ROBOTICS

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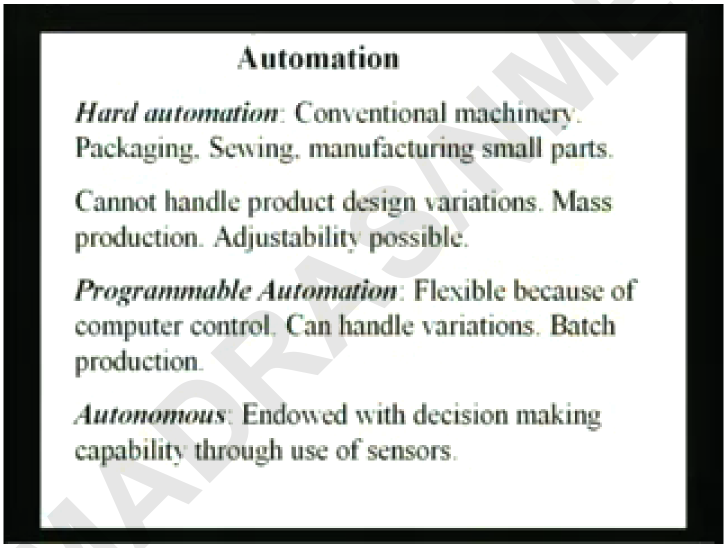
Lecture No. 1

Introduction to Robotics (Time 0:42 min)

Friends, welcome to this course on robotics. I will be giving the introduction, this is the first lecture in this course, and in this lecture I will give you an overview of what the area of robotics is and in the subsequent parts of the course, we will go through the more details of this particular area.

So let me begin without much preliminaries by directly going to the subject of robotics, giving you details beginning with what we call as automation (Refer Slide Time 1:17 min)

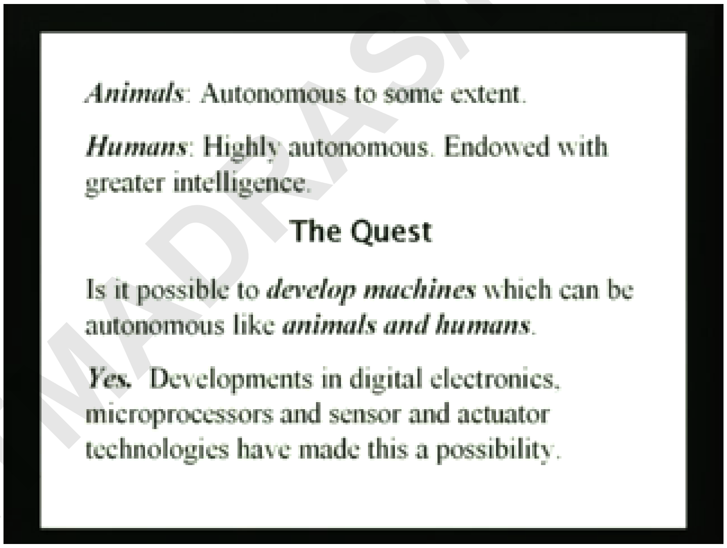


There are two types of automation—one is hard automation. This has been there for long time; most of you are familiar with it both at home and in the industry or elsewhere at work. Familiar examples are sewing machines, washing machines, electric irons, these are all forms of automation. These are what are known as hard automation, any of these forms, in the sense that you cannot do much of a change over from one particular type of work that the automatic machine does to another type of work that you desire. It cannot handle product design variations; this sort of automation on the shop floor, if there are changes in the design of the product, these sorts of automation cannot handle. But it has served us well for several years. For example, you have these automatic devices in a lathe, you have these in a shaper, which has served us very well. Subsequently people came out with what is known as adjustable automation; you want to adjust the stitch length in your sewing machine there are some adjustments which are provided and you could adjust the stitch line; similarly you could adjust the pitch of the screw turning on your lathe, and so on. These are known as adjustable devices, which have been used after people sought a variety of products, but of the same nature. Subsequently came what is known as programmable automation, though it is not very clear as to when this emerged. This began particularly with the arrival of computers, when people started reprogramming machines to do a variety of tasks, and then we have come to the highest level today, what we call as autonomous devices. Robots belong to this class of autonomous devices and are perhaps a very good example of what can be achieved if we combine the power of the microprocessor with conventional automation systems and arrive at very powerful systems.

The number of systems which are available to you in this class today are enormous; it is very difficult to describe or list down what are the various systems which fall into this class of highly programmable and autonomous systems.

These autonomous systems are endowed with decision-making capability (Refer Slide above) and that's a very important thing. You would like the machine itself to take decisions, rather than human being continuously interfering, resetting or changing it.

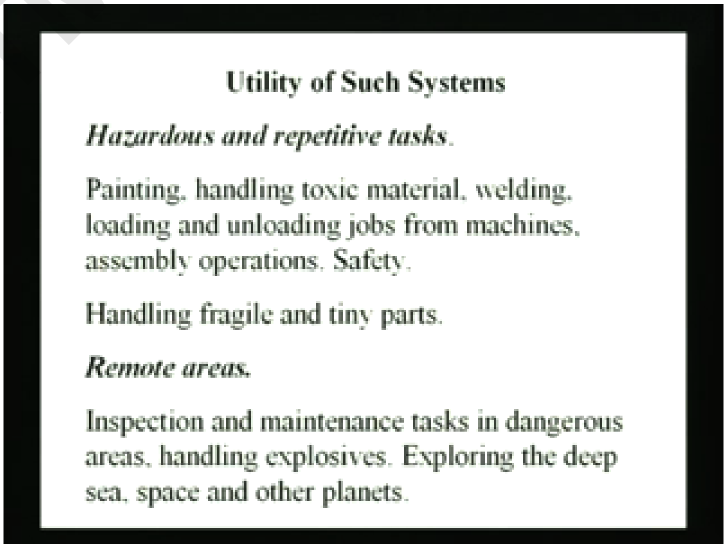
If there is a fault, the machine itself detects and corrects itself. So we have slowly reached this high level of automation and we are tending towards living beings; (Refer Slide Time 4:10 min)



animals have certain degree of autonomy. When they move around, they see food, they move towards it, they sense the presence of food or a threat through several ways: through sight, through smell, and so on. They react to the environment and do what they desire or what is best for them at the given moment. Perhaps among these, the most autonomous devices or autonomous capabilities are possessed by human beings; they are the most advanced in terms of autonomous capabilities. We think, and we react, and we can change our actions, if we can plan new actions—this is the highest level of autonomy which most of us encounter.

(Time 5:05 min) Now where does the robot fall into this? Many people seem to think that robots are like human beings. It is not really so; we can develop machines which can be autonomous like humans, but do not reach the same level of autonomy. This is because there has been tremendous development in digital electronics and a lot of development in sensors; all these put together, the marriage of these devices together, have made it possible for us to now come out with autonomous devices, which are, many a time, called robots. There is no definite definition of robots; I shall now show you a short clip to indicate to you how much autonomy is possible, when we have a marriage between electronic systems and mechanical systems. Let's have a view; look at this particular clip. (Refer Slide Time 6:13 min)

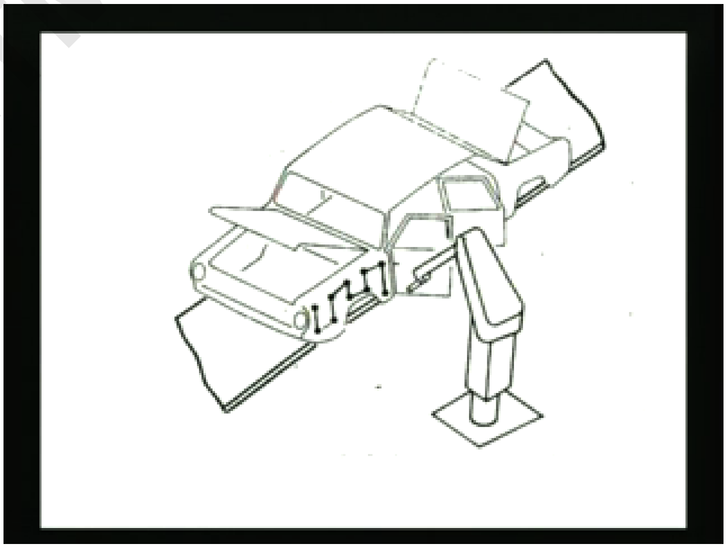
Here is a two-wheeled machine, which is balancing itself. This has been built by an IIT student and this particular machine has been using gyroscopes in order to balance itself. What is the utility of such systems? Such autonomous systems can be used to undertake hazardous tasks. (Refer Slide Time 6:13 min)



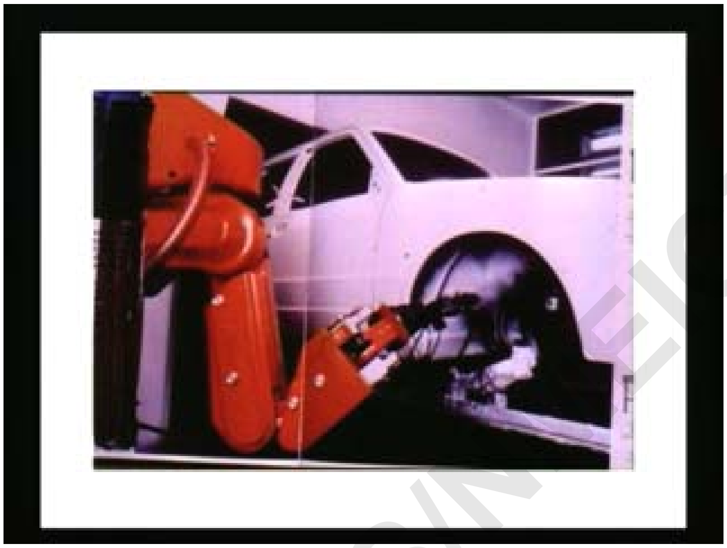
Painting on the shop floor is a very hazardous task because you are handling toxic material and it is injurious to the health of workers; welding is a hazardous task and also welding is a difficult task. The human being, if he has to weld two pipes together sitting on one side, has to weld all round the pipe, whereas he is able to see only one side of the pipe. Then, loading and unloading a job from a press or a lathe is a tedious, repetitive task—this is one more place where robots come in and can handle them with ease.

Assembly operations: for example, when we assemble a chip, you have a very fine silicon vapor, to which you have to solder very fine wires. Lot of precision is required; it is not easy to do because human beings cannot handle such very precise tasks and that's where the robots come. Such tasks, when handled by robots, promise consistent quality. That is a very important reason robots are being increasingly used. Second thing is you can reprogram the robot if there is any change in the design of the product; for example, if you are welding or soldering fifty leads in a chip and in the next chip it requires may be thirty two only, then the robot can be reprogrammed to solder thirty two.

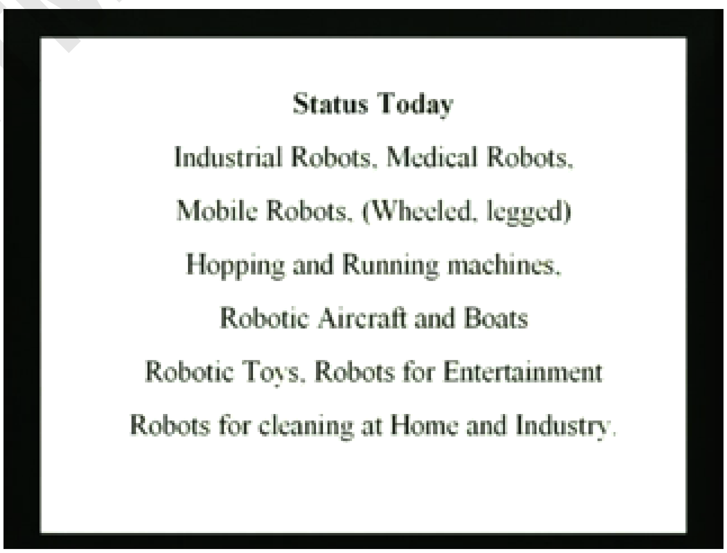
Yet another reason for use of robots is safety; when you are handling dangerous materials, chemicals, biochemicals, and nuclear materials, safety is paramount and robots can handle these materials with ease, with smooth operations and repetitively without fatigue and so safety is promoted. (Time 8:31 min) I have already spoken to you about handling fragile and miniature parts, fragile parts, like vials of medicine. These require careful handling and that is one more place where robots come into the picture and can do the task with much ease. Further, you must all have heard of exploration of planets like mars, moon, and so on here we need devices to move around, gather samples, do tests, and so on. When you want to approach such remote areas, it is very easy to use robots and undertake the tasks. Even for terrestrial applications, there have been recently use of robots for exploring volcanoes, for exploring remote heights in inaccessible places in mountain ranges, all this has been done by robots; or under the sea. you all are familiar with the Titanic and how the wreckage of the Titanic was surveyed by an under-water robot. Now we have seen all these things; let's now go over a few of these things, whatever I have mentioned, the tasks I have mentioned. (Refer Slide Time 10:00 min)



Here I will show a picture of a robot painting a car; the car is seen on the conveyer. The car doesn't stop for the robot to paint it; the conveyor moves at a very slow speed, and the robot keeps painting it. You get a uniform coat on all the cars on the conveyor, because the robot has been properly programmed to repeat the same thing over and over again, infinitely. So that's one of the reasons robots are used in order to get uniform quality and good quality. Let's see the picture of a painting robot; (Refer Slide Time 10:35 min)



you can see the painting robot painting a car here. Notice that these painting robots have a high degree of flexibility in the sense that they can maneuver inside—through the window of the car, they can maneuver in—and paint the ceiling or the roof of the interior of the car. These things can be done; these robots can do it with ease. A man or a worker, if he is supposed to or who is required to do this, will have to carry a heavy painting gun, will have to mask himself to keep the toxic gases out of his breath, and there is always the hazard that there would be a fire. Painting robots are special in the sense that they should be able to ensure that no fire breaks out when they are acting. What is the status today of these robots? (Refer Slide Time 11:30 min)



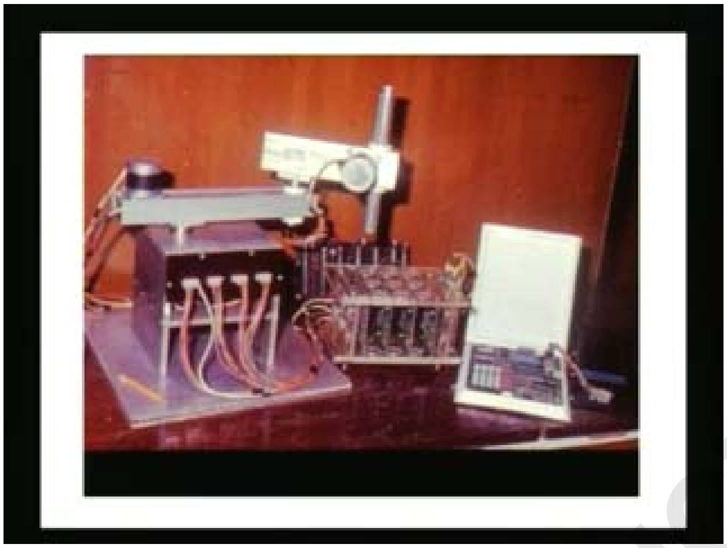
There are what are known as industrial robots; that's the one like the painting robot you have seen earlier. There are robots in the industry for load and unload presses; these are very hazardous tasks. In a press, when a sheet of metal is introduced, there have been many accidents where the workers' fingers have been injured by the moving ram of the press, which sometimes comes on and the worker forgets to remove his hand in time from the loading point, and gets them crushed.

There are medical robots, which help a surgeon undertake an intricate surgery; there are mobile robots, which allow you to go and survey various planets, remote areas in nuclear power plants, or in chemical power plants, inaccessible areas. These could be wheeled or legged—wheeled robots can go wherever there is a smooth surface or an inclined surface and also on the road trail. Legged robots, on the other hand, can step over obstacles. Wherever a human can go, the legged robots can go—there are many places. All you have to do is imagine that wherever a horse or a goat or a human can go, a legged robot can theoretically go; people are trying built devices which will approach that level of confidence and performance. Scientists have also started coming out with robots called as hopping and running robots.

Then there are robotic aircraft; you would have read about this, where aircraft without any pilots go and survey the enemy territory, and guide the land armies towards the enemy's fortifications. These have also been used in rescue operations to spot people who are trapped during earthquakes and other places; these robots are used. These robots are autonomous; they keep flying around and, using cameras on board, people can direct the robotic aircraft towards the target.

There are also robotic boats, submarines, of course, robotic toys are there; they are very popular and we find them in every shop now. And there are also robots for entertainment; little robots—we'll show you one as we go along—which are companions to the elderly and entertain them. One of the most important tasks at home and in industry is cleaning: there are robots for cleaning.

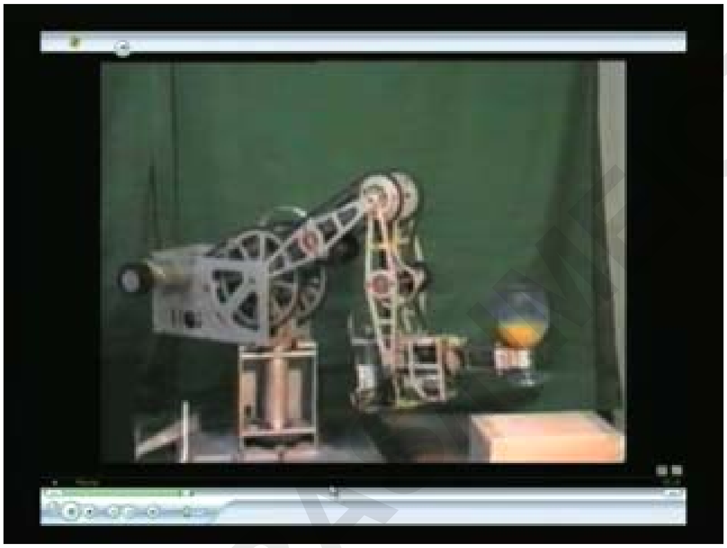
This is just an example of a few applications of robots. If you were to really ask me I would say there are much more applications possible today through this marriage of mechanical engineering, electronics, computer sciences, artificial intelligence, sensors—it is a multidimensional area involving almost all aspects of engineering. If you want to look at smell, some aspects of chemical engineering come in and there is no end—it's a very big area which draws in upon the scientific expertise in almost every technology known to humans. So, we will begin with industrial robots. (Refer Slide Time 14:50 min)



I show you here a simple industrial robot built in our laboratory here; and it is known as SCARA robot. It's a very simple device; it is the earliest one we have built. It has been built with stepper motors, something which most of you are familiar with, and is controlled by a microprocessor which is to the right. It could conduct and replicate simple tasks repeatedly; there are three motions, the main motion is the motion of the base around vertical axis; second, there is a sort of an elbow motion; and third, there is an up-and-down motion of the gripper as it moves up and down. We had put together these three motions using a set of links, a set of drives, stepper motor drives, and also a rack-and-pinion system for the up-and-down motion. We control the stepper motor using the microprocessor, and in between the microprocessor and the robot, we have the drivers for the stepper motor and through such artifice, we control the robot to do a variety of tasks.

Here is another robot (Refer Slide Time 16:00 min) we had in our laboratory; this is driven by servomotors, as opposed to stepper motors. So obviously, in a stepper motor if you

give the number of steps, you will know how much the motor has rotated. In a servomotor the same thing is done by having what is known as feedback. There are encoders here, which provide you the feedback, and as you notice, you will see the motors convey their motions to the various joints through a set of chains. As we go along, we will see how the particular device works. I will show you a short clip on this particular device let me just show you how this device can be used to transfer the contents of one glass into another; it's a clip which runs for about one and a half minutes. (Refer Demo shown in video Time 16:54 min) You can see the robot; you can see the various



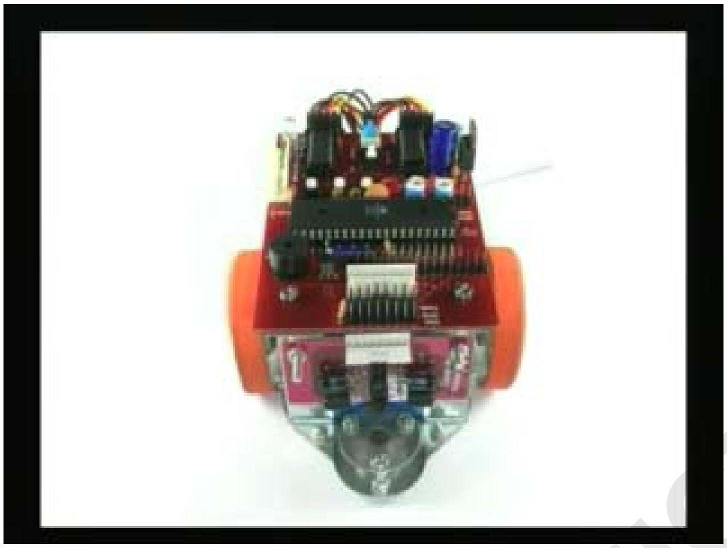
motions. The robot has got two fingers; you can see the robot has approached the glass there containing the orange juice (refer the slide below); the robot is picking it up by the stem and it is now lifting it up; it is turning around, towards us. It stretches its arms, then turns and then it is emptying the orange juice into another cup very slowly. It doesn't want to spill; and there you see it has completed emptying the orange juice into another cup, and now it is returning the stem glass to its original place.

Apart from these, we have what are known as mobile robots. I will show you the picture of one mobile robot (Refer Slide Time 18:00 min), which is a track vehicle, which can explore uneven terrain.

You can see a couple of motors driving through chains, the tracks. Here is another view (Refer Slide Time 18:18 min); you can see the battery—all robots are more or less required to carry their

power on board. They are not connected through wires to a source of power in the laboratory or in the industry. Mobile robots invariably have to carry their source of power on themselves. Robots which are stationary, like the Rhino I had shown you, could be powered from a stationary power source, but mobile robots cannot. So whenever one designs these mobile robots, the ability to carry a lot of power in a compact package becomes a limiting factor.

Here is another little robot (Refer Slide Time 18:58 min), which can follow a line on the ground. This has been built by one of the companies established by one of our students. This robot can follow

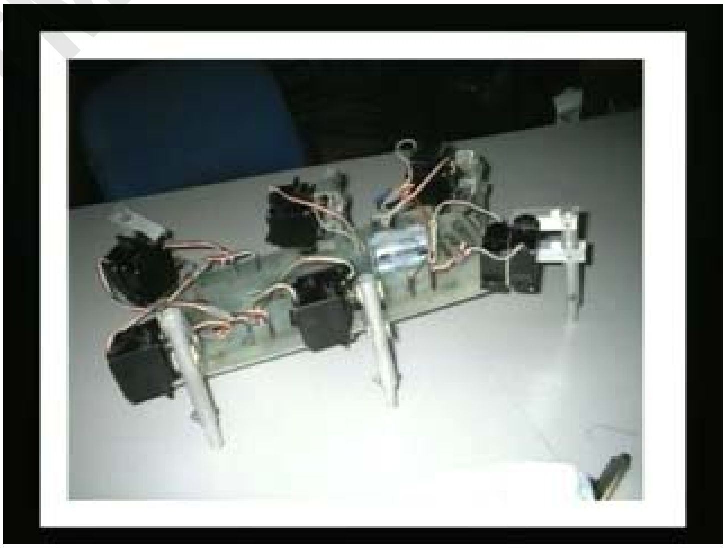


a line, which is drawn on the ground. You have a white line on the ground and this robot follows it, whichever way it is; if you can draw the figure eight the robot will follow it. How does it do it? It does it through a set of sensors, which allow it to sense the position of the line and guide the robot accordingly.

Here is what is known as a walking device—earlier I had told you that walking robots (Refer Slide Time 19:36 min) can cross over obstacles, can cross over debris wherever there has been an accident,

something which a wheeled robot cannot do. Track vehicle can do, but suppose a track vehicle is asked to step over a pipe which is at a height of two feet from the ground without damaging the pipe, the track vehicle will not be able to do it; it will damage the pipe whereas a walking device can step over the pipe and walk off, just like a human being does. Without damaging the pipe I can cross over the pipe; here is one of the earliest walking machines built in our laboratory here, and it has what are known as single degree of freedom legs (Refer Slide Time 20:22 min),

you can see the legs; it's a mechanism. What the mechanism does is it permits the legs to lift itself up, through itself forward, and come down. So it has a single degree of freedom leg; this has limited capabilities. There were six legs in the machine as you could see—three legs on this side, three legs on the other side—and it had a limited capability because it had single degree of freedom legs. The legs were driven by stepper motors, so we could control. When one leg is moving in the air, another leg is stationary. Watch how you walk—you will notice that when you lift and throw your legs forward, the other leg is stationary. In the case of the six-legged robots, here we have a three legs stationary on the ground to provide tripod support and three other legs are thrown forward; thereby it achieves stability. Another robot where we have a leg with two degrees of freedom (Refer Slide Time 21:12 min)—a little bit of more freedom than the previous leg—

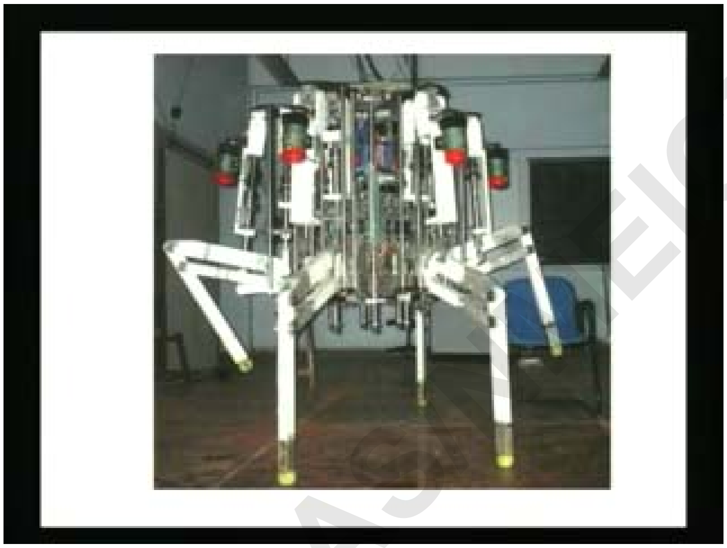


you will notice that this robot has also got six legs. Again we are aiming at static stability in order to keep it stable. There are six legs; you can see the black boxes, these are the servomotors which drive individual legs. Each leg has two degrees of freedom, so two servomotors are required to drive the leg. Now what do I mean by two degrees of freedom? Look at yourself, you can move your shoulder and your elbow—you can move shoulder up and down; you need one motor here for shoulder and another for elbow. Similarly when you lift your leg, you need a motor at the hip joint and also a motor at the knee joint. So this particular robot has got something similar; this robot is shown (Refer Slide Time 22:05 min) carrying a camera on the front to go around and survey places

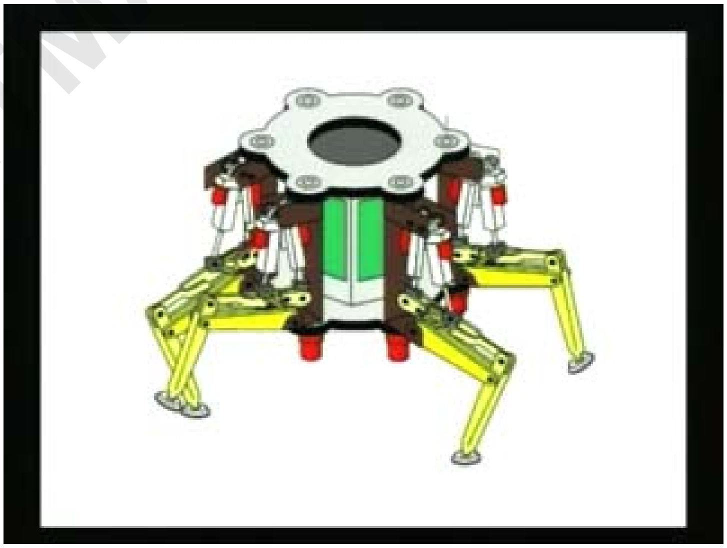
where there has been a little damage. We used this as a laboratory robot for our experiments and it did work successfully. It could see and locate objects with camera and move towards them. Here is a very sophisticated, four-legged robot (Refer Slide Time 22:24 min). This is Ibo, built by Sony Corporation; it has got an infrared sensor in its nose, which can detect the orange ball out there,

and then it has got the sound sensors, which can receive sounds and can determine from which direction the sound is coming. It has many other sensors built in to the system in order to enable it to behave almost like a real puppy. This picture shows the Ibo playing football; the ball is colored orange in order to identify the ball to the Ibo dog. It is a very popular one and it is now being used as an entertainment pet by senior citizens.

We now come to one more robot (Refer Slide Time 23:15 min), which has been built here at IIT Bombay: the six-legged robot called Natraj. This has six legs; unlike the previous robot which also



had six legs, these six legs are disposed around a circle. As you notice here (Refer Slide Time 23:32 min) there are six legs so we have them disposed around a circle and you can notice

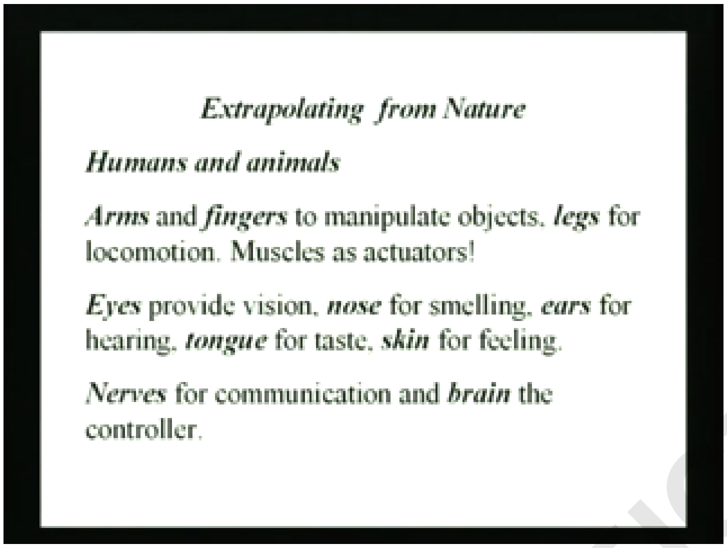


that there are red-colored units on the robot; these are the actuators. They actuate the individual legs and each leg has three motors and a total of eighteen legs. As you can see in here, these red colored units are the motors; each leg has three motors, so six legs makes it eighteen motors. In the central portion is the electronics; there is also a four eight six computer sitting in the central portion, which synchronizes the motion of all these eighteen motors in order to arrive at a particular way of walking. That's what we have done with our Natraj robot. Now I will show you a clip of the Natraj robot; you will watch the robot walking forward and backwards (Refer Demo shown in video Time 16:54 min) as it walks forward and backwards here you will see

the size of the robot in comparison to humans around it. You can have a look; you can see the motors, the red and green ones are the motors; then there are ball screws which are used. Now you can watch the walk; you can very clearly see the robot lifting up three legs, throwing them forward in order to move—the front two and the rear one leg are moving. It is a very slow motion because the robot is very heavy; this was the first walk it took.

I am showing you the video of the very first walk the robot had taken; it has taken about two steps it is taking the third; you can see the light from the electronics, the LEDs on the central well which are controlling all the eighteen motors simultaneously. Notice that it is now walking backwards. So this robot can climb because it has three degrees of freedom legs and it can lift the leg up and climb any object.

Now that we have seen all these types of robots, let's just summarize what we have seen (Refer Slide Time 25:55 min). When we extrapolate from nature, we find that there is an equivalence



between the humans and animals and we are trying to imitate these human and animal abilities: that's what we are trying to imitate, the abilities of humans and animals. For example, we have arms and fingers to manipulate objects, robots have similar capabilities; we have legs for locomotion, robots have the similar capabilities; and actuators are muscles in our case, we have electrical actuators, there have been hydraulic actuators and pneumatic actuators in robots.

Our eyes provide us vision, and we have cameras mounted on these robots—I showed you one little walking robot with a camera which is used by it to see various objects around it.

We have of course many more additional sensors like the ability to sense smell; scientists are trying to develop equivalence for this, which could be used in robots. We can hear; robots can hear using microphones, convert the sound into something useful;

we have a tongue in order to taste food or whatever it is, one day scientists hope they could come up with a robot for a similar purpose. And we have some very surprising sensors like the skin, which can sense temperature, which can sense touch, tactile sensing, people are attempting to come up with sensors of similar nature for robots, and we have nerves for communicating with the brain; there are electronic devices communicating with the computer in a robot.

So when you look at nature, we are trying to mimic nature through robotics and many a time, in order to understand robotics, it suffices if you understand the corresponding nature. Whenever I try to explain to students how an arm works I have shown you how to transfer orange juice from one glass to another I usually use my hand as an example and tell them that look if I have to command you to rotate your shoulder or your elbow by this much, ninety degrees, you would respond and the muscles would act as actuators and they would fold the elbow. In a similar fashion, in a robot also, we need these: we need the muscles in the form of motors, we need something which could hear our command

and convert it into a command to the motors and move the motors through the necessary angle.

So we can always use the analogy of the human being or an animal in order to explain many of the things that these robots could do. We do it more easily, we do not realize how complex it is to convert our performance or to make a machine, which would mimic our performance, is quite a complex task.

Now here I will show you something that mimics fish (Refer Slide Time 29:14 min): a submarine which goes under water, which was built by one of our students. There is a small propeller,

which is not shown here, and it has some electronics which allows it to sense the quality of water in a pipe or in a tank both on the surface and below the surface and transmits this data to a land station. Here is a photo of a medical robot (Refer Slide Time 29:40 min); any surgeon if he wants to operate, he cuts open the body and then operates. This is always a dangerous thing because

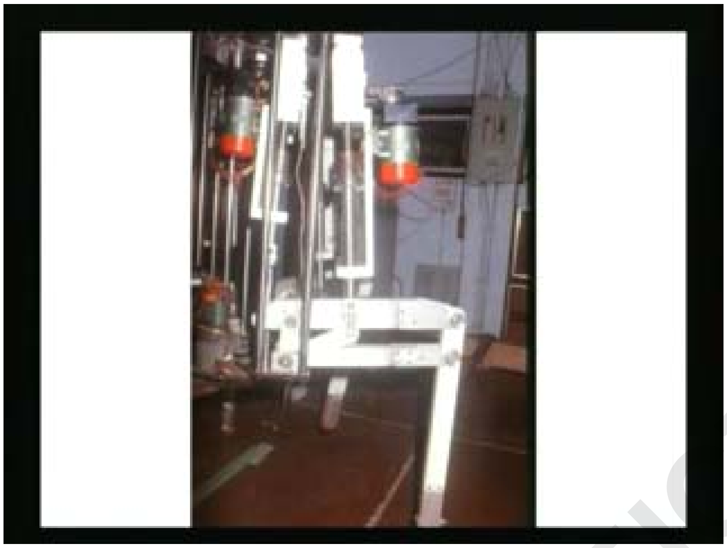
many bacteria can get in and infection sets in.

Now what they do is they make a simple keyhole and through the keyhole, they send a little device in order to cut or suture or suck blood. The devices are made tiny, and they are sent in through a tube; you can see three tubes being sent into the body in this particular picture—one tube carries a camera so that the surgeon can visualize what is going on and then he guides the little robot, which is passing under the tube and guides it and commands it to do the task which he thinks it ought to do. Having seen the various types of robots, let us see the robotic components (Refer Slide Time 30:37 min): here are the three motors which we had used in our Natraj. We had converted the conventional

motors into servomotors. You do get readymade servomotors also; in these motors you have a feedback. Let's assume that the motor rotates through about 20 degrees; how do you know whether

it has rotated through 20 degrees? Obviously, a potentiometer will allow you to determine how much rotation has been made. You can always measure the voltage output of the potentiometer and determine. Such devices are incorporated into servomotors and with the assistance of two electronic boards which are shown, one can command the servomotor to rotate to the given angles and so on.

Here are the examples of servomotors. You will be seeing this as you go along the course (Refer Slide Time 31:30 min). Here is the leg of the robot; you can see the three motors in the Natraj



which we have built—the reddish looking ones are the servomotors I had shown in the earlier slide, and these three serve to move the foot up to down or to the side, left or to the right, or to the front or to the back. This is what the three motors allow.

So you see you have the up-and-down motion, which is provided by one of these three motors; a forward-and-backward motion provided by the second motor; and the ability to look right or left, provided by a third motor. We have designed a special mechanism for the leg; this mechanism allows us to decouple these motions to a certain extent, if not fully, and, by commanding these three motors, we will get a variety of motions for the tip of the foot of Natraj.

So here is an example of execution of this, all that we know in robotics into something like this (Refer Slide Time 32:40 min). The leg of the Rhino or the other robot I had shown you earlier

are somewhat similar; if you watch your own leg and your hand you compare them the shoulder is equivalent to the hip and the elbow is equivalent to the knee. So if you know how to design a robotic hand which will transfer objects from place to place, you also know how to design a leg for a walking robot. Let me just show you a movie of the walking robot, the Natraj robot. It was built at IIT Bombay; you can see it (Refer Demo shown in video Time 33:23 min); it's a massive robot. You can see the

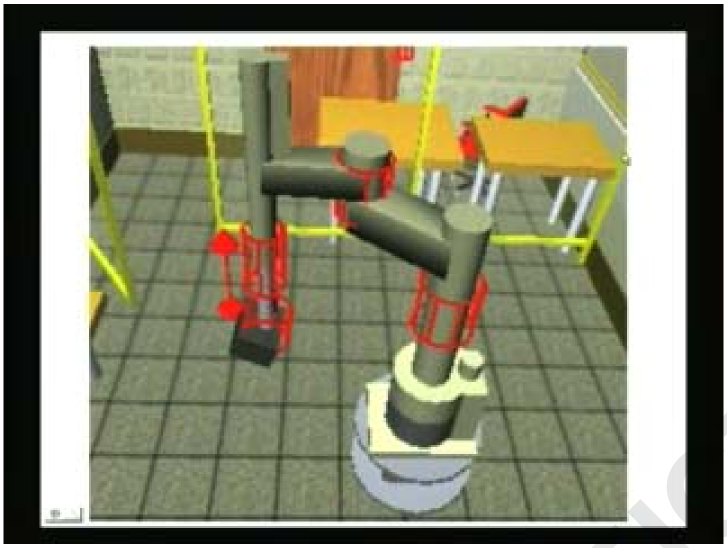
various motors, and I am just repeating this in order to give you an appreciation of the size of a robot. So we have seen these robots; whether their arm and leg are equivalent.

Now let us see how one is going to tell what the robot is supposed to do. The painting robot traditionally does it by what is known as teaching by showing; teaching by walk-through; that is what we call it. Whenever you have a child, when you want the child to write an alphabet, what you tend to do is you hold the child's hand and make him write the letter a or b or whatever it is. The child is holding the chalk, you hold the child's hand and lead it through the phases. So this is called lead-through teaching.

Now this is typically used in painting; as you notice, a worker is handling the robot. He paints the car; the motions at the individual joints of the robot are recorded and when one replays them, you get the robot performing the same task flawlessly and repeatedly.

If the worker has painted it badly, obviously the result would be a bad job of painting. So very skilled workers are used for this task; they do an excellent job and the entire motion of the various joints is recorded and replayed, and whenever the car comes on the conveyor, the robot automatically replays the particular program which has been stored and painting is flawless.

(Refer Slide Time 35:20 min) Here is another way of teaching a robot; we are showing it the task that needs to be done. The entire robot and the environment is



replicated as a virtual world on a computer and the robot is put through its spaces in this virtual world. All the parameters associated with the control of the robot are captured, taken down to the shop floor, and the risk is fed to the robot on the shop floor, and the robot on the shop floor faithfully reproduces what has been programmed in the virtual world. The virtual world contains all the machines sitting close to the robot, all the loading stations, all the components, so without much of wastage of shop floor time, these robots are programmed.

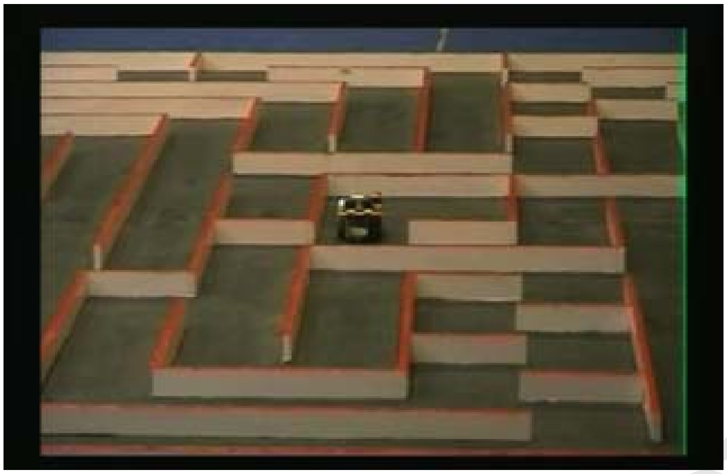
Compare robots with nature (Refer Slide Time 36:02 min): for manipulation, arms and fingers driven by motors and other form of actuation; for vision we have cameras; for hearing we

have microphones; for smell we are yet to develop; for taste we are developing; for feel what are known as tactile sensors; for communication we have wires, fiber optics, and radio systems; and for brains, computers and microprocessors. These we have in robots as compared to nature. Robots need not be so advanced; there are simple devices which can be used where you have hazardous tasks to be conducted. Here I show you one such simple device (Refer Slide Time 36:45 min); this is a device to climb up a pipe. Here you

have got one bellow in the centre and two balloons at each end. Now let us assume that it is pushed into the pipe and the balloon on the extreme left is inflated, it is pushed into a vertical pipe and the balloon on the extreme left is inserted on the vertical pipe and the balloon inflates. The whole thing hangs there because the top balloon is holding on to the side of the walls. Then you push it further and inflate the bottom balloon; the bottom balloon will hold on, and deflate the top balloon. Once you do this, you inflate the intermediate bellow so as to push the top balloon up; though it is deflated you can push it up very easily.

Once the top balloon has reached a particular position, you inflate it and grip the side of the tube with it, then deflate the bottom balloon so that it doesn't touch the wall of the tube and deflate the bellows. The bottom balloon rises and goes up when you repeat the cycle again by inflating the bottom balloon, deflating the top balloon, inflating the bellows—you repeat the entire cycle. This is how a simple device is used; we have used this simple device to climb up a pipe; it can go through curved pipes also.

(Time 38:12 min) So we have seen a lot about various robots, starting from very advanced ones. We have also seen that it is possible to come out with very simple devices for robots. Now I shall close this lecture. In the subsequent lectures, you will learn more details about industrial robots and industrial manipulators but before I do that, I will show you an example of an autonomous capability. In this particular clip you will see (Refer Demo shown in video Time 38:44 min),



an autonomous robot solving a maze. It is going through the maze, you can see that. This has been built by one of our IIT Bombay students; wherever there is a gap, it senses the gap and moves. You can see how it moved from the edge of the maze to the center. I will replay it again; you can see the robot. Whenever it senses a gap, it moves and also you see the speed at which it turns. All this requires a very careful attention to the mechanical engineering dynamics, servomotor control, and artificial intelligence. He uses the artificial intelligence to know where the robot is exactly going and he captures the motions of the robot, the turns it has made, and memorizes them so that next time around it doesn’t make the same mistake. It maps the maze and solves the maze the second time around at a very high speed.

Such robots could be used to explore mines, where you have no reference points. In order to know where you are going you can move around randomly first and determine the map of the mine and use it to comeback. Such are the capabilities; here, this particular example which I have shown you is typically the capability of computer science and artificial intelligence married to mechanical engineering, the dynamics, because if you want to turn so fast, you have to really work out the dynamics properly; otherwise, it will keep spinning on the spot. Then, electronics: you have to sense where the walls are; if there are ambient light changes, the sensors will not show you the exact locations of the wall because it may show you the wall across the gap rather than the fact that there is a gap here. Here is an example of several disciplines coming together into a successful product, robotic product, and an autonomous robot.

I think in the next class we will look at industrial robots; with this I complete my lecture and thank you for your attention.