Manufacturing System Technology - II
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Lecture – 28

Hello and welcome to this manufacturing systems technology; part 2, module 29. We will be mostly, dealing in this module with issues, related to robotics and some issues related with factory automation. Let us looks at robotics and how historically, robotics systems really emerged.

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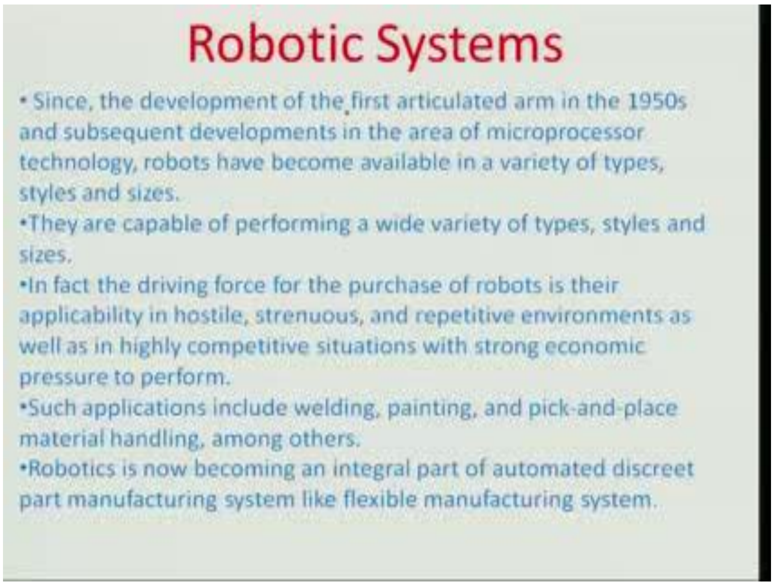

Of the a first articulated arm, which can be associated with the beginning of the whole robotics area, was developed in 1950 and this, sort of articulated arm was controlled through microprocessors, which were developed a little earlier, but then there was a lot of technology growth in the area of microprocessors in the end of 50s and 60s, which fuelled this development of so called robotics systems. So, now robots have become available in a variety of types, styles and sizes, staring from 1950s. They are capable of performing a wide variety of again, operations in the industry. Examples could be, common place examples could be robots, which are used for a car assembly, for weld assembly, for even painting in automotive industries extensively. Robotics also are used in electronics industry for assembling of different printed circuit boards to different levels of micro electronic processing, as well as assembly etc. So, there is n number of applications in the industry for these robotics systems. In fact, the driving force for the purchase of robots is their applicability in a hostile or strenuous and repetitive environments.

When we are talking about producing many items with a time demarcation of producing one item for a longer range of times; obviously, if a rapid production is needed and with more repeatability and accuracy, such production is needed so, therefore, robotics systems are considered because of that aspects. Applications again, as I told you, welding, painting, pick and place, material handling among others; is becoming now an integral part of automated discreet manufacturing, part manufacturing systems, particularly, systems like flexible manufacturing systems are as applied, cannot think of the system being in place without robots maneuvering different operations or different sub system activities within that overall system.

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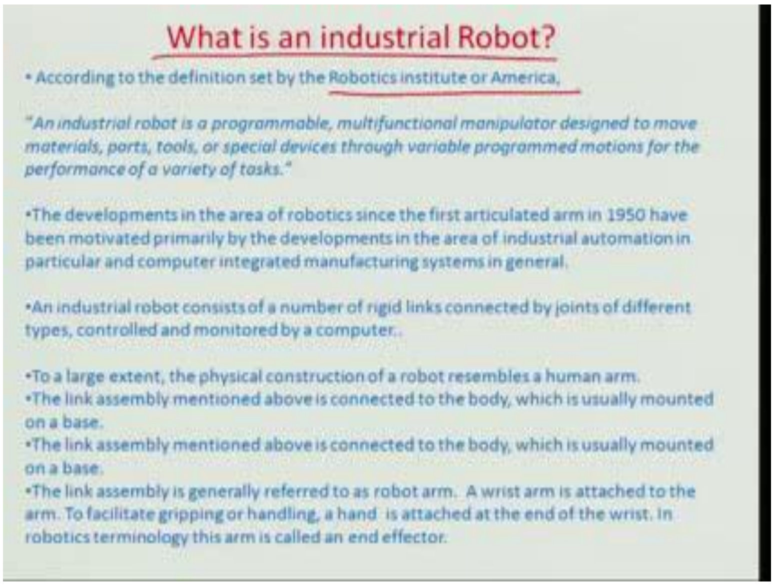

Let us look at some definition of what is an industrial robot according to the robotics institute of America. An industrial robot is a programmable multifunctional manipulator, designed to move materials, parts, tools or specified devices, through variable programmed motions for performance of a variety of tasks. The developments in the area of robotics, since the first articulated arm in 1950, have been motivated primarily by development in the area of industrial automation and particularly, computer integrated manufacturing systems based automation in general. We had a extensive course earlier in manufacturing systems technology, part 1, where these sim system or the computer integrated manufacturing systems were described in great details. An industrial robot consist of a number of rigid links, connected by joints of different types, controlled and monitored by a computer to a large extent. The physical construction of a robot resembles a human arm, like you have a lower part of the arm, an upper part of the arm a wrist and then, something like the portions of the hand, which were in question. In a similar manner, if I can have all these degrees of freedoms with respect to a lower arm, the upper arm, the wrist and the forward hand portion of this arm; this could actually be mechanized to be implemented as a full fledged robot arm.

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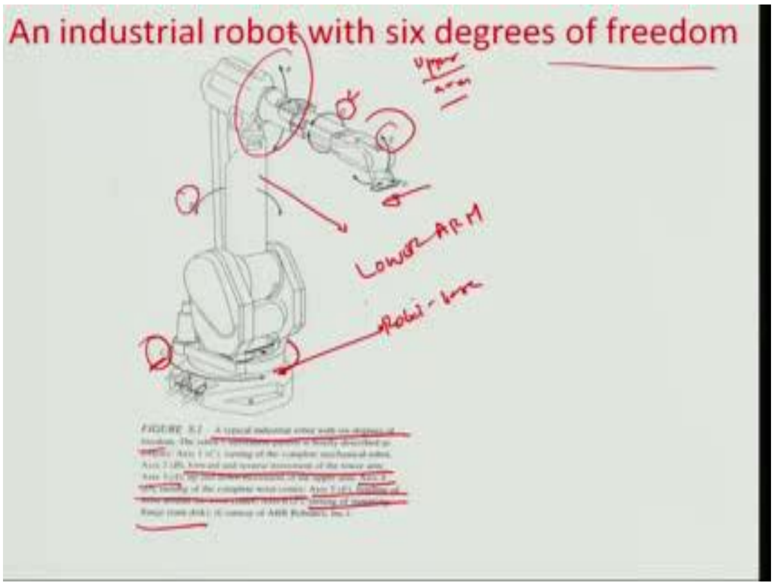

Let us look at such a example here, and understand what are the kinds of degrees of freedom, which are available. A typical industrial robot with 6 degrees of freedom has been illustrated here. You can see a ABB robotics incorporated. So, here you can see the first degree of freedom is basically, turning of the complete mechanical robot around the points. See the turn angles have been shown here. So, the whole arm here; this whole arm is going to get rotated in this particular direction about. See the other you know, turning can be about the point being, where the foreword and reverse movement of lower arm can take place. So, there is the movement of the lower arm as you can see in the hand. So, this is the movement of the lower arm.

So, this can augur. Again, axis 3 about a, where this is the axis that we are talking about, where the up and down movements of the upper arm can be formulated. This is the lower arm. This is the robot base for executing overall missions and this right here, is the upper arm. So, you have at least, 3 degrees of freedom recorded so far. So, the moment about the point d; this corresponds to access 4; means the turning of the complete wrist center.

Let us say for example, in the human arm also, once you have positioned the upper arm at a certain angle, then you are able to, enable to sort of turn the wrist portion of the arm. So, that is given by the term d and then finally, you have another axis, which corresponds to bending of the wrist around the wrist center. Basically, once the wrist center axis is enable to rotate, you can also turn the wrist upside down and bend wrist about wrist center. So, that is what is meant by the axis e and then finally, the 6th axis of the robot is by virtue of the turning of the mounting flans or the turning disk, which would do some operation; may be let us say, we are talking about a dispensing of spray paint, where there is a flan rotation, which is very important to atomize the paint as in automotive industry, or then, we are talking about some kind of painting, painting polish or buffing kind of robotic system, where again, such rotations are used for moving the buffing wheel, very close to the body. So, that can be accumulated with all these six different motions as in a human arm and this typically, have a robotic system is classified geometrically.

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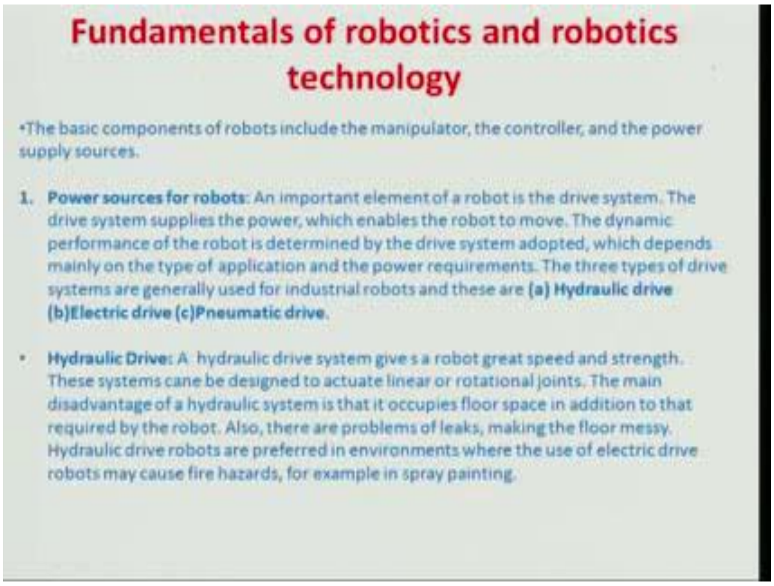

Having said that, let us look at the basic components of the robots. They include typically, a manipulator, the controller and a power supply source; these are what is needed; power sources for robots. So, an important element of the robot is the drive system that robot has. The drive system supplies the power, which enables the robot to move. The dynamic performance of the robot is determined by the drive system adopted, which depends mainly on the type of application and the power requirements. Mainly two system or three systems are there, which applies the mechanical power to the robots.

One is the hydraulic drive system and another is the electrical, and third is a pneumatic. Of course, there are many advantages and disadvantages in all the three. Let us look at the hydraulic drive first. So, hydraulic drive; it gives the robot great speed and also, lot of strength in doing its operation.

These systems can be designed to actuate linear or rotational joints for example, and as the main suggest it, through wild movement in certain pressurized pistons across the robot; obviously, as a medium is involved. There are additional problems of leakages, which would come in such a robotic system, making the floor particularly, messy and also, the occupancy level of the floor is high, because of additional pressure cylinder and storage tanks for the oil, which would generate this mechanical motion in turn. So, hydraulic drive robots are provided in environment, where there the use of electric drive robots may cause fire hazards; for example, when we are talking about spray painting in a paint shop in an automotive; obviously, there is going to be paint thinner, which is very highly inflammable and also, volatile. So, there, you cannot afford to have an electrical hazard or fire hazard. So, there is a typical application, where you can deploy a hydraulic drive robot.

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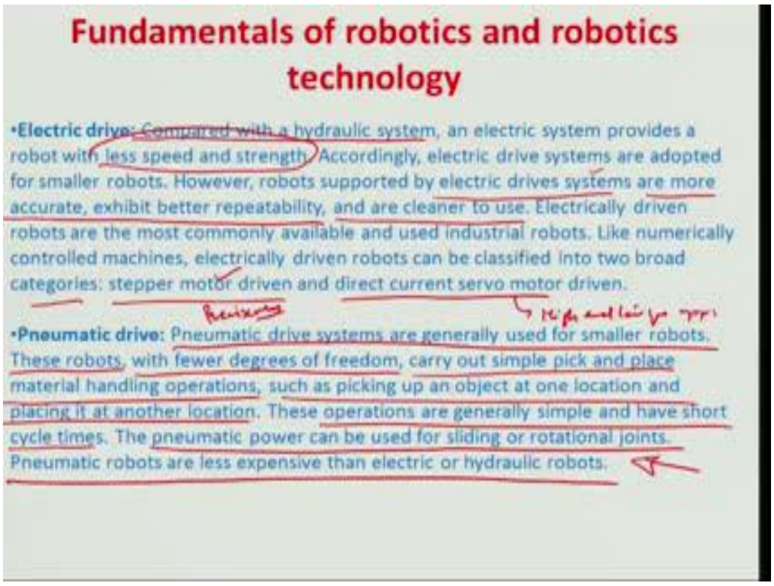

There are electrical drive robots, which are comparatively, much more accurate you know, because; obviously, the electrical drive systems are better controlled. They exhibit better repeatability. They are also cleaner to use, but its disadvantages could be not as high strength or speed as can be given by a hydraulic actuation, because there is cylinder based pressure, which can be maneuvered to a higher value. Unfortunately, the kind of a product that can be given by electrical drives, are typically limited by the power requirements or power limitation of the motors, which drive such systems. So, just as in CNC control, we head earlier seen in manufacturing systems technology, part 1; here also, the categories of motors can be either stepper motor driven processes or direct current servo motor driven processes. This would be the high end torque application and this would be more related to preciseness or accuracy.

I need not illustrate this anymore, because you have done in great details in CNC, while doing that lecture. The third type is pneumatic drive systems, which are generally used for smaller robots. So, these robots with fewer degrees of freedom carry out simple pick and place material handling operations, such as picking up of an object at one location and placing it to another location. So, these are already well defined in terms of the weights that they would have to carry and it is merely, a location change. So, these operations are generally simple and have short cycle times. So, the pneumatic power can be used for sliding and or rotational joints, and pneumatic robots are much less expensive than electrical and hydraulic, because you do not need to develop much of a control system.

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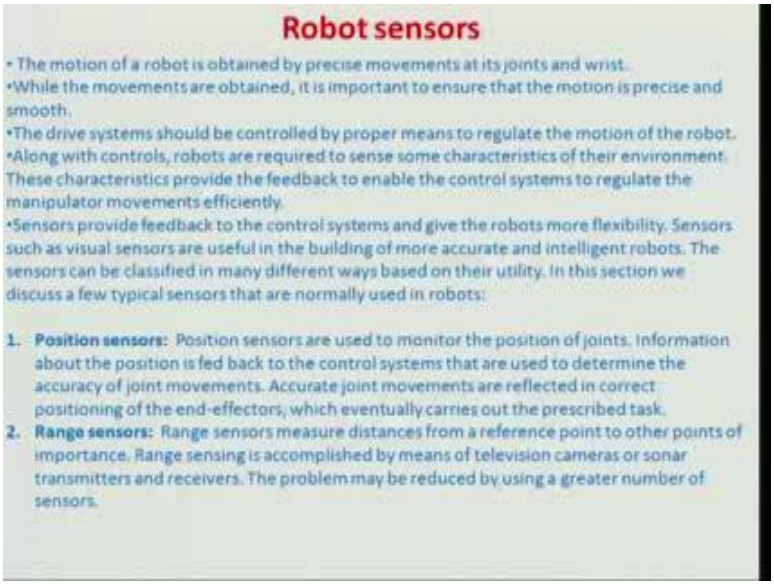

All you need to do is a sort of actuate the various valves in a certain sequence so that, the airflow can actually, make the robot do mechanical work. So, that is how the power systems are classified, categorized. The other important component the robot has is the sensors; obviously, the sensors are systems, which provide feedback to the control system and gives the robots, more flexibility. Then, may be several sensors; there can be visual sensors, which are useful in building of more accurate and intelligent robots. They can be classified in many different ways based on their utility. So, for example, you can have a position sensor, which is used to monitor the position of joints. Information about the position is fed back into the control system and that is used to determine the accuracy of the joint movements. Accurate joint movements are reflected in correct positioning of the end effectors, which eventually carry out the prescribed task.

Robot sense; then there are range sensors, which talk about range of operation. So, it measures the distances from the reference point to other points of importance. Range sensing is accomplished by means of television cameras or sonar transmitters and receivers. The problem may be reduced by using a greater number of sensors. The idea is that within the robot range, there should be identification; if there is any other movement in the range of movement of the robot, and there is a case of collision. There has to be a self correcting mechanism, which stops the mechanical activity of the robot, the movement it faces an obstacle of that sort in a varying environment. So, that is one issue that is very important in the sensing.

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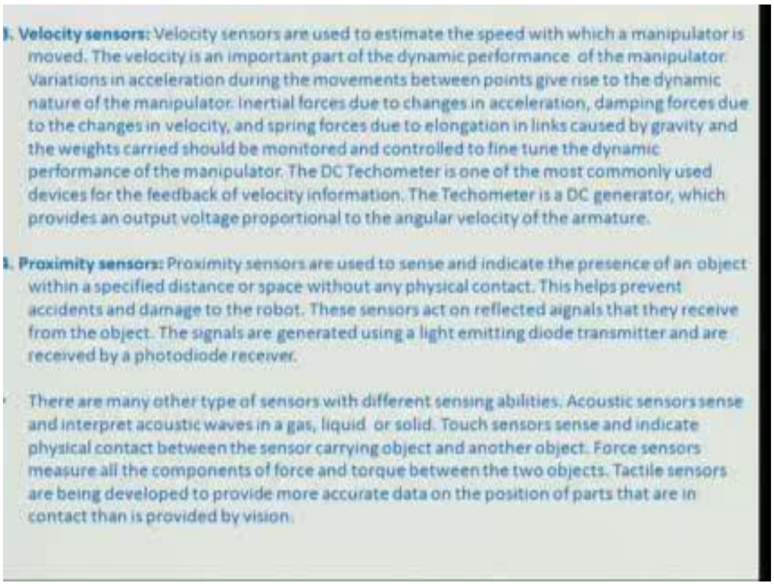

There are velocity sensors, which are used to estimate the speed with which, a manipulator will be moved. The velocity is an important part of the dynamic performance of the manipulator. So, variations in acceleration during the movements between points, give rise the dynamic nature of the manipulation. Inertial forces due to the changes in acceleration; damping forces due to change in velocity and spring forces due to elongation in links caused by gravity and the weights carried, should be monitored and controlled to fine tune the dynamic performance of the manipulator for which, this continues monitoring of velocity particularly, of the end effector or the other linkages, which are associated with the robots, would need to be sensed.

So, the best example is a DC tachometer, which is one of the most commonly used devices for feedback of velocity information. So, it is a DC generator, which provides an output voltage, proportional to the angular velocity of the armature, which will be a able to again, back calculate the type of the speed sensing that is going on. There are going to be also, proximity sensors, which are used to sense and indicate the presence of an object within a specified distance or space without any physical contact. So, this is more or less, similar to the range sensors. The range sensor is basically, up to what range the robot will move, and some range sensors are also, serving as proximity sensors from time to time, but you know, there are independent proximity sensors, which will only do the job of sensing the presence of a foreign object within a specified distance or space. These sensors are typically, working on reflected signals on any such object comes on the path as an obstacle.

It reflects the light back to the source and they receive this from the object; these signals are generated using may be, LED transmitters and are received by a photo-diode receiver sort of a arrangement. As soon as you get a signal, the idea is to sort of mechanically, change the path or the track of the robot, to avoid collisions. So, there are many other types of sensors with different sensing abilities; for example, acoustic sensors sense and interpret acoustic waves in gas, liquid or solid; touch sensors sense and indicate physical contact between the sensor carrying object and another object; force sensors measure all the components of the force and torque between two objects; tactile sensors are developed to provide more accurate data on the position of parts that are in contact and that is provided by the vision so on and so forth.

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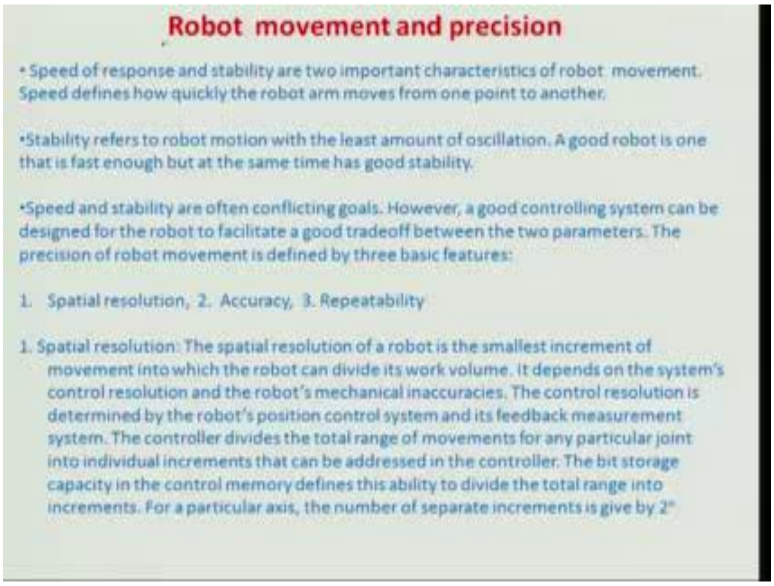

So, we now talk about robot movement and precision. So, speed of response and stability are two major important characteristics of robot movement. The speed defines how quickly, the robot arm moves from one point to another, and stability refers to the robot motion with less amount of oscillation. A good robot is one that is fast enough, but at the same time, has a good stability. So, three important basic features, which are very important to be controlled is spatial resolution, the accuracy and the repeatability. So, the speed and stability are often considered as conflicting goals; however, a good controlling system can be designed for the robot to facilitate a good tradeoff between the two parameters.

You know, the three important aspects or three basic features, which are there in any robotic movement and precision description, is spatial resolution, accuracy and repeatability. So, definitionally, this spatial resolution is the sort of this smallest increment of moment into which, the robot can divide its work volume. It depends on the system’s control resolution and robots mechanical inaccuracies. So, if supposing the control resolution is sort of not very high standard, then it may mean that the amounts of the increment that the robot moves in its motion path way, may be higher and that also, this increment can probably be unstable, because the increment may keep on changing or vary. So, that is how the spatial resolution is defined.

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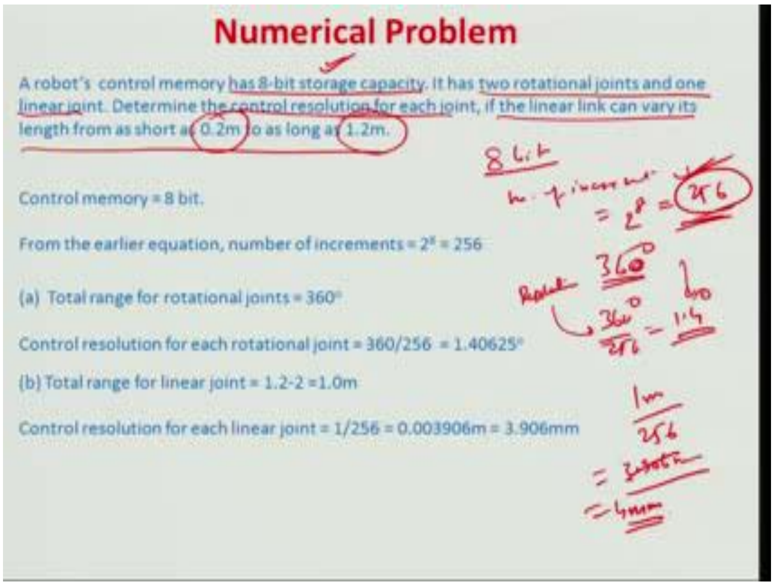

Let us now, talk about numerical example; how you will find out, let us say a robot's control memory has 8 bit storage capacity; it has two rotational joints and one liner joint, and you have to determine the control resolution for each joint if the liner link can vary its length from as short as 0.2 meters to as long as 1.2 meters. Obviously, if the control bit memory is 8 bit; that means, the number of increments that can be programmed into the system are exactly 2 to the power of 8; it is a binary number so, around 256. So, with this kind of a storage capacity, the total range of the rotational joint; for example, if the joint were to rotate 360 degrees, would actually to be equal to 360 by 256; that is about close to 1.4 degree resolution, right. So, this is the resolution. So, basically, you can see now that how the capacity storage of the controller or the control memory of the robot is directly, related to ability to store small increments. Therefore, in this case, if the robot has to be positioned at less than 1.4 degree rotation, it is not possible, because the robot's controller is giving a resolution of 1.4 degree and above.

So, that is the minimum sort of a least count moment in terms of rotation, which could be executed in this particular robot. Similarly, if the range of the robots is from 1.2 meters to 0.2; that is about 1 meter; the resolution that this would have is again, 1 meter by 256. That is about close to 3.906 millimeters or obviously, means it doesn't. So, between let us say 3.9 or 4 millimeters, is the resolution. If I wanted to position at an accuracy of less than 4 millimeters; with this kind of a 8 bits storage capacity, this is not possible in doing the less than 2 millimeters or less than 4 millimeters position. So, that is how you define in the spatial resolution part of the robot.

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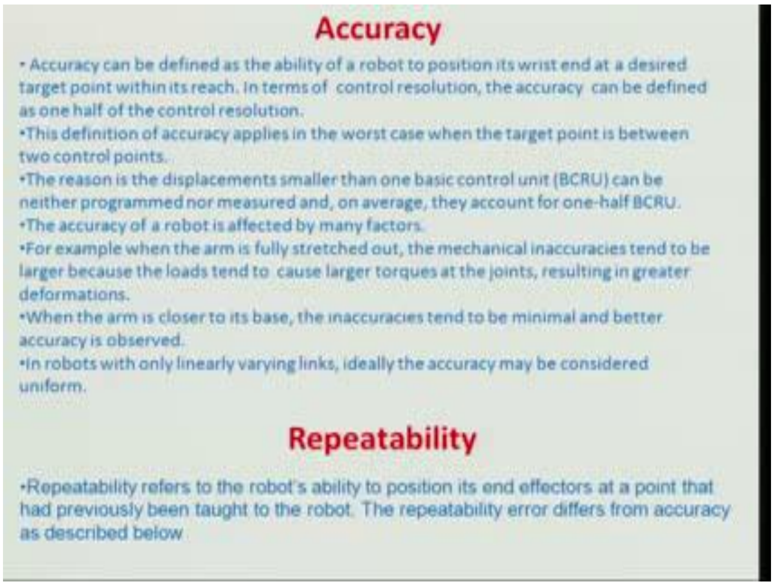

Obviously, accuracy, which can be defined as the ability of a robot to position its wrist end at a desired target point within its reach, in terms of control resolution; the accuracy is defined as one half of this control resolution. So, supposing there are two control points, which are 4 mm distance; the accuracy should be at least, 2 mm for it to be enabled to position. That is the whole idea behind accuracy. So, the reason is the displacements smaller than one basic control unit, can either be programmed or measured on an average; they account for one half BRCU. The accuracy of a robot is affected by many factors; for example, when the arm is fully stretched and it is a full load conditions; the accuracy may be smaller, because of greater deformations, etc. because of the load.

If the arm is closer to its base and the inaccuracies tend to be minimal, because now, you have less loading condition in the robot arm, etc; obviously. So, the accuracy also, is a dynamic phenomenon. It keeps on changing, whether the robot is fully stretched or the robot is in its base position. So, in robots, only linear varying links ideally, the accuracy may be considered to be uniform, but if there are angularly varying links, etc. There are going to many other factors like you know, different kind of stresses, because of rotational as well as leaner motion, and the accuracy may change because of that. The other aspect is repeatability. So, this refers to the robot's ability to position its end effectors at a point that had previously been taught to the robot. So, if I want the robot to go to the certain point a how much accuracy has how much you know a compliance it does to going to a point A, how much accuracy has or how much compliance it does to going to the point A is what the repeatability would be. There is a way to measure the repeatability error and it differs from the accuracy as given below.

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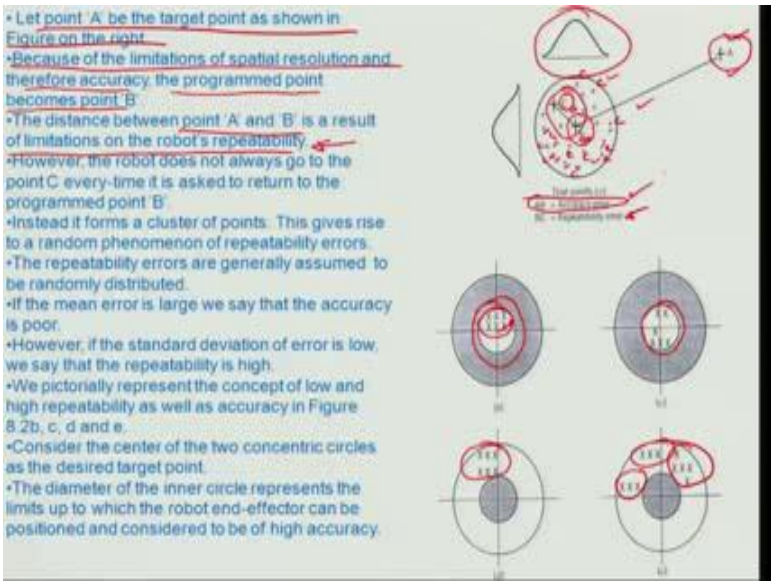

Let us understand this example more thoroughly. Let us say there is a point A, which is the target position as shown in the figure on the right. Position A is represented here in this particular figure. So, therefore, this is the position, where the end effector of the robot should go once it has been programmed, because of the limitations of the spatial resolution, and therefore, accuracy; the programmed point becomes point B. So, instead of going to A, the robot goes to certain point B, right about here. The distance between point A and point B is a result of limitations on the robot's repeatability, because obviously, every time it is going to the programmed point A; there is an error, which it has in going to A and it actually, accidentally, goes to B; however, it may not be possible or it may not be reasonable to assume that every time, it will be go to point B, because there can be another instance, where it can go to somewhere, around C, which at more or less, similar distance or similar sort of repeatability from A as shown here.

You know, there are a variety of such points as represented by these pluses, where there can be the robot position, programmed position, once it is supposed to go to the point A. So, the accuracy error now, would therefore, be represented by AB, but the repeatability errors would actually be represented by the point BC. So, one aspect is to accurately position. Another aspect is when you are positioning it, how repeatable you are positioning it, is the question. So, you now understand what is repeatability, and what is accuracy. So, AB for example in this case, is the accuracy error and BC and there can be many such BC; C point can be here or here or any other such in a certain close domain, may be, where the Cs could be there. In case of many trials, you will find out that this desire set of Cs, which are there. The question is how well defined you make this C, and what is the range within which, this robot will operate so that, C can minimize.

So, you have a very less repeatability error, which is in question. So, this typically, can be represented by let us say, this inner circle here. So, if supposing I had a lower repeatability error; obviously, these are cases, where the repeatability here is lower. In fact, slightly higher, but then again, within the same range, can also be treated. So, this is essentially the radius between which, such C point will be positioned with respect to the actual point B, which is you know, inaccurately being transverse while the programming point was A so on and so forth, but then you know, it can be a case, where this is actually, the repeatability error is very high and the points are actually, at the outer side. So, this is how, you sort of plot the repeatability and accuracy errors. A good idea is to be able to look at it from a stand point of a standard deviation and mean, just as you did in SQC earlier. Then, we can see what is spread you know, around the accuracy error, which would be able to give you, whether the spread is more or less, depending on whether the repeatability error is more or less so on and so forth. So, this is how accuracy and repeatability can be defined in terms of robotic motions.

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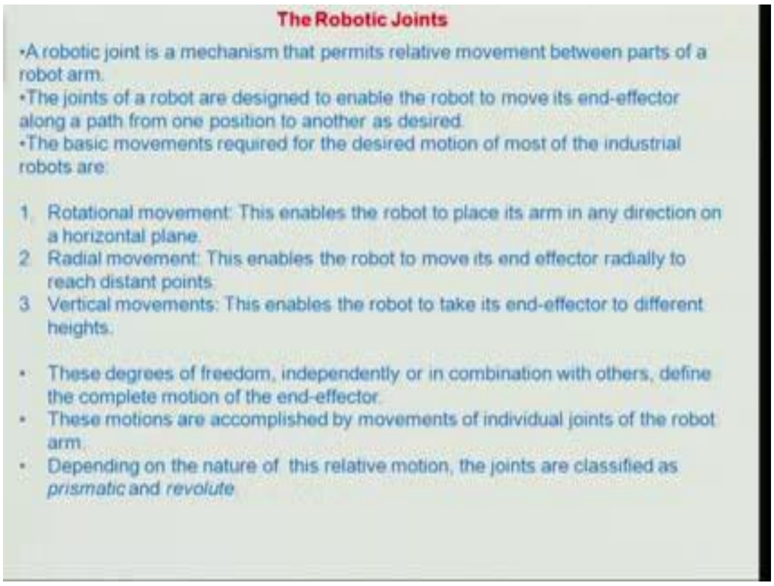

Let us talk about robotic joints now. A joint is a mechanism that permits relative movement between parts of the robot arm. The joint of a robot are designed to enable the robot to move its end effector along a path from one position to another as described.

The basic movement required for the desired motion of most of the industrial robots are rotational movement, which enables the robot to place its arm in a direction on a horizontal plane. The radial movement, which enables the robot to move its end effector radially, to reach distant points and obviously, the vertical movements, which enables the robot to take its end effector to different heights. So, these degrees of freedom independently, or in combination with others, define the complete motion of the end effector. These motions are accomplished by movements of individual joints of the robot arm and depending on the nature of the relative motion; the joints are actually classified as prismatic joints and revolute joints.

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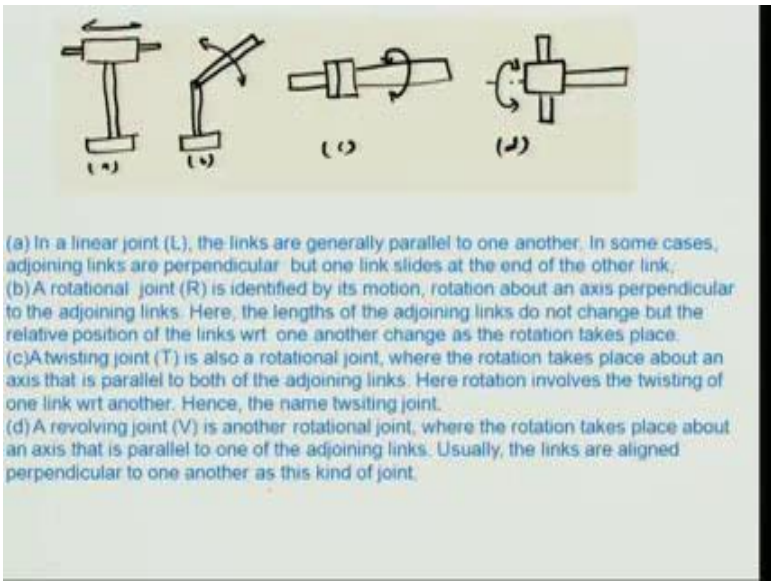

Here for example, showing different cases of a linear joints, rotational joints, twisting joints, revolving joints so on and so forth. This right here is a linear joint. The links are generally parallel to one another. In some cases, adjoining links are perpendicular, but one link slides at the end of other again linearly. A rotational joint R, which is some kind of an angular motion of one joint, with respect to this shaded joint, with respect to the non shaded one. So, it is identified by its rotational motion about the axis, perpendicular to the adjoining link. Here, the lengths of the adjoining points do not change, but the related position of the links, with respect to one another change, as the rotation take place; obviously, there is also twisting joint T, which is also the rotational sort of a joint. Now, it is not about really changing the distance, but about changing the angular orientation of the axis 1, with respect to that of axis 2.

So, that is how twisting can be described. So, this rotation involves twisting of one link with respect to another; hence, the name twisting. The revolving joint, V is another rotational joint, where the rotation takes place about an axis that is parallel to one of the adjoining links; for example, in this particular case, this is the axial center and this joint goes all round or vice-versa, as has been illustrated in the figure. So, this can be typically, a revolving joint. Usually, the links are aligned perpendicular to one another and one of them is revolving around the other.

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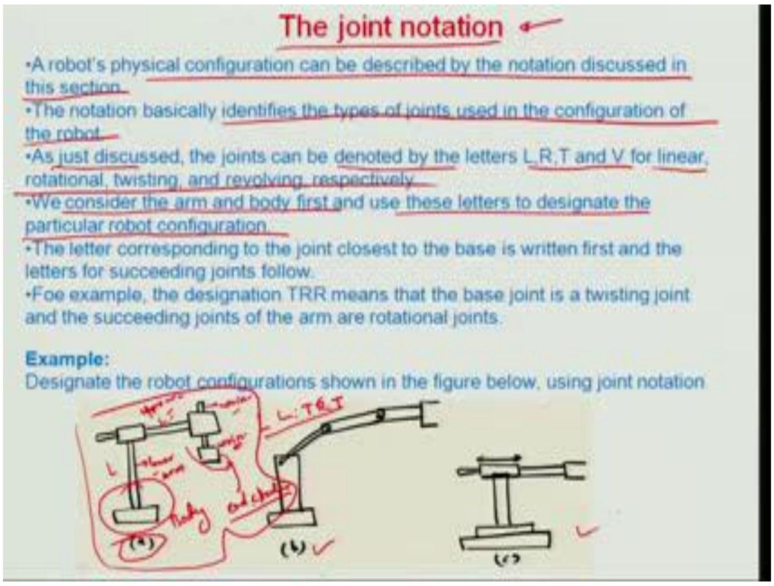

So, this is how you classify all the different joints of a robot. There is a certain standard way to describe the joint notation and I am going to just, show you how to describe that. The robot's physical configuration can be described by the notation, described in this section. The notation basically, identifies the types of the joints that are used in the configuration of the robot. As just discussed before, the joints can be denoted by the letters L, R, T and V for linear rotational twisting and revolving, respectively. So, if we consider the different robot arms, which are here in this example, we could be able to give a joint notation to show these arms. So, for this we consider the arm and the body first, and use these letters to designate the particular robot configuration. In this particular case, this is the body. Let us say, this is the body portion and this is the lower arm. This is the upper arm and this is the wrist region.

So, we can consider this robot to be a configuration of LL; that means linear lower arm, linear upper arm and then, followed by a twisting wrist, and also a rotating wrist. So, this capability of the movement, rotational moment and then again, a twist on the end effector itself. So, you have the lower arm; you have upper arm and you have the wrist here and then, you have the end effector here. So, this can be a represented therefore, by LLTRT, which means that you have a linear lower arm, a linear upper arm, a twisting wrist and then, also a rotational wrist and a twisting end effector. So, this is how you are describing the full configuration of this particular case A of the robot. Similarly, you can make other configuration, B and C, which we will probably, discus a little bit later. So, in the interest time, I will close this module here and then, we also have a portion of the course, which is still left over, which includes how the you know, co-ordinate system can be mapped from a local to a global coordinate system for the robot and the vice-versa, and they are basically, kinematic transformations.

Then in a similar manner, as I had earlier illustrated while doing the computer aided design in the first part of this course, and I will probably like to derive some of these in the next lecture, but this lecture would be the last lecture of this whole session. It will be sort of a rapid lecture with little bit longer duration, about probably, close to about 40 or 45 minutes, and this will be posted and it will come on line on the 26th, that is Monday of October. So, up to this particular week, we are going to post only these five modules, starting from lecture 25 all the way to lecture 29, and the 30th module will be web posted on 26th.

So, as of now, good bye.

Thank you .