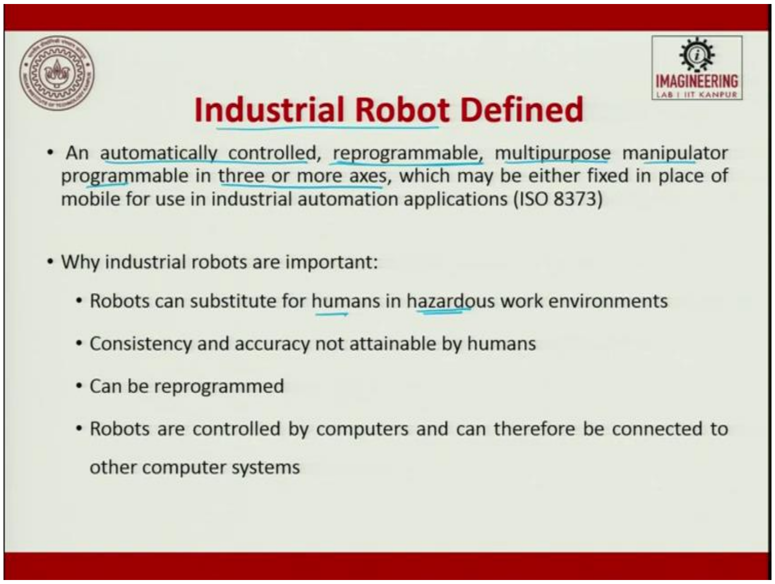

When we talk about industrial robots and automatically controlled, reprogrammable this is a very-very important word. Multipurpose manipulator programmed in three or more axes, which may be either fixed in place of mobile for use in industrial automation application, is the definition for industrial robots. So, the important things are automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes; this is very important.

Why industrial robots are very important? Because the robots can substitute humans in hazardous work environment. Hazardous work environment means we can also take it environment which is not so conducive for human or it can be even fatigue cycle. So, consistency and accuracy not attainable by humans because of his tiredness, then it can be reprogrammed. Robots are controlled by computers and can, therefore, be connected to other computer systems. Such that the data can be transferred quickly from on the go communication, can happen from one computer to another computer and this can work.

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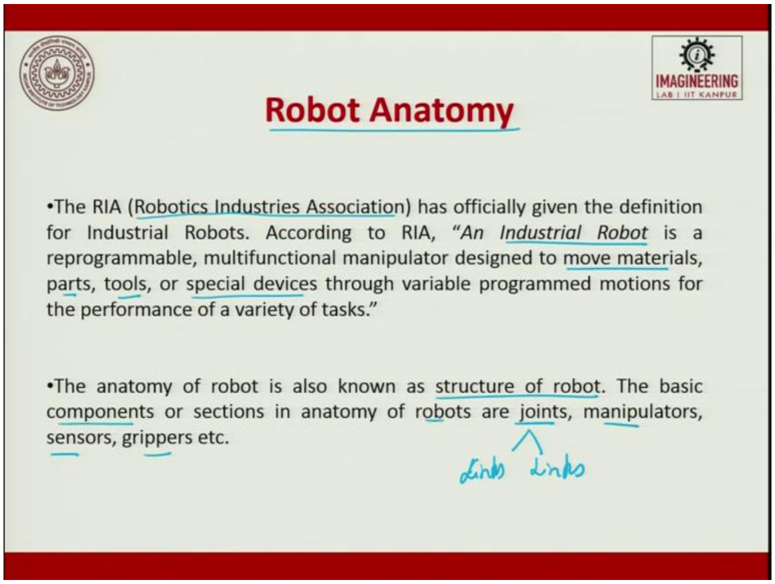

So, this makes industrial robots a very important member of computer integrated manufacturing. When we talk about anatomy: The Robotic Industries Association has officially given the definition of industrial robots. According to RIA, "An industrial robot is a reprogrammable, multifunctional manipulator designed to move materials, parts, tools or other special devices through a variable programmed motion for the performance of a variety of tasks." This is the RIA, Robotic Industries Association gave definition for industrial robots. The first one that we saw was a little generic so it is very precisely given.

So, what are the manipulator's job it is supposed to do? It is supposed to do move materials, parts, tools, special devices through a variable programmed motion for the performance of a variety of task. The anatomy of a robot is also called a structure of robot. The basic components or sections in anatomy of robots are joints, manipulators, sensors, and grippers. Joints are used to connect links; two links are connected by a joint. So, this joint can give you rotational motion or linear motion.

Then manipulator: The manipulator is the end effector, depending upon the job it changes. Then you have sensors, grippers, etc. So, these are the basic components of a robot.

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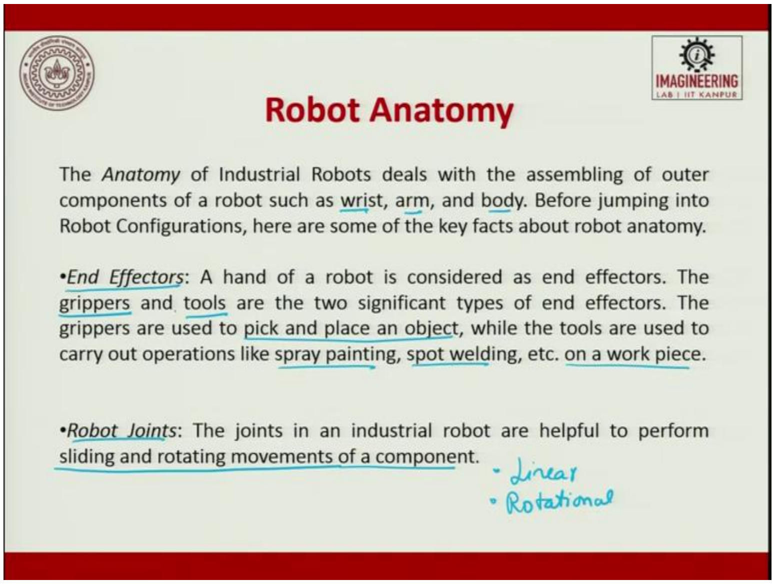

The anatomy of industrial robots deals with the assembling of outer components of your robot such as wrist, arm, or body. Before jumping into Robot Configuration, here are some of the key facts about robot anatomy we should know. End effector: A hand of a robot is considered as end effectors. For example, we talk this is an end effectors. So, this end effectors depending upon your requirements, it can do multiple operations like gripping, and then it can help in loading and unloading of parts.

It can be used for eating; it can be used for washing and so many things it can do, this is an end effector. The grippers and tools are the two significant types of end effector. Gripper which grips it; the tool is the, what is attached to the gripper. So, gripper and the tools are the two significant types of end effectors. The grippers are used to pick and place an object, while the tools are used to carry out operations like spray painting, spot welding, and on a workpiece. So, the end effectors plays a very important role.

So, the end effector has two significant types of end effectors one is for gripper and tool. What is a Robot joint? These are important anatomical terms which you have to understand. The joints in an industrial robot are helpful to perform sliding and rotating movement of a component. Two things, one is linear and the other one is rotational. Of course, if you combine these two you can also have helical whatever it is. But, if you can do these two operations like basic linear and rotational; so that is done by a robot joint.

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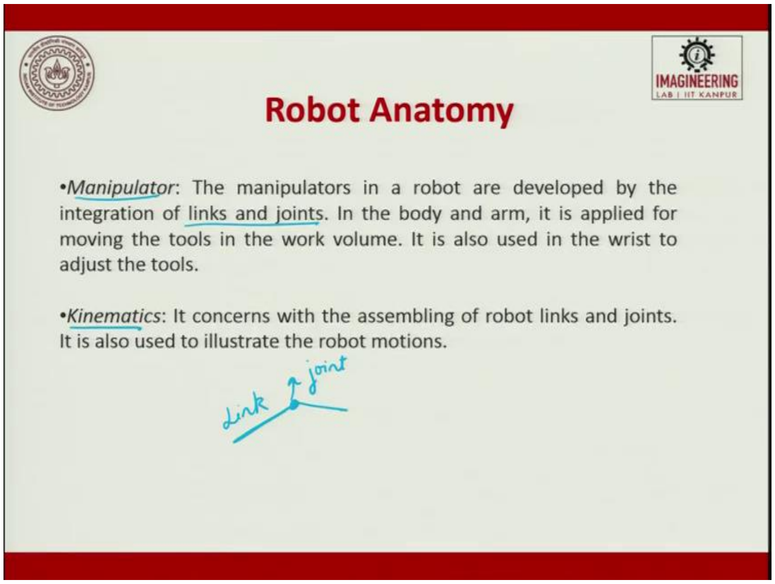

So, the gripper joint and next is manipulator. The manipulators in a robot are developed by integration of links and joints. So, links, manipulators are nothing but you have a link then a joint a link. So, this is a link, this is a joint; it is also used in the wrist to adjust a tool. Kinematics: It concerns with the assembling of robot links and joints. It is also used to illustrate the robot motion kinematics. So, four important things are very important in anatomy; end effectors, robot joints, manipulator, and kinematics.

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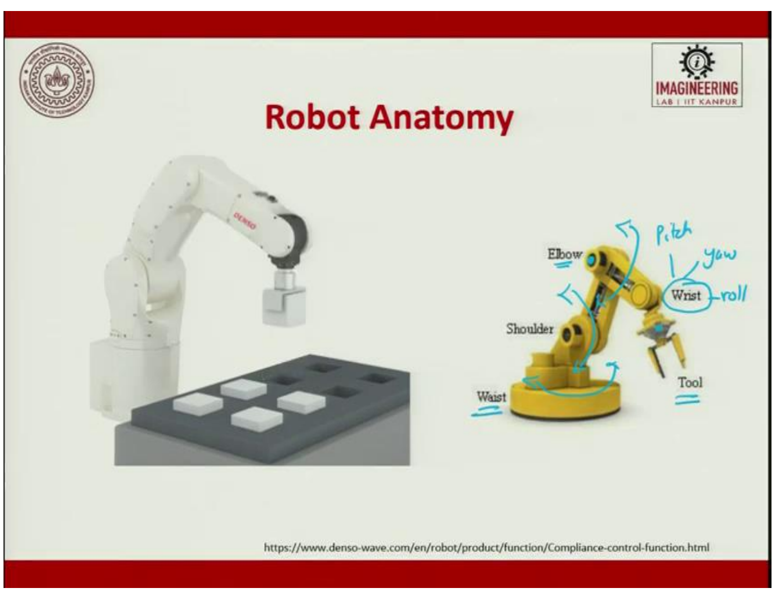

This is a robot which is used for pick and place. So, it can the toughest job is picking and placing it inside a slot. If I do not put the slot, then this is not a very tough job. The resolution or positioning accuracy is very important. So, when we talk about robots, we talk about accuracies, positional accuracy, and resolutions which in this lecture we will see what are those. This is a very challenging task. So, here is a robot which is used for pick and place, so here is a tool, this is a tool, this is a wrist. The wrist can rotate and try to do various operations.

What are the things? It can pitch, it can do yaw, it can roll. So, roll is rotation, pitching is moving up and down and yaw is moving left and right. So, all these things can be done by a wrist. This in combination with an elbow where there is again a rotational joint. It can move this up and down, then a shoulder this can also help to move up and down. This all rests on the wrist which can rotate; so now you see how many freedoms are there. Rotation about the base, then rotation about this axis, then rotation about this axis, then rotation about the wrist axis.

End effectors are the tools that are attached which are supposed to do the operation depending upon the requirement. So this is a pick and place robot.

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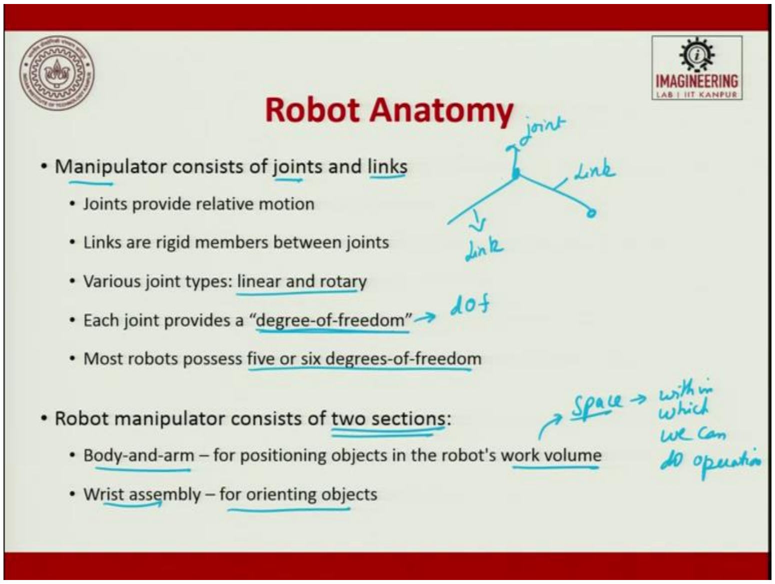

When we talk about manipulator; manipulator consists of joints and links. So, joints provide relative motion, what is relative? I had a link, I have a joint, I have a link. So, this joint is going to bring relative motion between these two fellows. So, links are rigid, this is a link; these links are rigid members between joints so this is a link, this is a joint.

Various types of joints are linear joint and rotational joints. Each joint provides a degree of freedom which is otherwise written as DOF. Degree of freedom is very important more and more and more degrees of freedom; it is more and more versatility the robot has to do a job. But, it is it will make it expensive, the stability is a problem; so all these things you have to have a tradeoff. Most robots possess five to six degrees of freedom, so generally, five degrees of freedom is good enough to handle a complex job. Depending upon a special purpose requirement; people have even gone a ten degree of freedom and twelve degrees of freedom.

So, generally, a complex job can be done by using five or six degrees of freedom robots. So, now this clearly tells and talks about the manipulator; manipulator consists of joints and links, and the joints there are basically two, linear and rotational. Link is going to come in between two joints, so this each joint is going to dictate the degree of freedom. So, there are five to six degrees of freedom attached to the robot. The robot manipulator consists of two sections; one is body and arm and the other one is the wrist assembly, for positioning objects in the robot's work volume.

What is the work volume? Space within which we can do the operation. We can do operations which are specific towards, work volume space. So, for positioning objects in the robotic work volume we will, that is a space where and which we can do operations. Wrist assembly for orienting the job, so two things please understand two sections. Body and arm so body let us take an example of a human body. Body and arm for positioning and the wrist for orienting.

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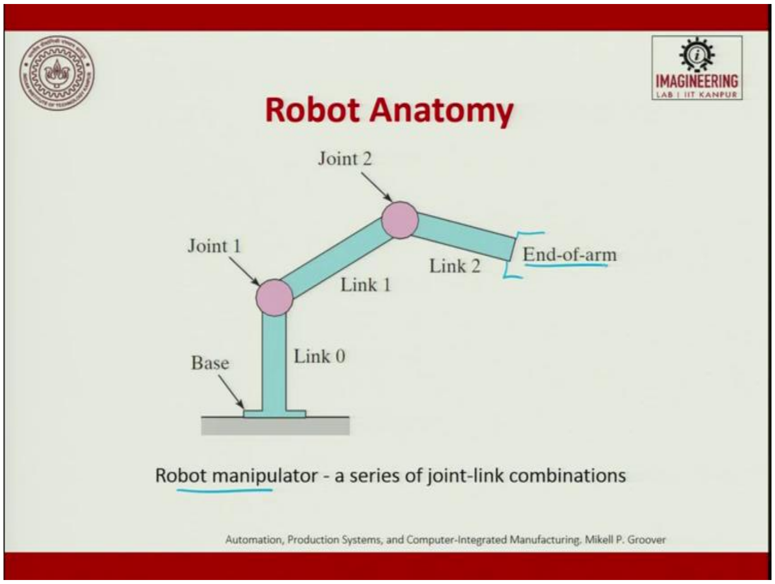

So, this clearly talks about whatever we have discussed till now.

So, robot manipulator- a series of joint link combination, is called as a manipulator. So, you will have a base, link 0, link 1, link 2, link 0 is attached at joint 1. Link 1 and 2 are attached at joint 2 in the end what we put is the end effector or end of the arm.

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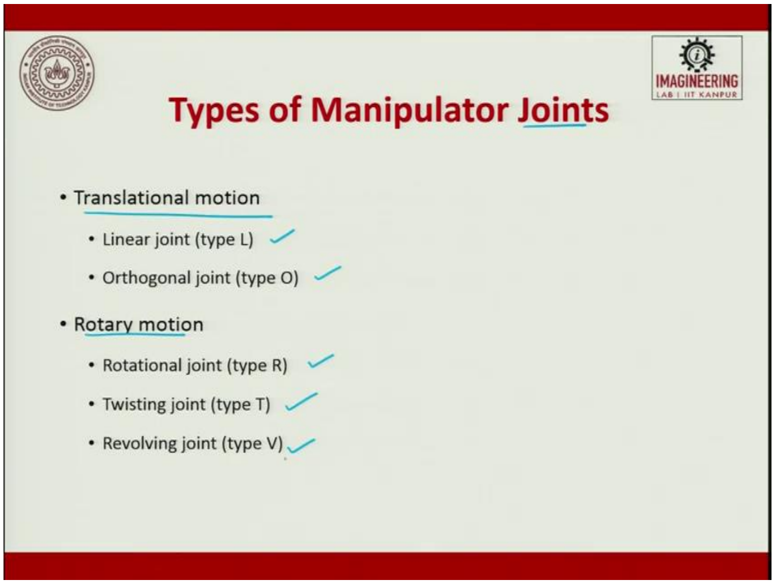

So, when we talk about types of joints we have two major classifications; one is linear I said translational, the other one is Rotational. In translational you will have two things: one is linear joint and the orthogonal joints. Under rotational motion, you will try to have rotational joints, twist joints, and revolving joints.

So, when we want to buy a robot the joints will be written in acronyms. When we write a linear joint, we call it as L; orthogonal joint we call it as O; rotational we call it as R; twist with T; revolving with V.

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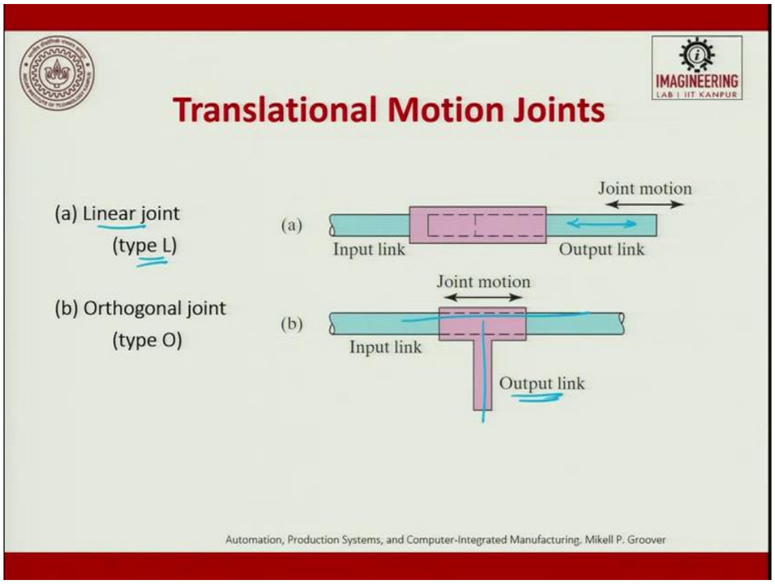

So, this is a typical linear joint, so link input, link output; so here is a joint. So, this is moving along this direction so this is linear joint. The next one is orthogonal joint, which is perpendicular, so you can see that orthogonal joint in link input and this is the output; so joint motion happens like this. So, these are part of translational; translational is to linear joints and rotational joints. By using several of these combinations of joints you make the body and arms structure.

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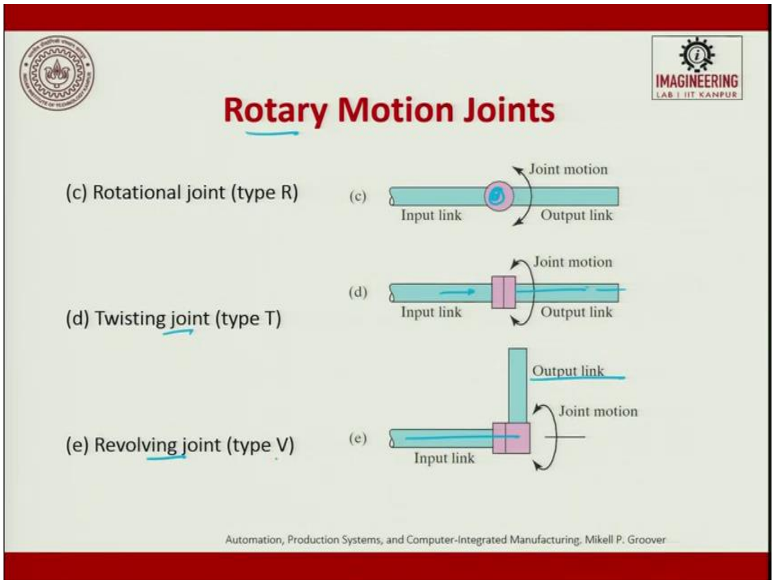

Then rotational, you have an input there is a joint which is fixed and this is able to rotate. So, this is a joint and then this swing in this direction; so this is rotational. Twisting is about this axis if it rotates; this is about this axis which is rotational and twists is about this. So, you will have a fixed axis and this rotates about the fixed axis. Revolving is you have this entire object the outer link revolves around this input link, so that is revolving.

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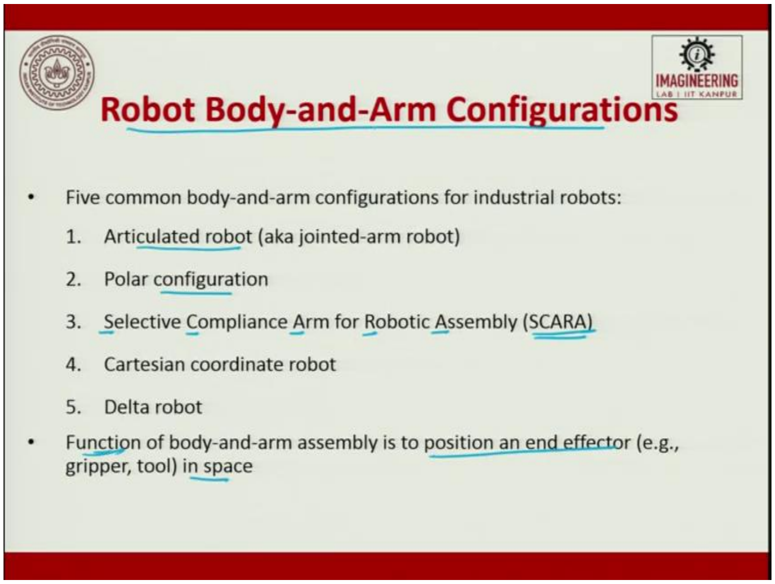

So, under rotational you will have rotational joints, twist joints, and revolving joints. The robot body and arm configuration, there are five common body and arm configuration for industrial robots. One is called as articulated robot, the other one is called as polar configuration. Then it is SCARA robot which is, Selective Compliance Arm for Robotic Assembly. A very commonly used robot for pick and place is SCARA robot. This is very important, this is the acronym supposed to remember this, Selective Compliance Arm for Robotic Assembly. Then, Cartesian coordinate robot and then you will have a delta robot.

So, these are the five robot body and arm configuration which are commonly available. The function of a body and arm assembly is to position an end effector in space. End effector in space, so this is the basic function of this body and arm configuration.

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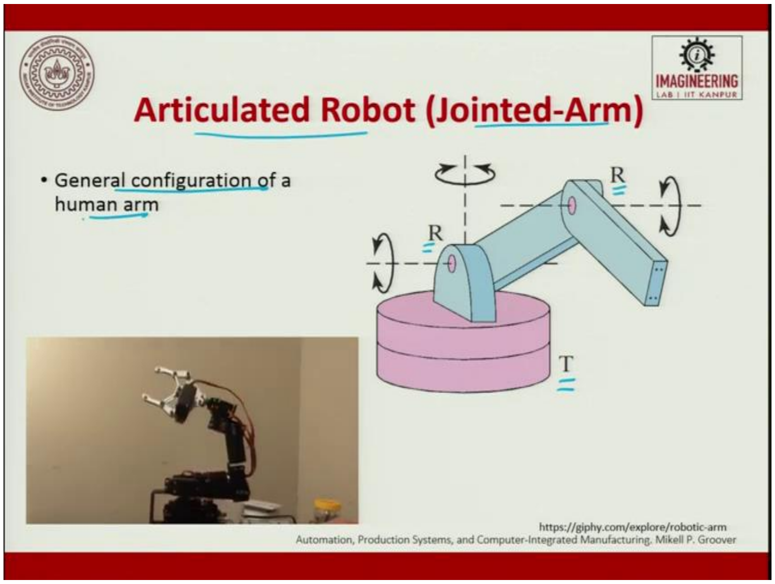

So, this is a typical articulate robot or the joint robot. So, you will have a base and when you see that please look at the acronym, this is twisting joint, rotational joint, rotational joint. So, if you go back twisting joint then rotational, rotational.

So, now on all the configurations will be written like TRR; so that means to say you have to put your understanding as: twisting, rotational, rotational. So, this is twisting so you can see one rotation happening here; this is twisting around here and then you will have one more rotation. So, this is an example of an articulate robot, its general configuration is like a human arm. So, what all human arm can do, this also can do. So, see you can do much more; but the only problem is, if you have more weight in the end effector it will topple.

Stability becomes a problem; so the biggest challenge is how do you make the manipulator? How do you make the links? How are you going to activate those links? So, here is typically it is pick and place or a grouping robots only. So, an articulate robot can otherwise be called a human arm robot.

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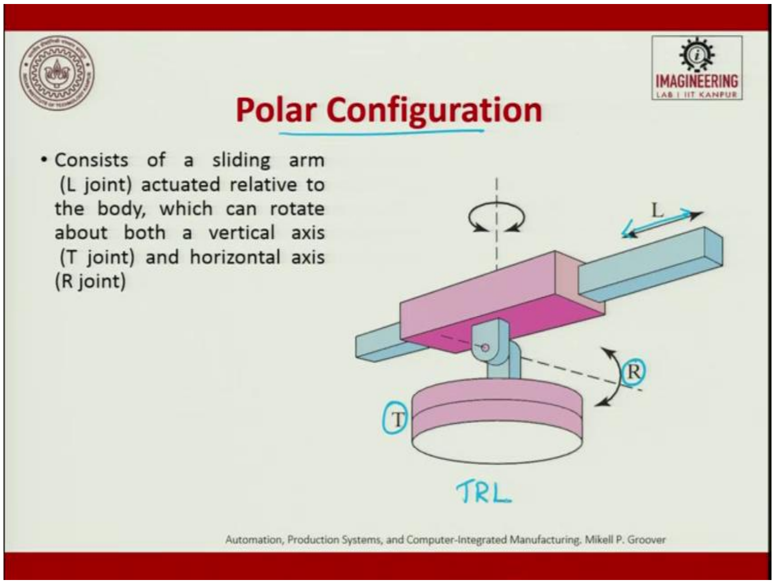

Next is Polar Configuration: Consists of a sliding arm actuated relative to the body, which can rotate about both a vertical axis and horizontal axis; so a vertical axis and a horizontal axis. So, this is LRR; so this is linear, rotational twist. So, here vertical axis will be T and the horizontal axis will be R. So, this is called a polar configuration body arm manipulator. So, this will be written as a TRL configuration.

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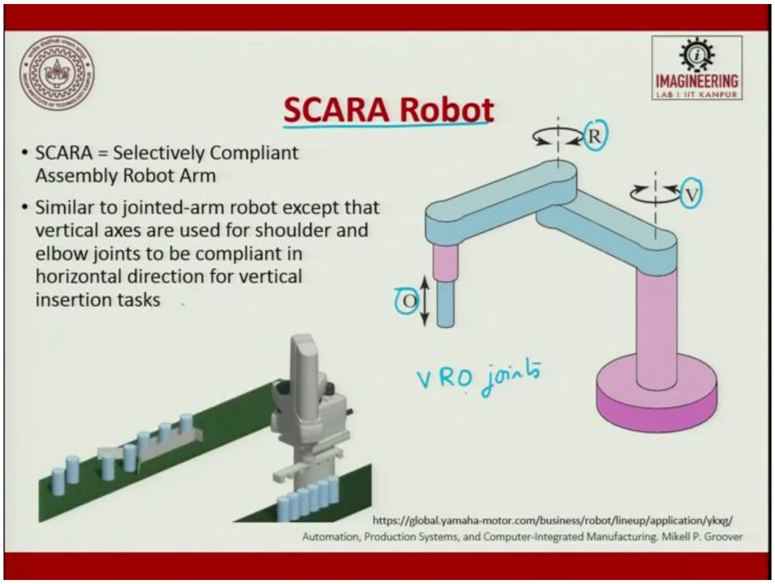

The next one that I was explaining to you is SCARA robot which is very commonly used. SCARA robot stands for, Selective Compliance Assembly Robot Arm. Similar to joint robot arm except that the vertical axis is used for, shoulder and elbow joints to be compliant in a horizontal direction for vertical insertion. This is the only change here as compared to the previous one. So, you will have a V joint, R joint, and the O joint. Let us see what are these V, O orthogonal is O, V is revolving. So, we will have VRO joints.

So, this is orthogonal, this is rotational and this is revolving. This is a very-very commonly used robot for assembly purposes. So, similar to a joint arm robot except that the vertical axis is used for, shoulder and elbow joints to be compliant in a horizontal direction for vertical insertion task.

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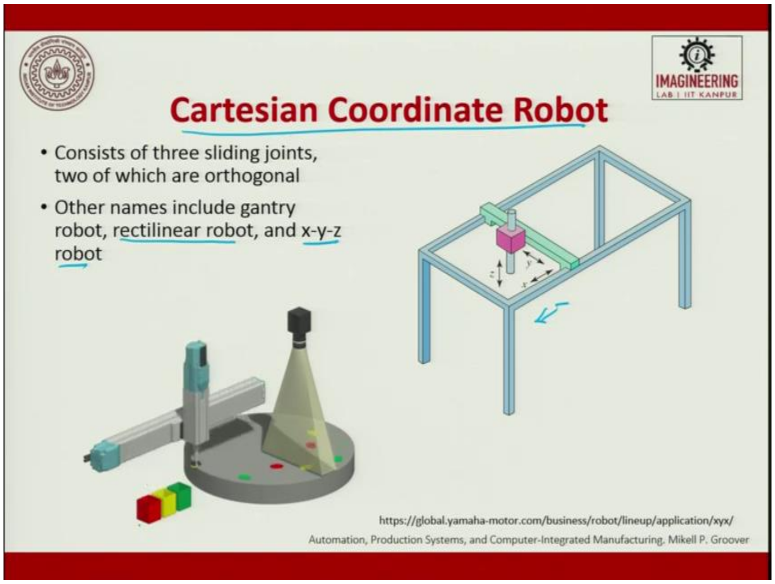

Next, is Cartesian Coordinate Robot; this is a Cartesian coordinate robot where we will have three linear joints x-axis, y-axis, and z-axis. So, all three are linear, so the work volume that it generates will also be linear. Rectilinear robot and x-y-z all are linear joints. So, this is basically used again for pick and place depending upon the sorting.

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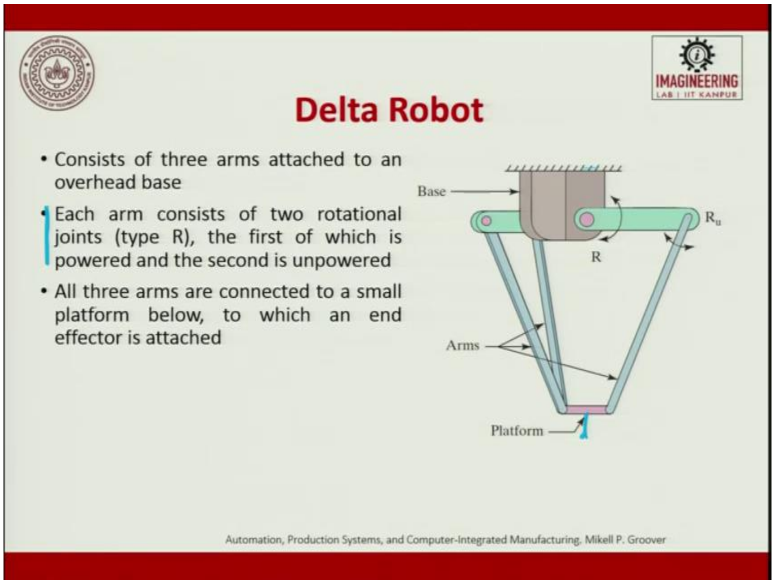

The last one is called as delta robot. Delta robot consists of three arms attached to the overhead base. This is an overhead base and each arm consists of two rotational axes. The first of which is powered and the second is unpowered, very-very important. So, one is powered and the other one is unpowered. All the three are connected to a small platform, this is a platform. So, you can have a drilling machine, milling machine or you can have a positioning device whatever it is.

All three arms are connected to a small platform below to which an end effector is attached, so the end effector is here. This is a delta robot. So, we saw five configurations, which is very important we should know. The articulate robot, polar configuration robot, then Selective Compliance Arm for Robotic Assembly robot, Cartesian coordinate robot, and delta robot. The function of a body and arm assembly is to position an end effector in a space. Then, comes the end effector, what operation you have to do is done by the end effector. Before doing it positioning will be done by the body and arm configuration.

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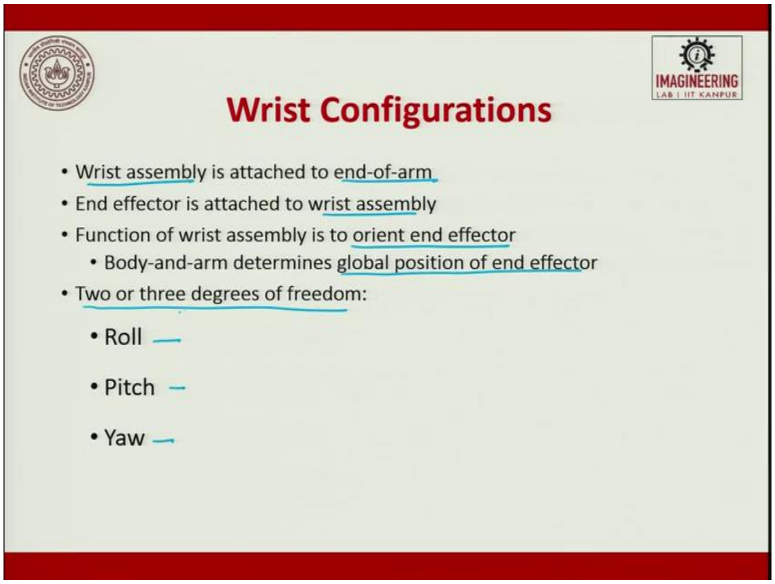

Now, let us look into the wrist assembly. Wrist assembly is attached to the end of the arm. The end effector is attached to your wrist assembly. The function of wrist assembly is to orient the end effector. Body and arm determine the global positioning of the end effector. The orientation of the end effector is done by the wrist configuration. So, you will have two or three degrees of freedom: roll, pitch, yaw. All the three, any two or only one, so you will have three degrees or two degrees of freedom.

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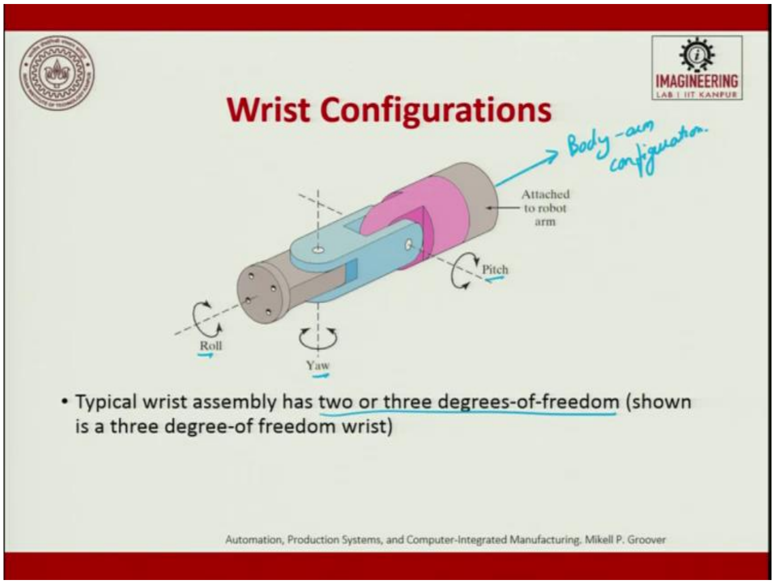

So, this is attached to body-arm configuration. And then what is happening is, this will be attached to your wrist. So, in the wrist you have the pitch, pitch is this motion which is pitch. And then you have roll, this is roll and then finally you have yaw. So, pitch, yaw, and roll all the three are rotational; pitch is this, roll is this, and yaw is this. Typical wrist assembly has two or three degrees or freedom. What is shown here is three degrees of freedom; you will also have two degrees of freedom. Just exactly pick and place you can have one degree of freedom also.

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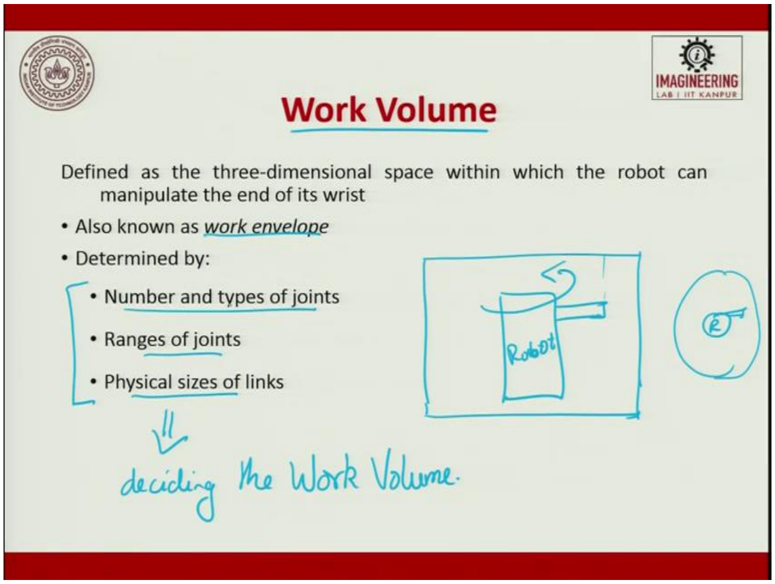

So, as I told you earlier let us try to define work volume. Why is it important? You have a robot here, this is a robot and now this robot has an arm. This will try to swing in this direction. Now, when this fellow completely in the robot completely swings, what is its working space? His working space will be something like this when you look in 2D. So, that means to say throughout the entire space he will go around and then he will start doing his operation. So much of space is called as the work volume.

Of course, here I have just put some safety stock but, it is there. When you look this is one side view and when you look from the top, it will be something like this. A robot is here and then you have this arm. So, you will have a cylindrical work volume, so what is a work volume? It is defined as a three-dimensional space in which the robot can manipulate the end of its wrist. Within the space whatever operations you want this robot can do. So, this is known as, work envelope. It is defined as a three-dimensional space within which a robot can manipulate the end of its wrist.

It is determined by the number and the type of joint, range of joints, and the physical size of the link. All these three play a very important role in deciding the work volume. Size of the link, range of the joint, and the number of joints.

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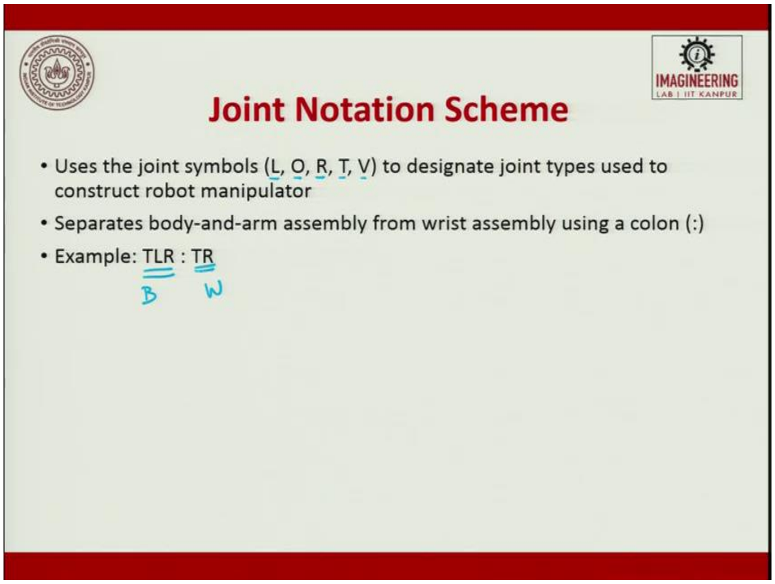

So, the uses of the joints symbol L, O, R, T, and V to designate joint type used to construct a robot arm. Separates body and arm assembly from wrist assembly using a code dot dot. So, you can see this is for the body, this is for the wrist. So, now if somebody writes TRL; this is for body colon TR it is for the wrist.

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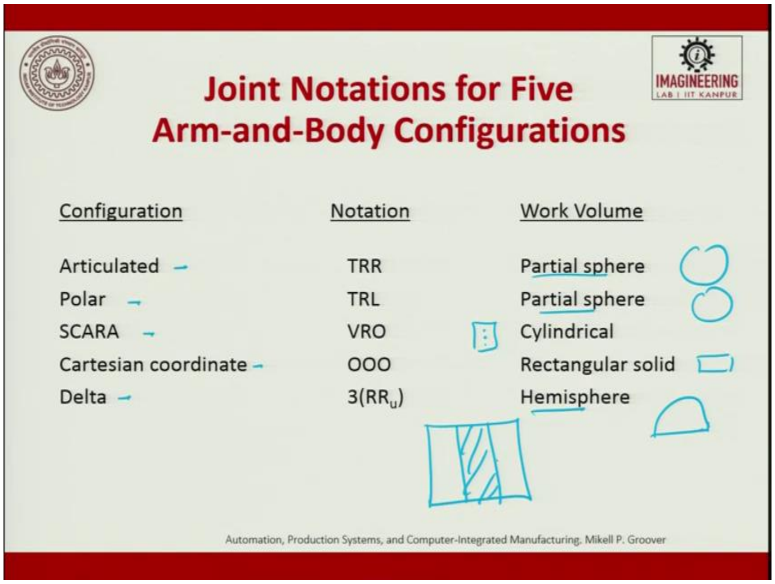

So, the joint notation for five arms and body configuration articulated will be TRR, polar will be TRL. SCARA will be VRO, Cartesian will be OOO, and delta will be 3 RR suffix u. So, what is the work volume? It is partially spherical, it is partially spherical, it is cylindrical SCARA, it is rectangular solid and this is a hemisphere. Partially sphere, partially sphere, and this is a hemisphere. This is a rectangle, this is a cylinder, so this is the work volume. Of course, in the work volume, there will be dead spaces also. Dead spaces means those spaces which cannot be accessed by the robot.

So, if you truly wanted to draw the work volume you might have something like this; this is a space where a robot is placed. So, within this space, it cannot work and this is the empty space where and which it is considered as the work volume of the robot.

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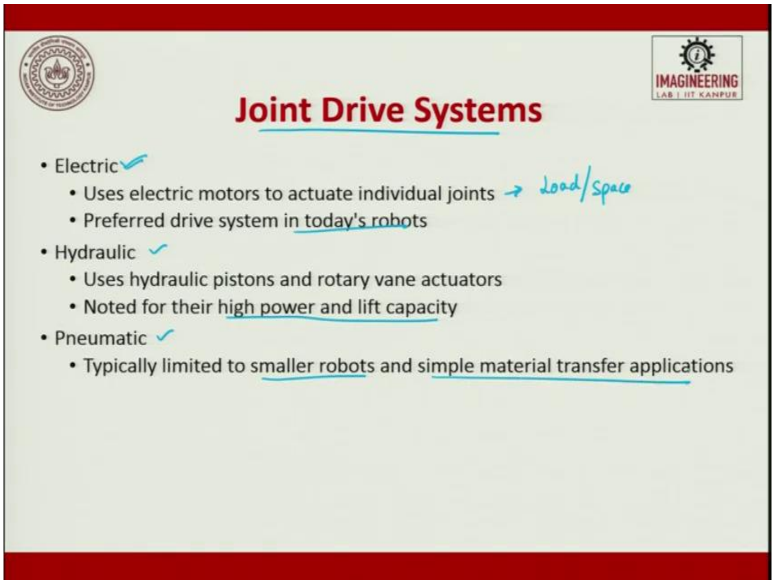

Joint Drive Systems: see you have now only put the joints. Now, each joint has to be activated, so how do you activate? This can be activated by three types. One, it can be done through electrical way; it can be done through a hydraulic way; it can be done through a pneumatic way. The most commonly used one is electric drive because its load per space whatever it is using is very high.

So, that it means to say it can carry heavy loads as compared to that of the space. Electric motors to actuate individual joints are very commonly used. It is easy to control; it occupies minimum space; it can have very high power; it is quick to respond. The preferred drive system in today's robot and it is very easy to control. You can control without even wires. So, electric motors are the most commonly used drive systems. When that load or the end effector has to lift a heavy load, then electric motors will get stalled and then high torque will burn the motor.

We might go for hydraulics, where the gripping load is to be done very heavy. The lifting load has to be 500 kilos or 100 kilos, then we will shift from electric to hydraulic. Use hydraulic piston and rotary vane actuators; noted for high power and the lift capacity. Pneumatics for very light load and very small robots are using is predominantly for pick and place or for linear motion.

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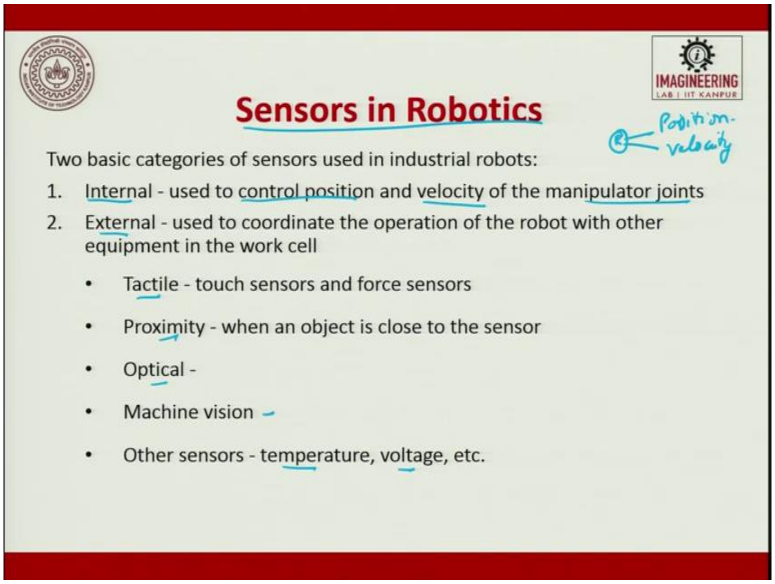

What are the different types of sensors which are used in robots? There are two basic classifications in sensors; one is called as internal sensors, the other one is called as external sensors.

In internal sensors, you will try to control the position and the velocity of the manipulator's joint. When we talk about any rotation we always talk about two items. So, this is rotation one is positioning, the another one is velocity; these two are very important. These two are the internal category of sensor which is used for the manipulator's joint. The external sensors used to coordinate the operation of the robot with other equipment in the work cell; work cell or work volume. So, it is tactile sensors which basically touch base sensors and force base sensors.

Proximity: when an object is present within the range; proximity and optical works on the same thing. But, optical here used light as a prominent sensing agent. We use machine vision the other sensors are temperature and voltage sensors. These are the external sensors which are attached to the end effector in the robot.

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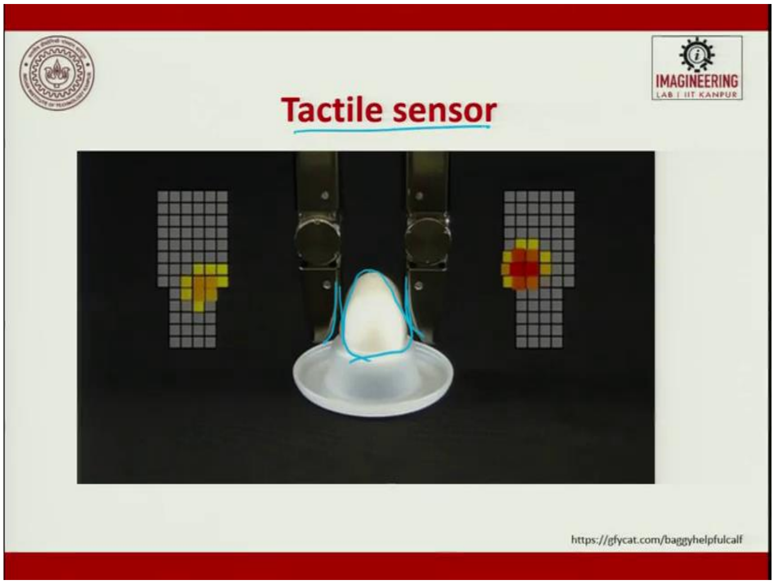

So, this is a tactile sensing device. A tactile sensing because lifting an egg is a huge challenge because an egg is not circular; it is not a sphere. So, it has a shape which keeps changing and there is a radius and here the gripper if it is flat. You will never get a proper contact.

So, what they do is? They try to have an inverse of it and then that when it touches, it has to do. When you apply a lot load, the egg gets shattered. Tactile sensing is used today; these are tactile sensors which are attached to the end effectors.

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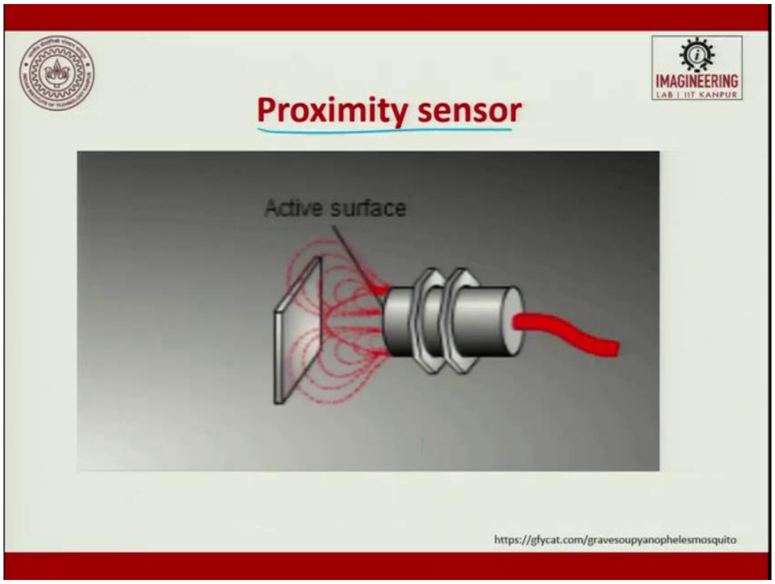

These are proximity as and when the current passes through or voltage passes through it creates an electromagnetic field. And when there is a metal object that comes in that range; it quickly activates senses or there is a metal object. So, then it tries to say yes or no; presence or absence of the sensor, so these are proximity sensors.

So, there is an active surface; so when the metal surface. So if it is a non-metallic object, it might not sense, and if the range might too large it might not sense. And here if there is a dirty environment proximity sensors works in a big way.

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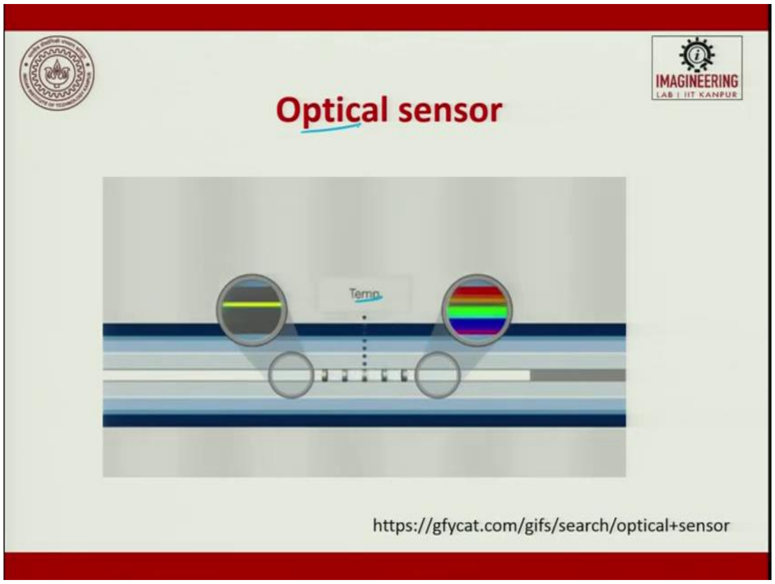

When we talk about optical sensors, these are sensors where we try to use optical fiber. So, the optical fiber is used and the moment you pull or push the optical fiber; you see the strains and then you might also try to see the passing of light passing through straining. So, temperature machining infrared is used, so there are so many things.

So, the temperature can be measured, strains can be measured and this is in turn attached to the external sensor of the robot.

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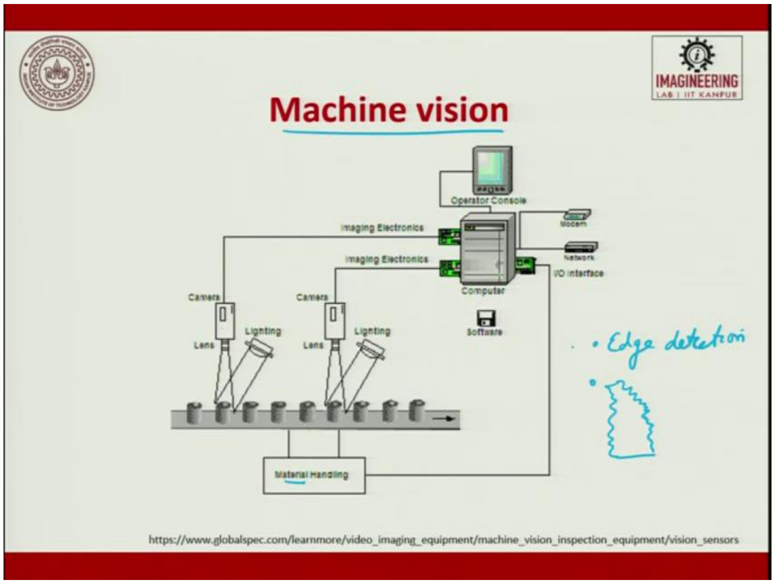

Then we have machine vision today. Machine vision works on edge detection and the other thing is if you have soft material. For example, rubber and if you want to measure the dimensions of the rubber; you want to do it without touching, then machine vision has a very important role. And suppose if you have a very complex texture which is on the surface. It is very difficult for measuring it through any other sensor apart from the machine vision sensor.

So, you will use a camera and there is a lens which focuses on the object. So, the light hits and there is a lens so if the camera captures the image and this image is checked with the standard. And then various dimensions are checked and then whichever is a defective one. So, then we put a material handling device and remove that defective sample, and the rest all is done. So, robot vision is also very important which is in turn attached to the end effector to do the job.

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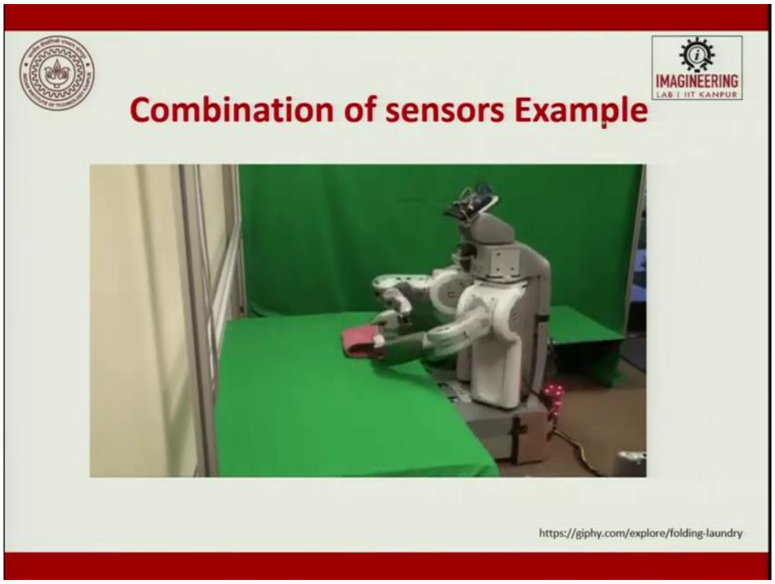

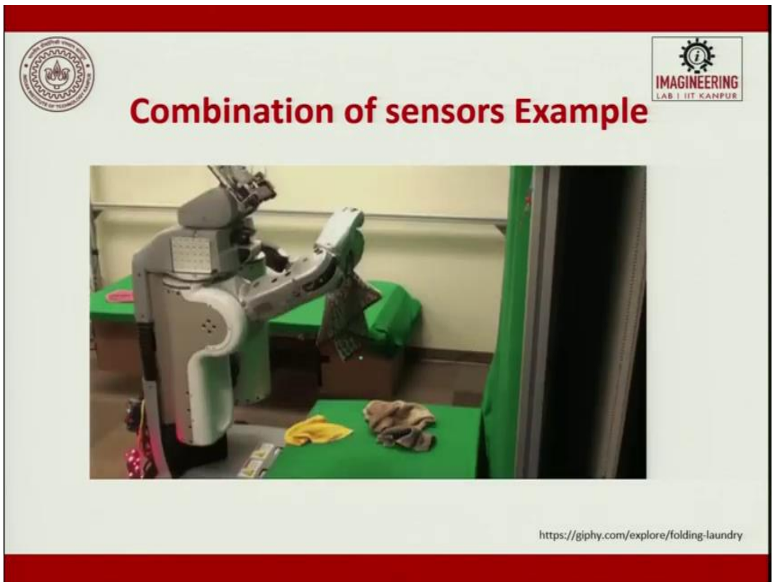

So, a combination of sensor examples, you can see here. Here is a sensor where and which you can see a cloth, which is getting folded and then placed it inside. Pick and place is also there and it is also getting folded. So, here we use combinations of sensors; first, we have to use a tactile, then we have to use vision, then we have to use image, and then finally we have to do this operation.

Though this is in manual way it is very easy, but asking a robot to fold a cloth is a big challenge. And a sensor to find out weight, color, texture, and then decide what is operation to do. So, this is a combination of several sensors which is used as an example.

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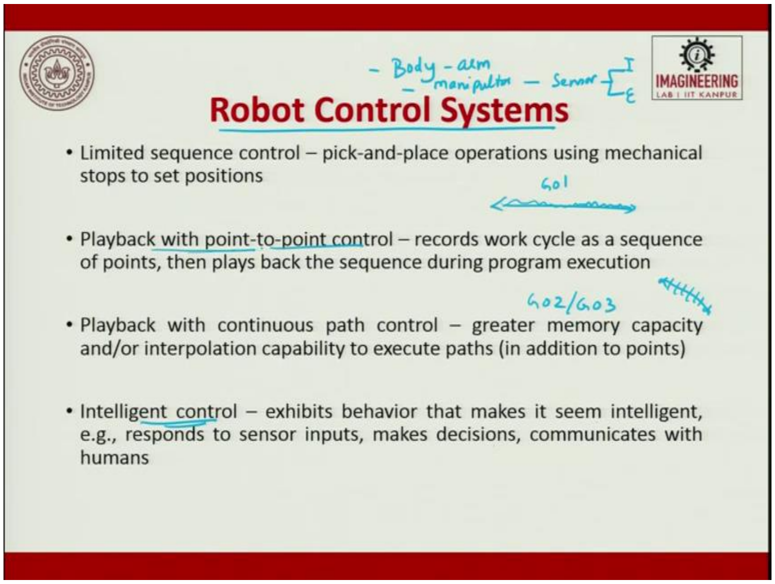

The next one is a robot control systems. Till now what we saw? We saw the body, body, and arm configuration. Then we saw different types of manipulators and then in the manipulator we saw, different types of sensors. And in sensors, we saw two which is an internal sensor and then external sensor. And now we will move into control systems. The control systems' limited sequence control is to pick and place operation using a mechanical stop to set positions. Playback with point-to-point control records work cycle as a sequence of points, then play back the sequence during the program execution.

For example, this is assumed that there is a blind man. The blind man is held by a stick and he is walking from A position to B position. He registers the number of steps and then when he has to repeat the same thing, he will do it the next day. By just doing the same counting of steps moving left and right and reaching towards the destination. So, that is nothing but playback with point-to-point. He is only worried about the line in which he has to move. Not worried about whether a zigzag motion a little bit, but he is only worried about the start point and endpoint.

Playback with continuous path control - greater memory capacity and/or interpolation capacity to execute a path, like in CNC machine. This is nothing but G01 command, this is nothing but G02 and G03 command. Start point, endpoint, interpolation, and several other details are to be loaded. So, it is playback with continuous and the last one is intelligent control. Exhibits behavior that makes it seems intelligent, responding to sensor inputs, make decisions, communicates with human and then it tries to control. Today all the driverless vehicles are thought of an intelligent control system.

So, these are the four different types of control systems limited sequence, playback with point-to-point, playback with continuous and intelligent control systems.

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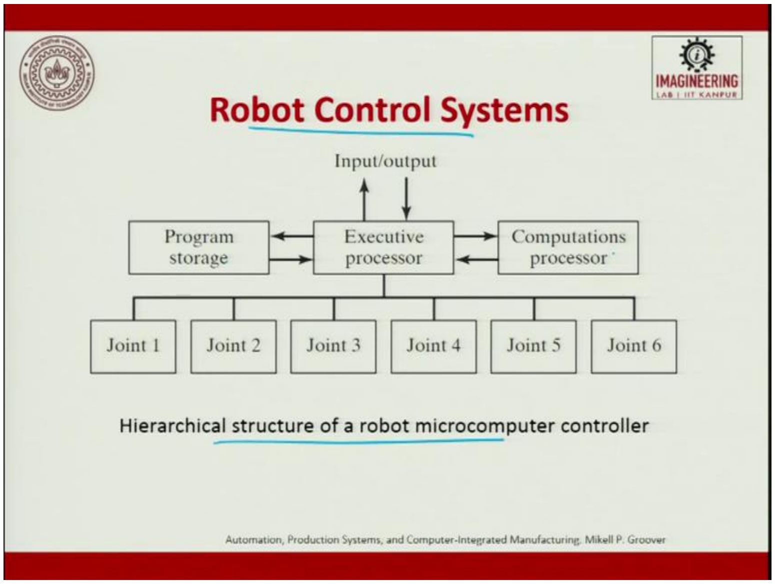

When we talk about robot control systems input, output. So, there is a program store and then there is an executive processor and then there is a computational processor. So, these are the joints which are linked to it. This is a typical hierarchical structure of a robot microcontroller used. So, we will have a program which is stored and then we will have a computational processor. This is the executive processor so input, output is given, joints are given there.

There values if it is rotational, linear, angle, or displacement is given, so accordingly the joints work. So, this is a hierarchical structure of a robot microcontroller system.

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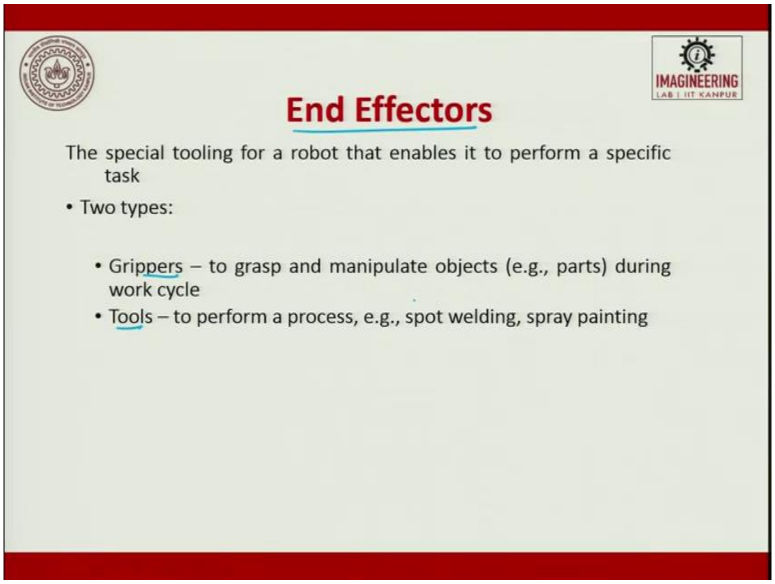

The end effectors for the robot that enables it to perform a specific task. There are two types of end effector: one is called gripper, the other one is a tool. Gripper to grasp and manipulate an object where the tool is to perform a task.

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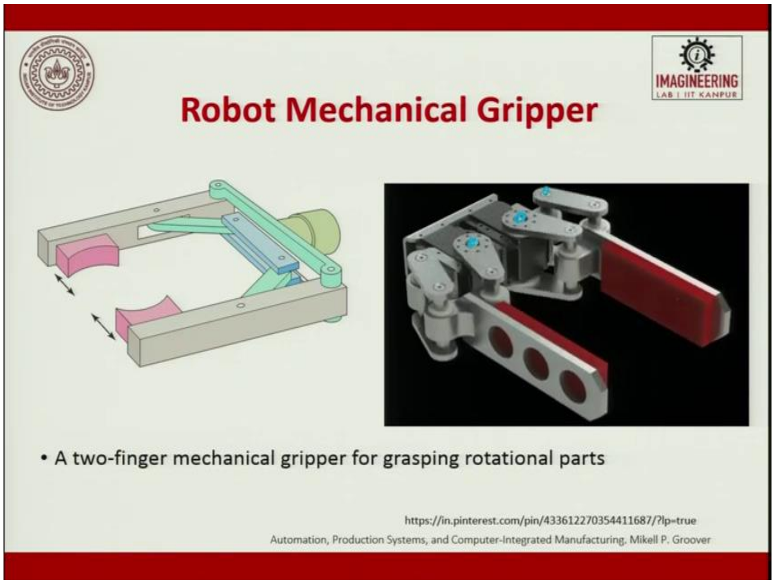

So this is a gripper. So, you can see a two-finger gripper, you can have both the fingers moving or you can have one finger fixed and the other finger moving.

Both are used for gripping action. A two-finger mechanical gripper for grasping the rotational part is there in a gripper. So, you can see here these are all rotational joints; this is a rotational joint which is given, and you just have to put a motor and activate it.

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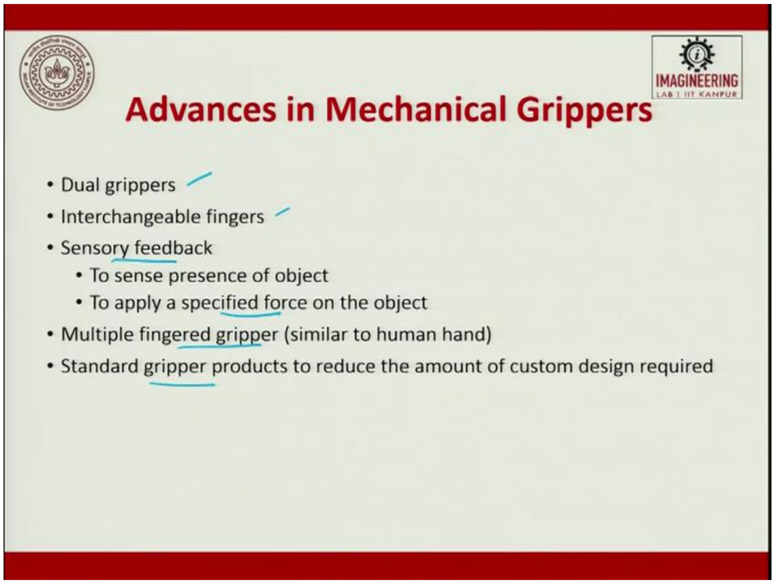

The advances in mechanical gripper are: there are dual grippers, interchangeable fingers, so that means to say you can make fingers like larger, smaller, round, box, prismatic like, helical like whatever it is. Then sensor feedback to sense the presence of an object; to apply a specific force on an object. So, these are some of the advancements.

Suppose if the object itself is not there, they have an optical sensor. It detects no objects there, it does not work. The second thing is, it tries to apply a load and if it feels that there is slipping happening by the object, between the object and the gripper. Then it will try to apply a specific force or increase the force to have proper holding. So, multiple fingered gripping is also there. Standard gripper products to reduce the amount of custom design requirements. All these things are recent advancements which are happening in robot so that they make handling and processing much easier and faster.

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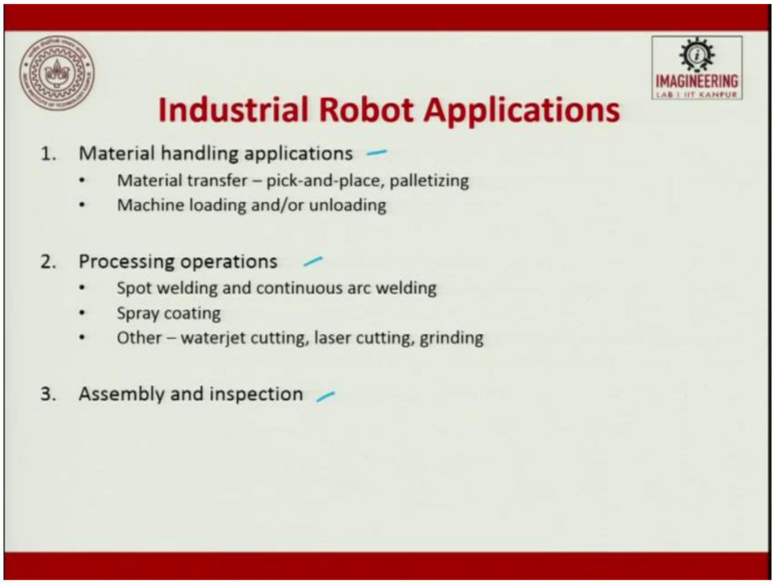

So, applications, material handling applications we have discussed, pick and place, and unloading. Then processing: spot welding, spray coating, water jet cutting, heat treatment etc. Assembly and inspection, these are the three areas where industrial robots play a very-very important role.

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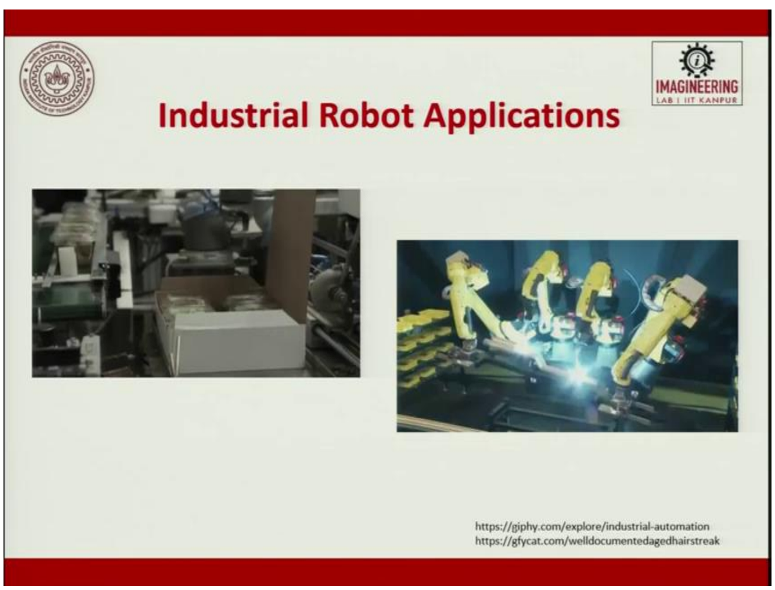

So, this is a typical pick and place robot you can see, and then these are robots, where there is welding which is happening. And these welding you can see there, the object is twisted moved up and down and then you can see the gun which is attached to a gripper.

Robot gripper which moves on a complicated profile to get the welding done. And simultaneously two welding are done and the job is done without any much of error.

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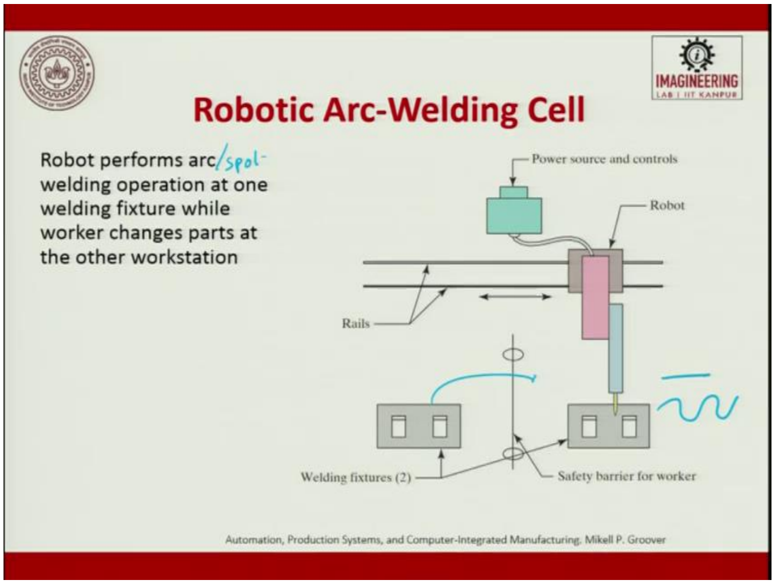

So, robotic arc-welding cell is now a common thing which is coming up, which is exhaustively used in car industry. The robot performs arc welding; arc welding/spot welding if you want. So, arc welding at one welding fixture while the work changes part at the other. So, it is typically like your CNC machines, so one place the new job is getting loaded; the other place the operation is going on.

By that time the operation is going on, the next job is ready. So, the moment it is ready this swaps, this goes inside and this will comes outside and the arc welding process continues. Here, it can be in a straight line, it can be in a contour. You can have multiple accesses either to the robot arm, or to the workpiece, to make complicated welding joints easily. So, the moment you say arc welding you can fix a laser; you can fix a water jet to get complicated profiles.

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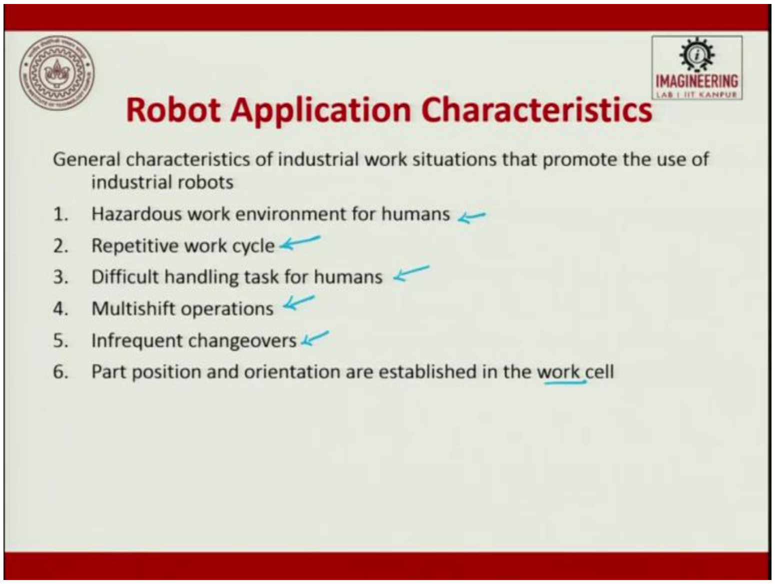

Today we have five-axis water jet cutting machines, five-axis laser welding machines. So, the robot application characteristics are general characteristics of industrial robot situations that promote the use of industrial robots. Wherever there is a hazardous environment try to use robots; wherever there is a repetitive task use robot.

Wherever there is a difficulty in handling by human use robot. So, you do multiple shift operations a robot can do, infrequent changeover. So, where the changeover is not very fast; one full shift one job is done or set of jobs are done, then we can use a robot. Part positioning and orientation are established in the work cell. These are the characteristics of a robot application.

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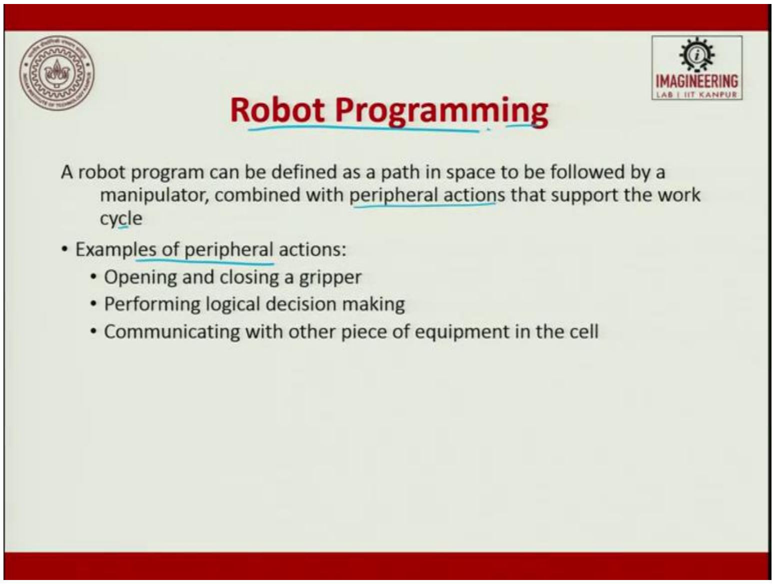

When we talk about programming, robot programming is also a very important thing. So, if you can teach by holding by hand it is by teach pendant or holding by hand it is primitive technique. Today, what has happened we have now started working on obstruction deduction, and finding out the shortest paths to reach from the source to the target. So, robot programming has come up in a big way. A robot programming can be defined as a path in space to be followed by a manipulator, combined with peripheral actions support the work cycle.

So, you will have opening and closing a gripper; you will have a performing logical decision making and communicating with other pieces of equipment in the work cell. These are some of the examples of peripheral actions. So, robot programming is coming up and there are several languages, which are developed today in which you can start writing the robot programming. And like CNC you can also use G codes for writing the robot programming.

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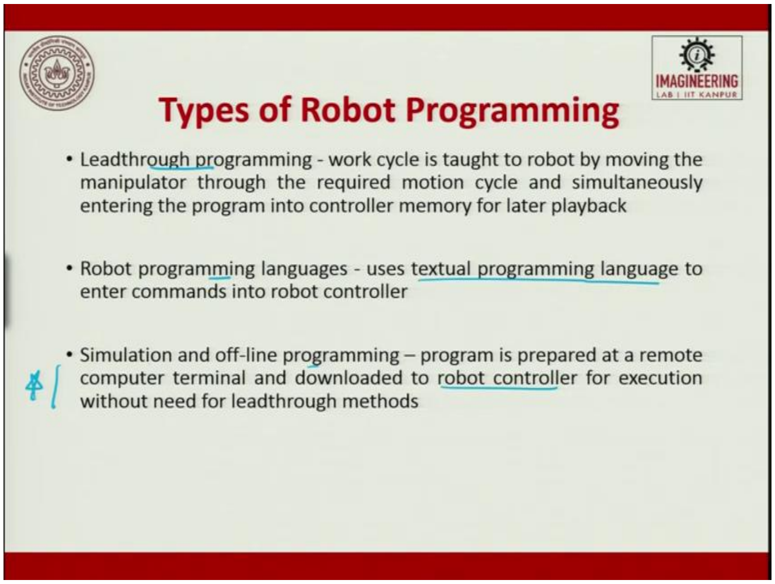

So, types of programming which I just discussed; leadthrough programming, robot programming through language, simultaneous and off-line programming. Leadthrough programming – a work cycle is taught to a robot by moving the manipulator through the required motion cycle, and simultaneously entering the program into a controller memory for later playback. So, it is just like holding a blind man walking through.

Having a teach pendant doing that, so lead through programming is there. Next is, Robot programming language: we use a textual programming language and enter the commands to tell the movement of the robot within the work volume. Next is Simulation and off-line programming: the programming is prepared at a remote computer terminal, and downloaded to the robot controller for execution without the need for leadthrough methods. So, this is an interesting thing.

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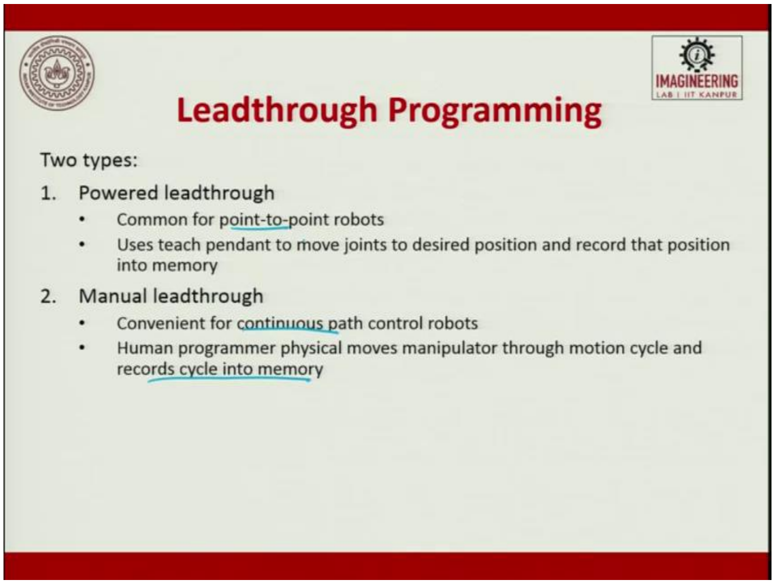

Leadthrough programming again there are powered leadthrough and manual leadthrough. Commonly it is point-to-point and manual leadthrough is continuous, this is very important. Uses a teach pendant to move joints to the desired position and record that position. So, it might move in a bang-bang position, start/stop.

So, it will go very fast and the part is immaterial. So, the human programmer physically moves the manipulator through the motion cycle, records the cycle into the memory; that is manual leadthrough. So, you have powered leadthrough and manual leadthrough.

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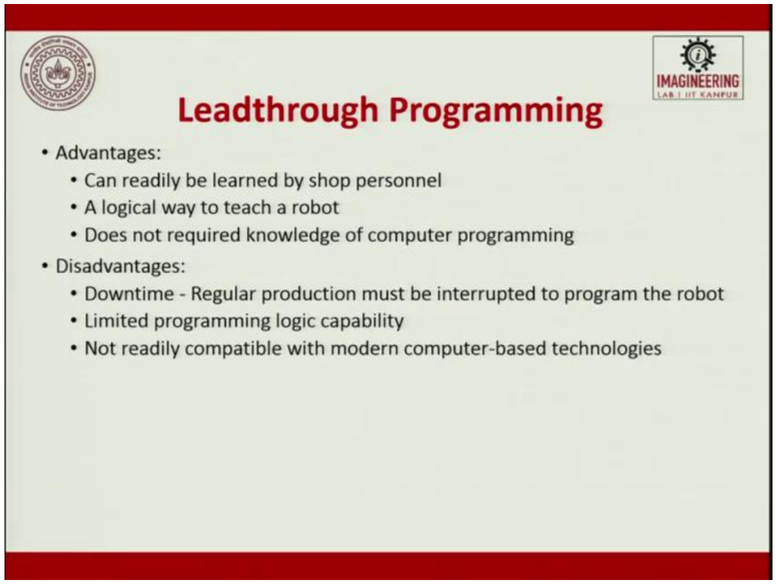

So, the advantages can easily be learned by the shop floor man. A logical way of teaching a robot; does not requir a knowledge of computer programming. It is something like a semi-scale labor can teach. So, here, the disadvantages are the downtime – regular production must be stopped to the program the robot. Limited programming logical capabilities; not readily compatible with the modern computer-based technologies is leadthrough programming.

So, once you have done leadthrough, if you want to edit that leadthrough programming, it is very difficult. So, that is why we use simulation and off-line programming.

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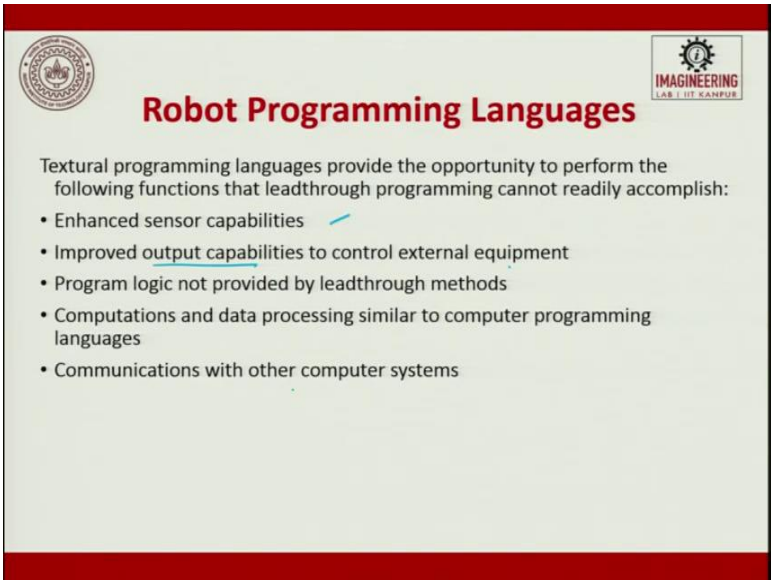

Textual programming takes the opportunity to perform the following functions that leadthrough programming cannot readily do. Enhanced sensors capability; improved output capability to improve external equipment. Program logic not provided by leadthrough methods will be done by robot programming. Computational and data processing similar to computer programming languages can be done by robot programming and communicates with other control systems.

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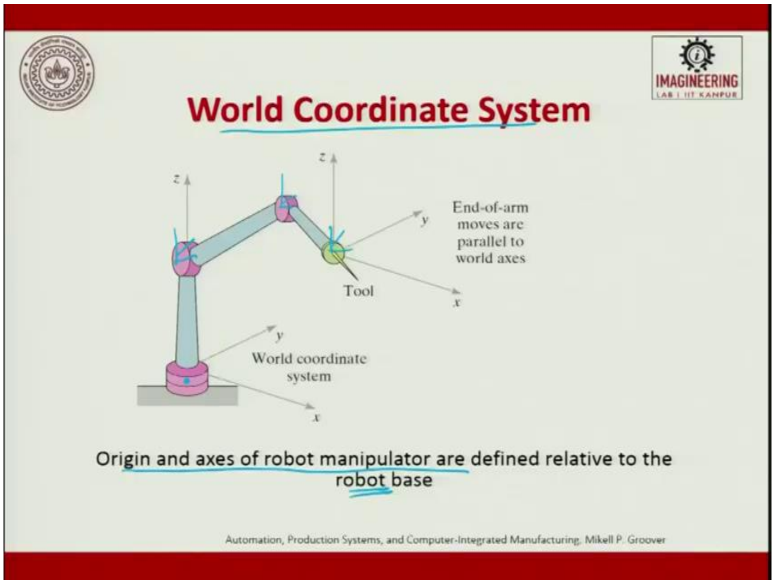

So, when we talk about a robot, there are two types of coordinate systems. One is called, world coordinate system; the other one is called a user coordinate system. This is the world coordinate system zero-zero and at every joint, you will have a user coordinate system. And you will have a tool also; you will have a user coordinate system. Now, every time when we write a program or we try to do an analysis, we should make sure that the axes of the world coordinate system and the user coordinate system are the same.

Otherwise, we have to transfer or translate these references in such a way with respect to the world coordinate system, and then execute the program. So, what happens is this will try to give you proper control over each of these joints to execute the job. So, the origin and the axis of the robot manipulator are defined relative to the robot base. So, the origin and axis of a robot manipulator are defined relative to the robot base. So, the world coordinate system is very important, at each joint you should be able to put a reference coordinate system.

Find out the x, y, z axis, and then try to put them properly, then start writing a program. So, in fact in the forward kinematics what we do? We try to bring all the translations rotation about the axis, and then we try to map it with the world coordinate system and then execute the moment.

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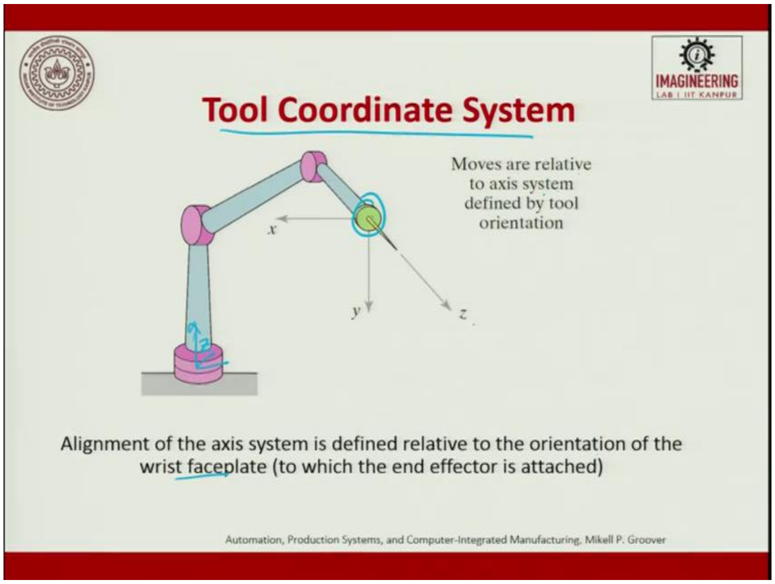

So, there is a world coordinate system there is a tool coordinate system; this is the tool coordinate system. So, you see here, this is the z-axis, x-axis; y-axis right-hand coordinate system is used. So, the world coordinate axis; so this is the z-axis and these are the other two axes. The alignment of the axis system is defined relative to the orientation of the wrist faceplate to which the end effector is attached. This is the wrist faceplate; so moves are relative to the axis system defined by a tool orientation.

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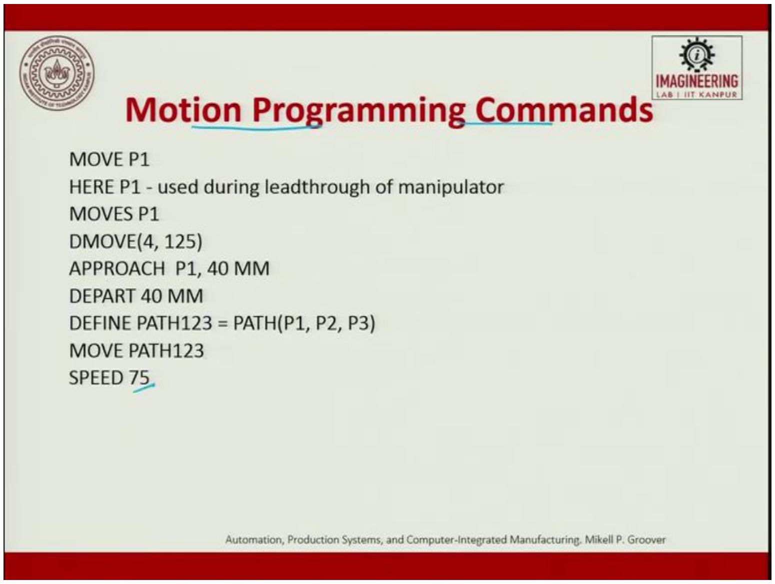

So, this is the motion programming commands, so we will say move P1. So, here P1 used through leadthrough manipulator. Moves P1, then DMOVE (4, 125) these are the coordinates. APPROACH P1 which is 40 millimeters; DEPART from 40 millimeters; DEFINE PATH123, PATH (P1, P2, P3). So, P1, P2, P3 will be defined earlier, MOVE PATH123 with the SPEED of 75. So, this is a motion programming which is used, leadthrough is 1, then it is motion-based.

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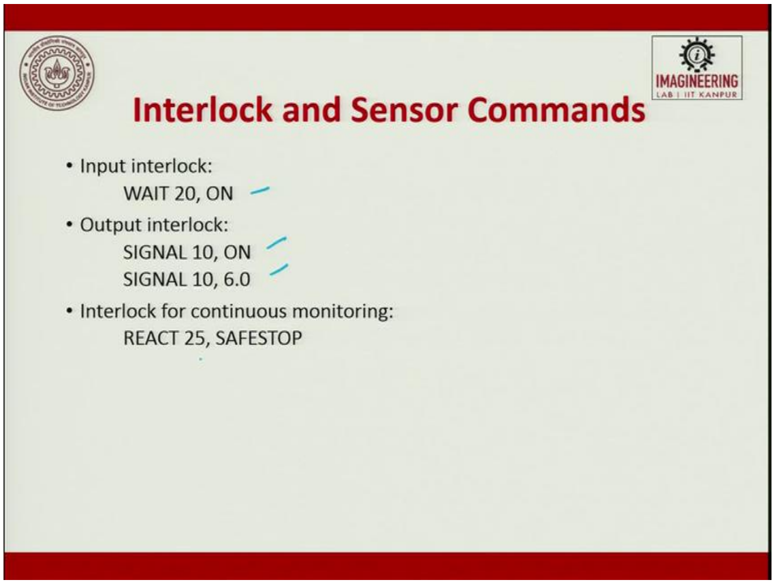

So then interlock and sensor commands are given, so wait 20 seconds or 20 milliseconds. SIGNAL 10 is ON, SIGNAL OFF, then REACT SAFETYSTOP YES/NO.

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The gripper commands can be basic OPEN/ CLOSE or it can be CLOSE and WAIT OR CLOSE with the load. So, it will be 25 millimeters, CLOSE at 2 Newton's.

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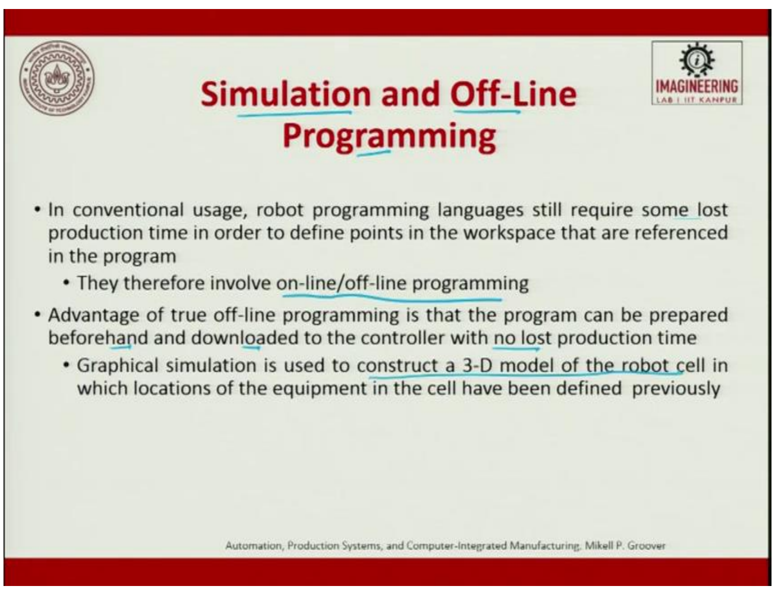

The simulation and off-line programming: In conventional usage robot programming language still require some lost production time in order to define points in the workspace that are referred in the programming.

They, therefore, involve on-line/off-line programming. Completely you do a robot pathfinding and then you make a layout and then allow a robot to move in that layout. And then find out, where all the obstructions are there; how can it jump over the obstacles or the tour from the obstacles and reach the target. So now, this is simulation is done and off-line programming is done. So, this tries to give a better control over the situation. So, in leadthrough it was not talking about the sensors and other things.

In motion control, we were talking about sensors and its functions attached to the leadthrough. Now, simulation and off-line is the next advanced one. The advantage of true off-line programming is, that the programming can be prepared beforehand and downloaded to the controller with no loss of production time. The graphical simulation is used to construct a 3-D model of the robot cell so that you can plan your operations.

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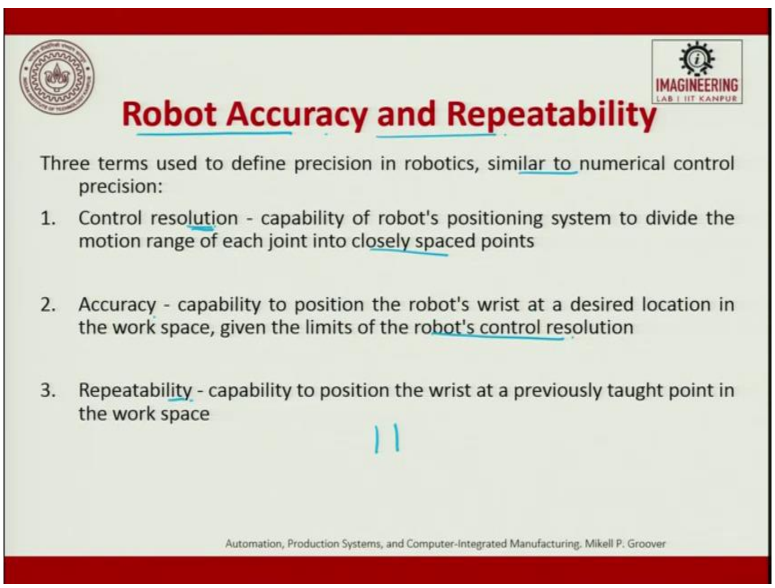

The last part of the robot discussion is, we have to understand robot terminology called robot accuracy and repeatability. There are three terms which are defined as far as robot is concerned.

Just which is very similar to that of a numerical control system. Control resolution, accuracy, and repeatability. Repeatability is nothing but the capability to position the wrist at the previously taught point in the workspace is repeatable. I repeatedly to do a task, what is the accuracy? So repeatedly do or repeatedly go to the same place. So, the capability to position the wrist at the previously taught point in the workspace is repeatability. Accuracy is the capability to position the robot wrist at a desired location in the workspace; given the limits of the robot control resolution.

Accuracy: accuracy is nothing but the capability to position the robot's wrist at a desired location in the workspace, given the limits of the robot control resolution. So, the control resolution is, the capability of the robot positioning system to divide the motion range of each joint into closely spaced points is resolution. If you talk about a computer pixel is a resolution. The least count, the capability of the positioning system to divide the motion range of each joint into closely spaced points is called as resolution. So, these are three important terminologies which are very similar to that of numerical control.

Control resolution, accuracy, repeatability repeatedly I go to the place that is repeatability. How close I go to the set target is resolution. Accuracy, the capability to position the robot wrist at a desired location in the workspace; given the limits of the robotic control system.

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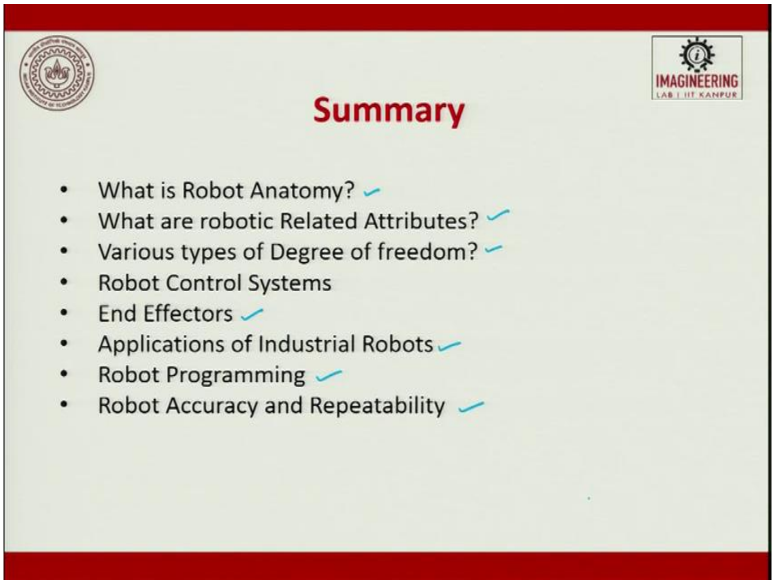

So, to summarize what all we covered in this. What is your robot anatomy? What is the robotic related attributes? What is degree of freedom? Control systems, end effectors different types; application of an industrial robot, robot programming and accuracy, and repeatability.

These are the topics which were covered in this lecture. So, I would like to give you a small assignment before I conclude.

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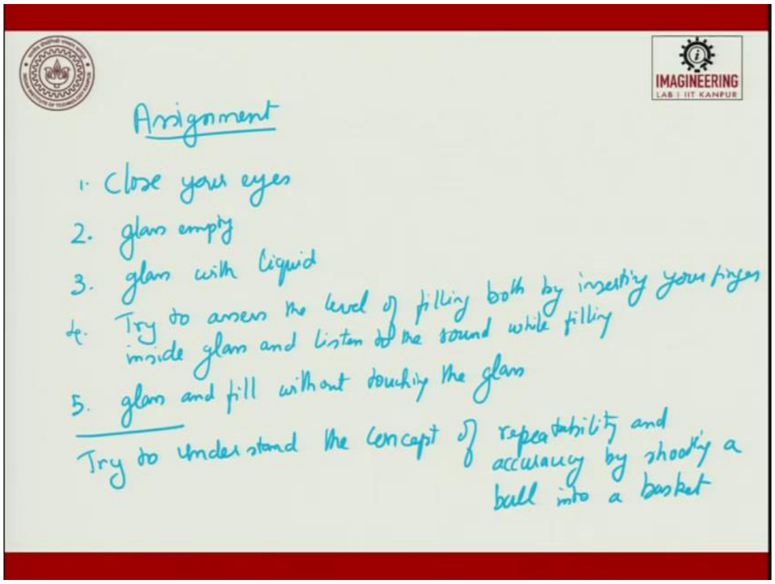

So this is an assignment; you do not have to give it to me or submitted. So, try to let us play a small thing and try to understand the resolution and accuracy we will try to see. First, close your eyes; first step. The second step, what you do is, you try to keep a glass empty glass in front of you and start feeling the glass with liquid. Try to assess the level of filling both by inserting your finger inside the tumbler/inside the glass and listening to the sound while filling.

You first try to do this and assess it. Now you see how difficult it is and after assessing it try to take another empty glass and fill without touching; touching the glass so now touching the glass. Now you try to see one more time, what you have assessed and when you stop pouring it, can you assess it? So this is a very difficult task to do. By practice yes it can come. The next thing is to try to understand the concept of repeatability and accuracy by shooting a ball into a basket, please do this. So, then you will know you as a system what is your systems repeatability, accuracy and these two points you please do it.

Do these two experiments and do not have to submit it to me. What we are trying to understand is, how teach leadthrough will be used and try to understand the concept of repeatability and accuracy as far as the system is concerned. Thank you.