ROBOTICS

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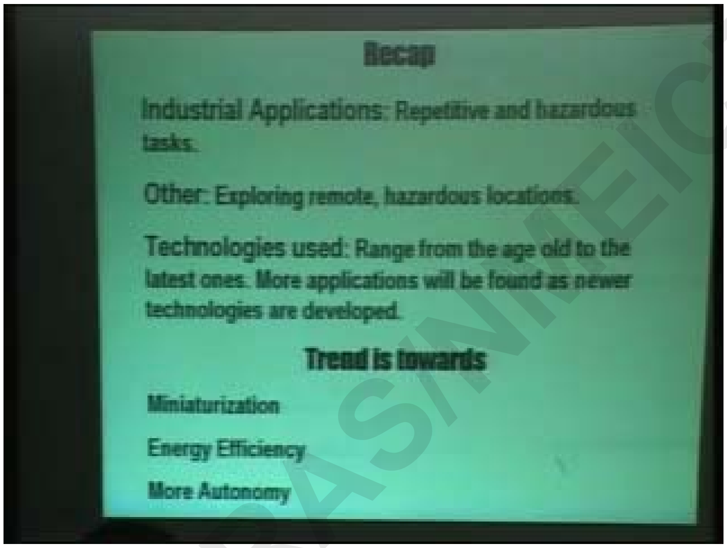
Lecture No. 2

Technologies in Robots

Let us go over what we had talked yesterday and then I will move on to a description of various subsystems in robotics (Refer Slide Time 1:20 min). We had seen yesterday that robots



are used in industrial applications, typically to handle repetitive and hazardous tasks like in forging shop, welding shop, and else where in assembly.

The other applications of robots are in exploring inspection and maintenance in remote and hazardous areas including the outer planet and the deep sea.

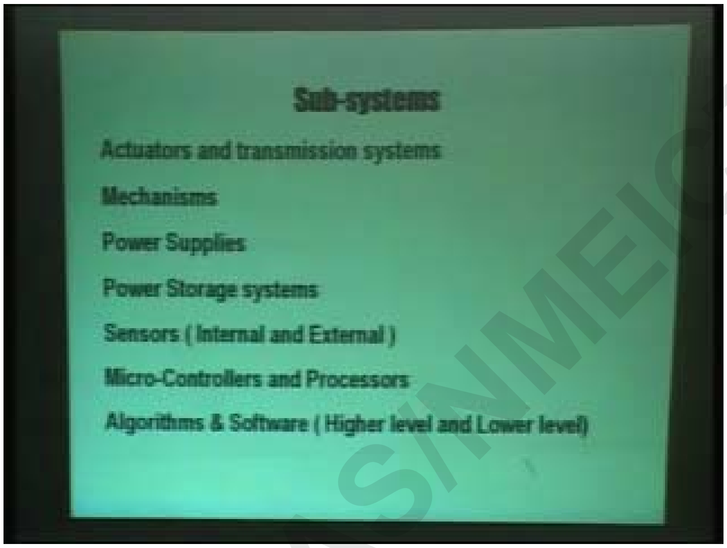
We had run through all these things yesterday, and today I will continue to talk about the technologies and the subsystems used in robots.

The technologies used vary from age-old technologies like the rope and pulley to a very modern one. As more applications come up and as more technologies develop, newer and newer technologies are being incorporated into robotics.

The trend in robotics is towards miniaturization; you want build robots the size of little ants, you want to build robots the size of little cockroaches, particularly when you are handling hazardous material you are looking for very tiny robots.

Energy efficiency is the another issue, because if you want a robot to be autonomous, it should carry its own power pack. So it should be energy efficient. You cannot afford to draw lot of power. That is being looked into in a very big way, and of course, people are trying to give more and more intelligence to robots trying to see more and more intelligent and consequently more and more autonomous robots.

What are the systems that go into a robot in order to help it do all these tasks? Have a look at this slide (Refer Slide Time 1:20 min); as you can see on the screen, there are several subsystems: actuators and transmission systems. Essentially a robot moves around a lot, so you need actuators.



Actuators in general words denote several things like solenoids, motors, pneumatic systems, and so on.

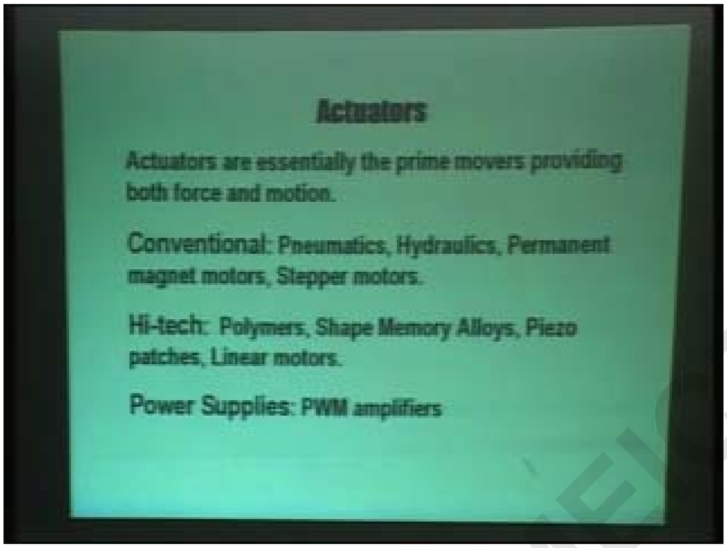
The motors typically rotate and you would like your leg or hand to move during different tasks; you have to convert the rotary motion into a useful motion for various devices.

Then you have the power supplies; motors are driven by special power supplies for amplifiers—that is what they are called—and we have to adjust these because many times these power supplies are on board the robot; they are mounted on the robot itself.

Then, there are power storage systems; if you want a robot to be autonomous you need batteries and instruments, equipment and other things; we will have a look at those. As I told you yesterday, in order to be autonomous, a robot should know its environment; so sensors are essential. Then of course there is the brain of the robots, the microprocessor and the various other computers; microcontrollers, which control the whole system. There are also the algorithms—none of the above would work unless you develop appropriate algorithm; we will have a look at all these things in a while.

Let us first look at the actuators. (Refer Slide Time 5:00 min)

The conventional actuators are pneumatics and hydraulics; these have been around for long time. You also have electric motors.



Here is a pneumatic actuator; it is a simple cylinder with a piston moving. The rod can come out and go out (Refer Slide Time 5:24 min), which you can see; you can see the piston rod coming in and going out.

Air is admitted to this particular port and it pushes the piston out and when the air is admitted to this port at this end, you can see the piston retract. When you use this in a robot you should know whether the piston has gone out so a limit switch is used. It is a typical limit switch. When the piston end hits the switch—you can see a plunger here—this plunger is depressed and the electric contact is completed and that is communicated to the controller. So when the plunger is depressed, it means the piston has reached the end of the piston. These two go together in a robot.

We have what are known as micro switches available, which are similar to these limit switches; but they are much tinier.

Once you admitted air—the exit is here and the piston is here—it shoots to other end it goes with a solid gap to the other end and when you admit air here it goes back to the other end. These pneumatic actuators typically cannot be stopped in between; you can't stop it here.

If you want to change the stroke, what you do is you put a ring out here. So when you come back the ring hits this front phase; it stops there. That is the only thing you can do in pneumatic cylinder.

Lately people have been trying to control and see whether they can attain intermediate range; this is because air is compressed. Pneumatic cylinders are not stiff.

Suppose I put a weight on this, I admit air, I put weight on top, then because of the compressibility of the air, this will go down slightly because of the compressibility of air.

A hydraulic cylinder is similar except that instead of air I pump in oil. I pump oil through a valve, typically something like this (Refer Slide Time 7:40 min): the oil comes in this way and it goes out this way. The cylinder is more or less the same, like this.

In the case of hydraulic cylinder, I can control the motion of the piston: when I shut the valve, it stops here and if there is a load, there is oil below—oil is incompressible— it won't move, unlike in pneumatics. That is the advantage in the hydraulic system; you can use some oils or sometimes even water can be used. Any liquids can be used, any liquid which is incompressible.

By controlling the valve, open and close, you can put a motor on top and control this with a computer; you open and close and control the velocity. If you can control the rate at which the oil flows, you can control the velocity at which it is coming out. You can stop it at any time.

That is the advantage with hydraulic actuators, but there are problems. If oil leaks, there is a potential fire hazard; you don't have any control.

You have to pulse it; once the high-pressure air starts expanding it is pushed. Even if you shut it down, it just occupies the volume there. You don't have any control there you have to pulse it.

So hydraulics has its advantages in its stiffness and pneumatics have their own advantages or disadvantages also. One of the disadvantages of pneumatics and hydraulics is energy escape. In an electric motor, it drives the compressor; so there is a loss of energy there. Then the compressor compresses the air and there is some more loss of energy. The air is in turn expanded in the cylinder to push, there is a loss of energy there in a friction.

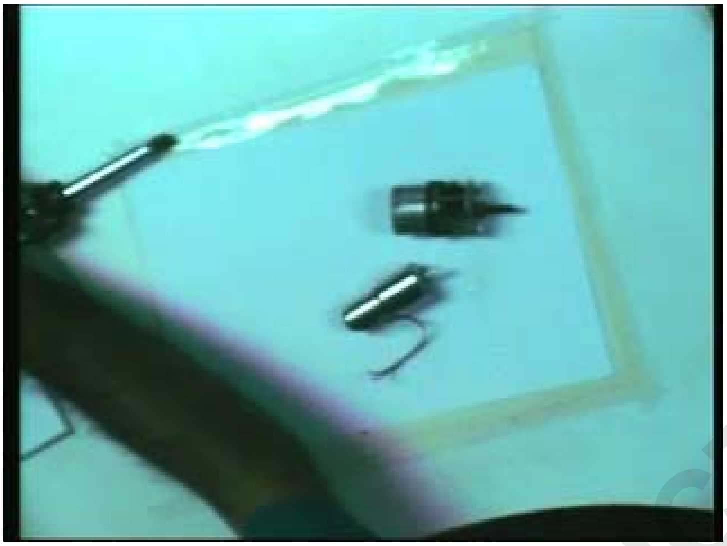
In the case of hydraulics you need a fluid power pack and hydraulic power pack, where the oil is pumped through the valve. You have to generate the pressure and pump the oil. The oil must be very clean, particularly if you want to have a very fine control on the valve. If the oil is containing dirt particles, it chokes up; you may not get what you want, you may not get the motion in the valve.

Oil has to be cleaned; so oil has to be filtered carefully. There should be no air entrapped in the oil. Otherwise you are pumping in air and oil mixed, and the motion will not be what you desire. The quantity of the oil will not come in and the motion will not be the way you desire.

So these are the pros and cons of these pneumatic and hydraulic cylinders and because of their energy efficiency today, the trend is more towards electrical devices, which can be controlled easily.

Direct motors rather than pneumatics are used to carry large weights. In hydraulics tiny part handling and also medium-sized part handling is done through pneumatics because in most of the shop floors, there is an air supply at about six atmospheres that is used by the pneumatic robots. The most popular form of driving these robots or activation of the joints of these robots—we have an elbow here to move a joint—is done by what is known as servomotors.

I will show you a couple of servomotors here (Refer Slide Time 11:45 min)I have brought small servomotors just for demonstration.



Here is a servomotor; you can see the motor is this. There is a gear box; typically these run to the order of about 2000 to 3000 or even more dc.

Now ac servos are also coming up and here you can see the gear box. It is a coaxially gearbox; this will give only very little torque. This is only meant for small tasks, may be about a couple of kilograms centimeters. Inside, there is a planet gear; I will show you some of these gearboxes.

One thing you have to remember is that many a time if you look at the torque output of the motor multiplied by the gear reduction, you will get a fairly high torque as it seems.

But the shaft or the gearbox may not be able to handle that much torque, the tiny ones in particular, the small ones. This particular one weighs about 1 kilogram meter. There is one more here; it is a servomotor (Refer Slide Time 13:22 min); this has a motor and a gear box built into it.

They claim that it can deliver upto 2 kilogram meter of torque. We haven't run it at that particular time.

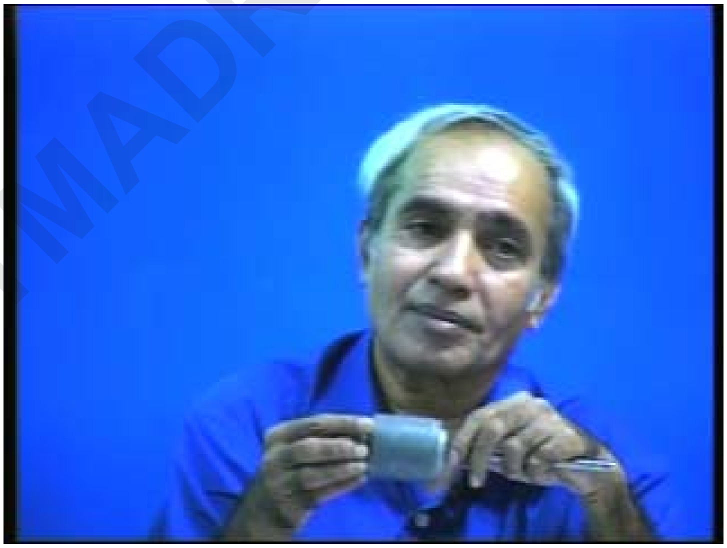
There is one gearbox; it's a conventional gearbox fixed on to a motor. It is not a coaxial; many a time if you want coaxial of the input and the output when the motor shaft is in line, the gearbox output is coaxial; then we can use what are known as planetary gearboxes

or you can use what are known as harmonic drives. It is important that the weight of the gearbox is as low as possible when we use it in robotics. We don't want to lift gearboxes; we want to lift the payload.

As I told you yesterday, unless all the motors—the shoulder lift, the elbow motor, as well as the wrist motor—are tiny or you position all the motors at the base you will have to have a very light gearbox in harmonic drives form.

We will see harmonic drives at a later date. Mostly we use what are known as permanent magnet motors; in the past the permanent magnet motor was not very powerful; we do not get much torque from that.

Today we use what are known as rare earth magnets and they deliver powerful magnetic fields for a given magnetic field of a given rare earth magnet has more torque than the conventional magnet. We don't use electromagnet because in the field coil, they will absorb energy. That is the problem with the electromagnets they will absorb some amount of energy. A very popular motor which most of you all are familiar with is the so-called stepper motor (Refer Slide Time 15:35 min); most of the students who have taken robotics like the stepper



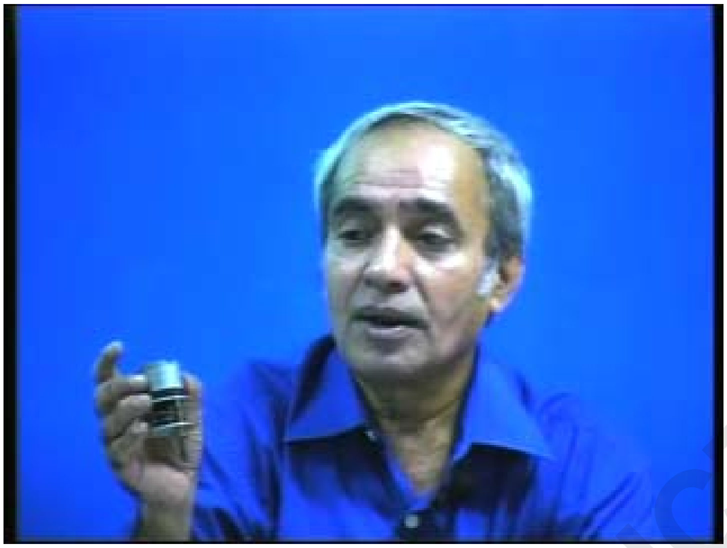
Motor; it gives a trail of pulses; it goes to some 0.8 or 0.9 degrees. I have taken it out of a disc. The moment you give it a series of pulses it goes to 0.9 degrees or 1.8 degrees; it depends on how you configured the electronics. Now you can tell the motor to go through say 20 steps 20×1.8 is 36 degrees; send as many pulses and it goes through that.

The problem with these motors is they are very sensitive to load; you have to very carefully design them. You have to match the load with the motor very carefully in the case of stepper motor.

The servomotor (Refer Slide Time 16:42 min), as the name implies, what it does is it obeys a command and can rotate at a diffusive angle. It obeys a command given by you, like, rotate to 90 degrees.

The electronics and the controller make sure it rotates to 90 degrees; obviously somebody has to tell you that it has rotated to 90 degrees. Most of you might have studied in automated control course about a feedback; somebody has to sense the angle. Some device has to sense the angle through which the output has rotated and communicate that to the controller. Those are typically done by what are known as encoders, we will see it later. So here is one example of servo, and there is another example of a servo (Refer Slide Time 17:28 min).

(Refer Slide Time 17:34 min) These days the motor, electronic controls, are mounted on the motor even for big servomotors. Let us look at it again.



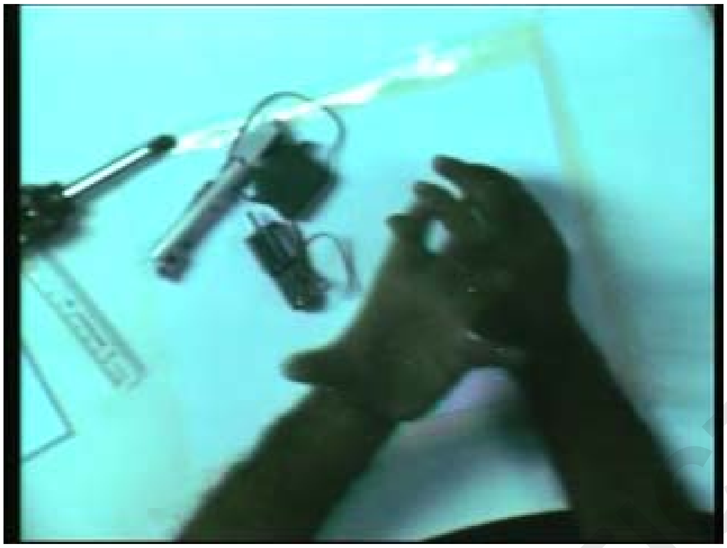
The servomotors essentially consist of a motor, a gear box, electronics mounted on the back of the motor in order to accept the computer commands, then there is a feedback element. We will see what the feedback element is,

which feeds back the position of the output or the position of the input, depending on how you have configured your motor through the controller. Depending on these, voltage or the current to the motor are adjusted by the controller through the motor in order to get the requisite motion.

We use permanent magnet because they give you lot of punch and reduce the weight. So these have become most popular.

Typically dc motors were used for a long time as servomotor, so we had those brushes—commutators—that was the source of parking, noise, wear and tear. Now we have what are known as brushless servos where that problem is eliminated. They have also come up with ac servos;

as we go through the course, you will get more details of all these particular devices. For the moment we will accept that the servomotor is one which, on command, will rotate the output to a specified amount with a specified velocity. Now let us go to more hi-tech things. Today, as I told you, we have polymers which are subjected to an electric field. You keep a piece of polymer like this, subjected to an electric field, through two capacitance plates in this form (Refer Slide Time 19:34 min) and use this for activation. You have shape memory alloy, essentially those we just virtually squeeze when you have an antenna in space and you want to send it up



with a spacecraft. You would like to fold the antenna, keep it inside, and when the spacecraft has reached the orbit, you open the antenna. What you can do is make it out of shape memory alloys; we actually crumple the antenna rehit it and bring it back or retain their shape.

Then there are pieces of patches; these are available in robotics laboratory. They simply look like a sticker may be an inch in size.

So let's say we have a dish; on the dish we put a piece of patch and pass an electric current. The dish will deform slightly; the piece of patch has an advantage. If we put a force on it will give a signal, so you can use it as an actuator as well as a sensor.

One typical application of a piece of patch has been that there is a dish antenna in space and let us say that the antenna is sending a beam towards Mumbai, and you want to deflect that beam towards Calcutta, the other end of the country.

One way is to turn the whole antenna or the spacecraft and point it towards Calcutta; other way is slightly deform the antenna you shift the beam right 15 degrees—1 or 2 degrees in space will translate into several miles on the ground.

The piece of patch that has been used as actuator—we saw that a piece of patch has been used as an actuator for tiny devices in electronic assembly. All these actuators require specialized power supply cord; one of them is the pulse grid modulation amplifier.

If I want to control the velocity of this particular motor, one way is to change the voltage; that's the way we do in dc motors. How do I change the voltage? You all are familiar with the potentiometer. When I put a dc on one side, there is a change in the intermediate position of the rider; you can get output which is different.

So if you have a 10 volt input, you can get 5 volt, 3 volt, or 2 volt. So you keep on changing the potentiometer, moving it in up and down. The speed will change but then remember

this is a resistance-based device; the whole thing heats up. You are losing energy there, so they come up with a speed amplifier. What they essentially do is nothing; they switch the dc at a very high frequency. If you pass it for a certain amount of time you will get 10 volt and if you pass it for a lesser amount of time you will get 5 volt.

So you can control the voltage and there is no loss of energy and heating to some extent; otherwise in electronics it is less but the loss is not as much as it was before.

(Time 22:50 min) These are the various actuators which have been used. Mostly you find the conventional actuators being used very heavily but the trend is towards using the hi-tech actuators, the linear motors. Take a conventional motor; cut it; and unwrap the motor.

So you have all the coils of the armature spread out you keep some magnets; instead of rotating, unwrap it. That's a linear motor; for a long time the linear motors could not provided the requisite punch, but now they have come out with so many special magnets and so many other materials.

We have got linear motors, which are now equipped in machine tools. So in a machine tool for the carriage motion, you have a motor; you have a screw; you have a nut; and then the whole carriage moves up and down. Then from the motor there is a gearbox to screw you can eliminate all these using a linear motor—simply a stator and a rotor all spread out—and it moves. They have become very popular.

Now let us go to the next one. Here I am showing you what is known as a pancake motor (Refer Slide Time 24:16 min). You can see the motor driving a special robot, high-speed robot mechanism built in the

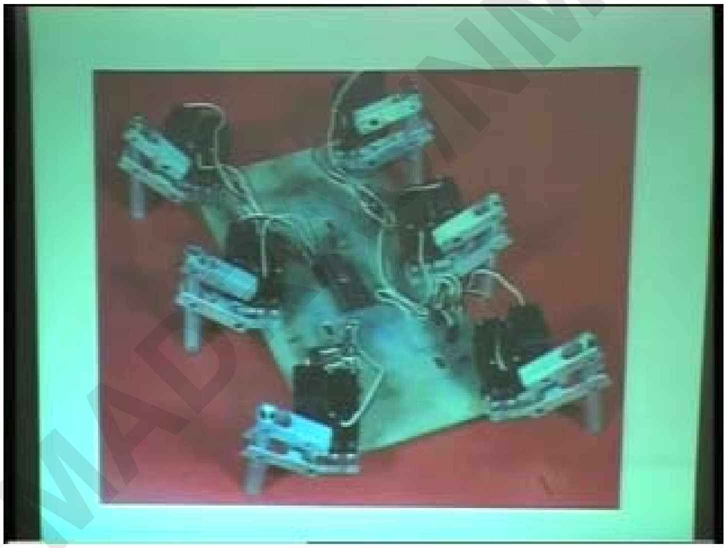
robotics laboratory here and you can see on the top there is a motor; it's a very thin motor the black box on the top is the tachometer. A tachometer essentially senses the velocity; below that there is the motor.

The tachometer is standing on three pillars, that is why you see the gap between the tachometer and the motor.

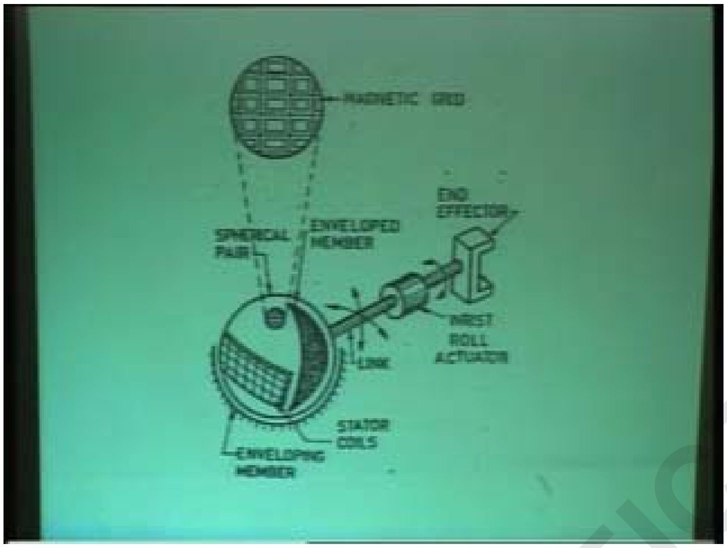
The motor is a pancake motor; it's a very thin motor. The rotor is something like PCB; I won't go into further details. It is just like a PCB; it is very light so that motor can accelerate very fast.

One of the important requirements in robotics is the ability to accelerate very fast. So we have used pancake motors in this particular experiment.

We were trying to build a high-speed robot you can see the electronics in the slide (Refer Slide Time 25:17 min) here is the same I had shown you this particular servomotor. These are in very small sizes.



This is one of our old ideas, some student of ours has come out with this (Refer Slide Time 25:28 min); the stepper motor is conventionally a cylindrical motor.



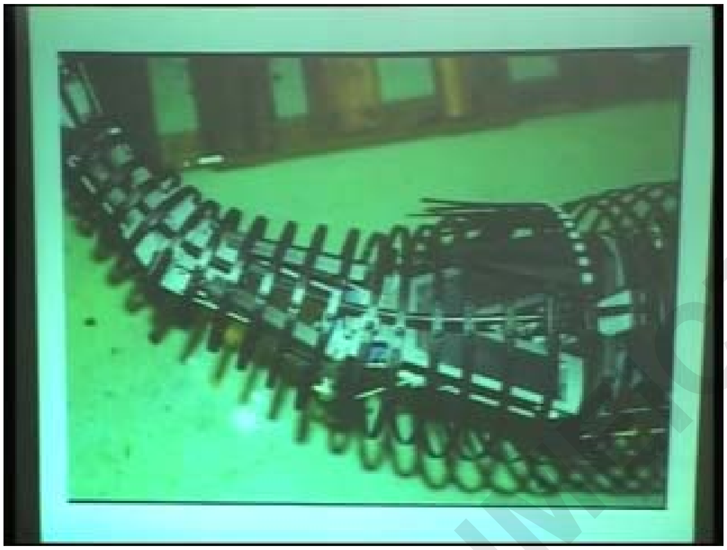
You have the cylindrical motor, there is a cylindrical rotor, and a cylindrical stator. Why not a spherical one, a ball and socket?

You have this magnetic coil with small grids and then you can move it whichever way you want; otherwise you will need several motors in order to get these movements.

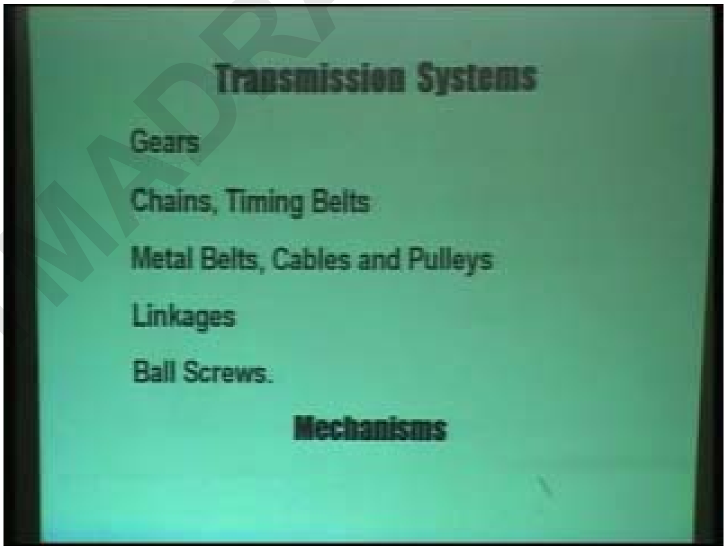
People have been attempting to build this; however, there are problems like lubrication, keeping the two together, and so on. But this is what people are thinking of. They will eliminate three motors because when you have a ball-and-socket joint, you can have several motions including the rotation of the ball around a particular axis; all these are possible.

These fancy actuators, hi-tech actuators, like all these polymers and all have been used to propel things like fish (Refer Slide Time 26:35 min), submarine is usually propelled by a propeller which spins, whereas a fish it moves

its tail, it moves its fins, and then it moves. Suppose we distribute the actuators all over the surface through patches, make the skin and the body deform, and make the body move the way I want, I could correct it. That's what people are trying to do; here is the internal structure of the particular fish (Refer Slide Time 27:05 min).



Once you have got the actuators, you have to convey the motion to the point where you require the motion; so you use gears (Refer Slide Time 27:07 min). These are well known, I don't



have to go over them as you all know well about gears, gearboxes. Lighter the gear, the better it is because the gearbox has inertia. When you want to accelerate

you need mostly a positive drive, that is quite important; chains are used—plastic chains, nonmetallic chains, and timing belts. Timing belts are quite important, then metal belts—

have seen you seen metal belts? You must have seen them; if you go to the carpentry shop you will see the wood working machine. You have the band saw, which is nothing but a metal belt. That technology is being used; so that is the advantage of a belt over a timing belt or a gear.

In your tape recorder, you will never find a gear box inside; you will always find a belt drive because otherwise a small velocity of fluctuation can distort the voice that is recorded or played back. So, metal belts, cables, and pulleys are used these days by most people.

For example there is a robot which can play table tennis, where the entire drive is through cables and pulleys. It's called the Wham—although we have used timing machines in our walking machines, when I want smooth dynamics I would go for cables and pulleys. A timing belt is nothing but a conventional belt with teeth on the inner side; I could have brought one and shown. It engages a gear-like pulley. Then you have the linkages.

The ball screw is a very important component in robotics, particularly in industrial types of robots. Any one of you who has seen the numerically controlled machine—in lathe, for example—would have seen that the carriage motion is through a screw driving and nut. If you want precision and low friction, the balls are kept between the nut and the screw. So it eliminates friction like a ball bearing and you can preload the whole thing, so that you can eliminate the backslash. So ball screw is a very important component.

Just imagine your own hand; most of the time you can understand industrial robots and many robots by looking at your own human body.

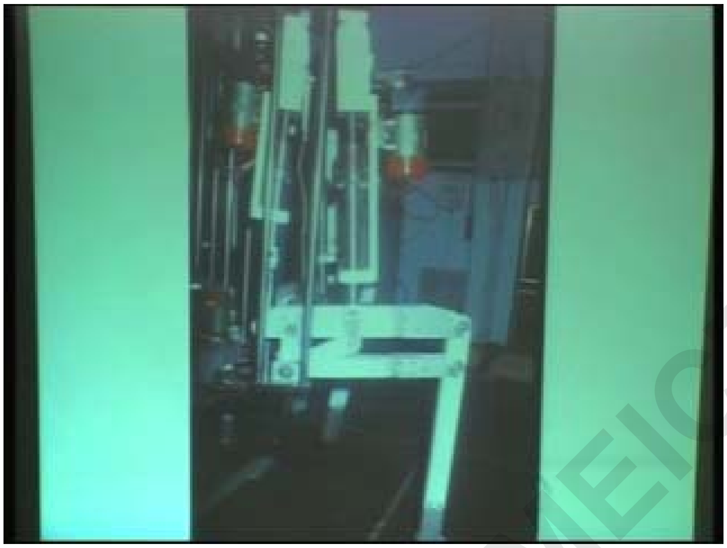
You can't move your shoulder at a very high speed when you are repetitively doing the task, or the elbow at a very high speed. But motors typically move at high speeds, so you have to convert the high-speed motor into a low-speed motor.

One way to do that is drive the screw, and move the nut. The nut is here; so when I drive the screw, as I remove the screw I am holding on to the nut. Otherwise, let me spin the nut. So what I do is I drive this nut; the nut is now like a piston moving up and down as I move here.

So I have a connecting rod like the engine mechanism; the crank will oscillate. You can now use the inversions of the slider crank what I have is the slider crank but I get a large speed reduction because of the presence of the nut and then I convert it. You can also use it in the inverted slider crank as you move.

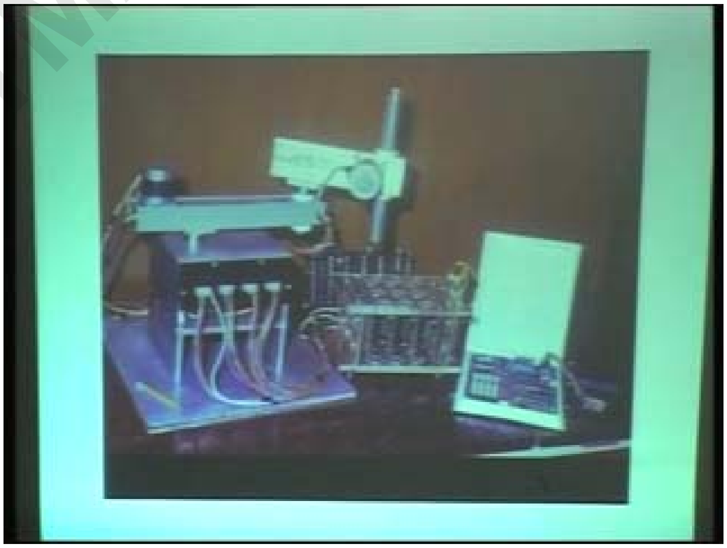
You might have seen the bulldozer, where this pneumatic cylinder is pivoted to the ground and it pushes and opens up. Instead of this, I put this motor and nut here. Instead of the piston moving, the nut moves and drives whatever. These are essentially being used for robots.

Then you have lots of mechanisms which are used for converting this motion into a useful one. Let us have a look at some of the mechanisms (Refer Slide Time 32:00 min); for example, the legs of the



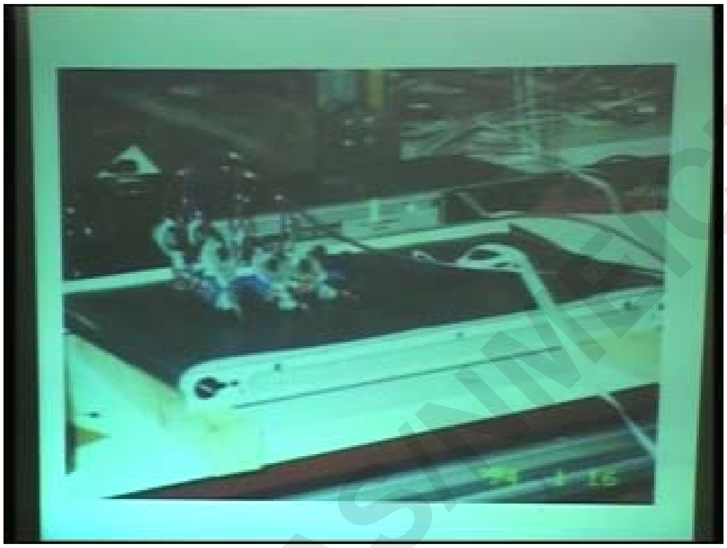
walking machine we had built in robotics lab Natraj uses what is known as pantograph mechanism, with two inverted slider cranks if I go into the correct terminology. The inverted slider cranks as here you can see. You have the green and the reddish colored servomotor; on top of it is a black colored gear box; and on top you can see the pulley and the timing belt. The timing belt drives the nut up and down, which in turn moves the lever at the bottom and the leg lifts up and down like this.

We have used ball screws; the ball screws have limited life depending on the load. Just like the ball bearing has limited life depending on the load and speed of operation, maybe once in three years, you have to replace them. This is the mechanism which converts the rotary motion of the servomotor into a useful motion of leg. Here we have used chain drives (Refer Slide Time 32:58 min); you can see the stepper motor,



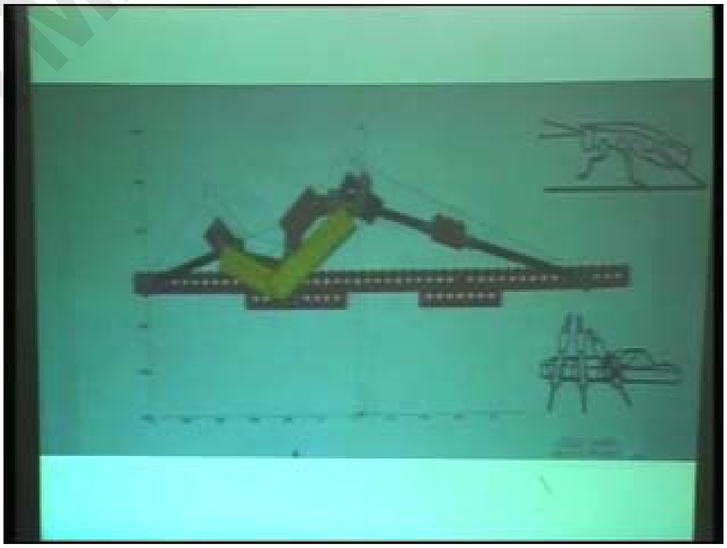
there is a stepper motor that is driving the base rotation like this and there is another stepper motor mounted here, which is driving the elbow joint. The stepper motor works from a chain drive.   So, all sorts of mechanisms and transmissions are used.

Here is a cockroach running on a treadmill (Refer Slide Time 33:34 min); it is pneumatically actuated. There are small tiny many hobbies to make this pneumatic piston; so you can see the pneumatic; this is built as a stand for pneumatic,

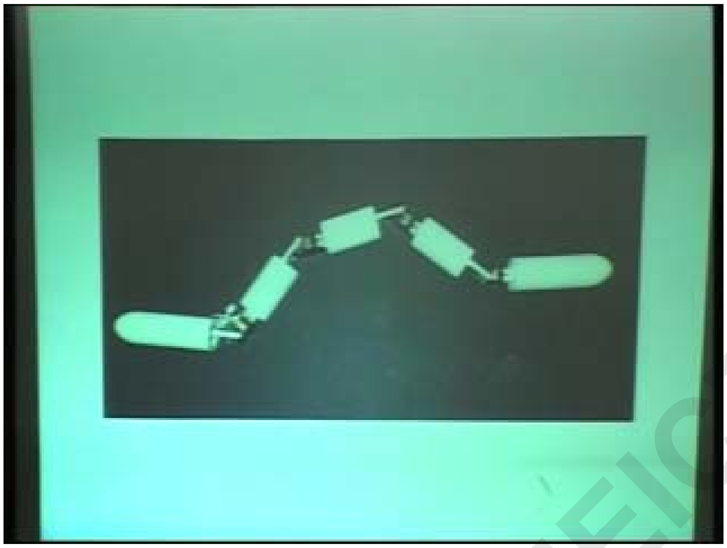


conveying the pneumatics, and you can see the cockroach. There are three legs as you can see. They look like pencils with erasers but they are not pencils with erasers that is a cockroach moving on a treadmill. We have used pneumatics and

a peculiar method (Refer Slide Time 34:15 min). So mechanisms are important when you want to get the desired motions you want.

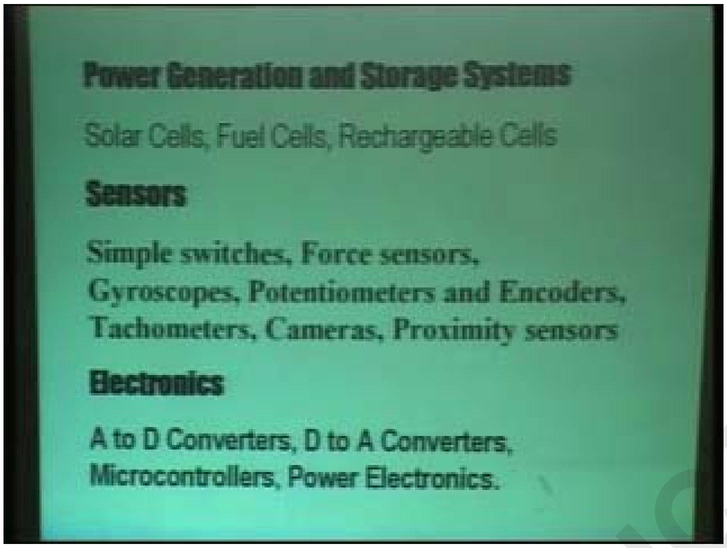


Similarly for keels, which can swim in water (Refer Slide Time 34:23 min) this is the mechanism.



(Refer Slide Time 34:32 min)

So these are the various mechanisms; you see that the area is vast, packed with electronics, and you also have the power generation and the storage systems. I have told you that solar cells generate power. If you want to work on moon or mars or space, solar cells have been generating power (Refer Slide Time 35:03 min). If you have a very large robot, you can put the solid power pack like a diesel engine on top, but for tinier ones you have to find some fuel cells where hydrogen and oxygen combine to give you electricity and these are also used.



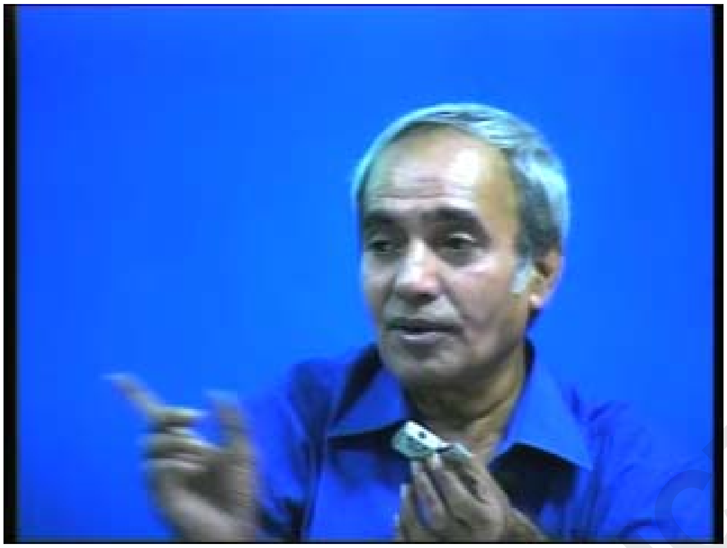
In the rechargeable cell technology, we have the conventional batteries that are lead acid cells, which are very heavy. Natraj uses lead acid cells; we had no choice but we were not getting any others.

A walking machine can run for half an hour on rechargeable cells, but today technology has gone so far ahead that in mobile phones and so many gadgets, you have rechargeable cells, which can store a lot of energy for a given weight.

It takes a lot of innovation in this direction. Recently if you recall they have sent an aircraft which was supposed to stay out there for about a month so without any need of refueling. What it was essentially doing was picking up solar energy from solar cells and for night-time operation or when the sun is not there, this energy was being stored in fuel cells. It decomposes water with solar energy and electricity is generated by the solar cells that are used to decompose water, which is stored as hydrogen and oxygen. When you need power at some other time and the solar cells are in the dark, you recombine them in a fuel cell.

Look at the amount of imagination that is exercised in the design of modern technology, something which we should not forget. There is no limit; it is endless. So this is what we use in motion.

(Time 37:00 min) We shall look at what are known as sensors; they are very simple switches like the limit switches (Refer Slide Time 37:10 min) I have shown you; this could be used as a sensor.



Yesterday you have seen that movie of the rhino robot, picking up a glass and transferring the content. What you did not see was that, below the stem glass, there is a tiny switch. Unless the switch is closed, the rhino's program could not have started. So unless you don't put the glass, the rhino's program will not start.

We were using it for an exhibition; we wanted to make sure that people don't start the robot unless the glass is influenced with the content.

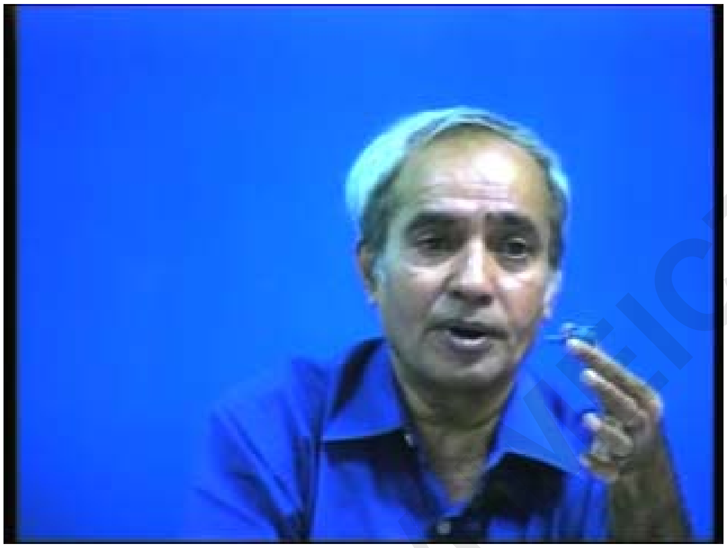
So, a limit switch is a sensor. Many times when the robot is blind, it has no sensors. A conventional robot, when it has to pick up an object, will go up to there and close on to hold the object. If the object is not present, it will simply continue with the rest of the motions.

So what you do is that you put a small switch here: like the refrigerator door switch, there are a lot of things that can be done with these limit switches.

Otherwise a force sensor, Natraj for example, the walking machine—when it puts its legs down, it will like to know whether the foot is down and what is the distribution of the weight on the three feet on which it is standing. You know that it has six feet, uses the three feet to stand on and the other three feet for forward motion. You would like know it, so you put a force sensor or you would like to know how much is the gripping force when you are holding a particular object because it is a fragile object, made of glass, you would like to know and say that beyond that grip you don't move the finger. Once you have reached the particular force any more force and harder grip can break the glass.

So we use what are known as force sensors. Force sensors are numerous; there are number of force sensors which are currently available

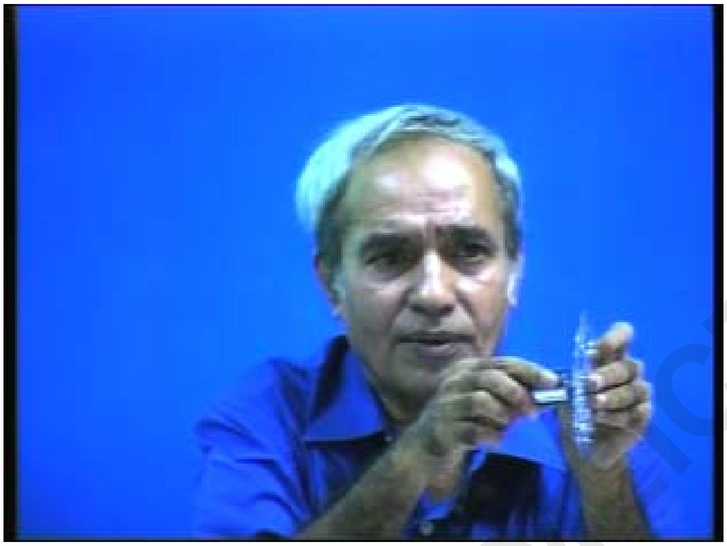
(Time 39:09 min). Gyroscope is something that tells you whether the walking machine or the mobile platform is horizontal or is climbing up or tilted down to one side. Very tiny gyroscopic chips are available—very tiny, very small. Previously gyroscopes were rotating masses, large ones. Now they are used in cars, and they serve a number of various purposes. A car today has several sensors. Here is a rotary potentiometer (Refer Slide Time 39:47 min): I would like to know how much my particular motor has rotated; I connect it to this potentiometer then turn it. It's an absolute way of



Measuring—here one end is 0 volt and the other end is 10 volt, full output. So if you get half way through, it will be 5 volt provided the potentiometer is a linear one; that is, displacement versus voltage would be a straight line—if you draw, it could be a straight line.

So I can directly say how many degrees I have gone; I can calibrate it. Encoders are slightly different; I have got an encoder here (Refer Slide Time 40:30min). It is going to be pretty tough for you to see what is inside. You can see the monitor; perhaps you can see the encoder in electronics. What is this encoder?

It is essentially a rotating disc, which is mounted on the shaft. So something like this: (Refer Slide Time 40:51min) a rotating disc mounted on the shaft. Now you have got lot of



lines scribed out here. You send a light beam and you have a light receiver at the other end. The beam must be very thin as each of these lines cuts the beam; the signal is generated in this; then the light is restored. So you have a measure of how much you have rotated.

But look at the size; the disc inside, which I cannot pull out, has about 2500 lines on it, spherical radial lines; so how thin a line must be will be seen in the receiver and in electronics there is one that gives you the position of the shaft as you rotate. These are known as encoders. These are incremental devices in this, which is an absolute method (Refer Slide Time 41:48 min). It tells you how much you have gone through from the previous position; this is an absolute method.

Tachometers are known as internal sensors—the potentiometers, encoders, and tachometers particularly, because they are used with these actuators.

A tachometer (Refer Slide Time 42:07 min) is essentially a generator.

Depending on the velocity of the shaft, you get a voltage output. Again if you plot angular velocity versus voltage, it should be linear. You can measure the speed at which the shaft rotates and also the angular velocity omega using a tachometer; it is a fairly large tachometer.

When you want to control a motor, you would like to know how much distance it has gone—whether it is accelerating or decelerating; then you can do it much better with control.

You would like to know the velocity just by looking at the position. Say you have given a command to go through 90 degrees to the motor; it started rotating; it would like to know whether the controller would be much more effective if it also knows the velocity at which it rotates.

Because you know it starts from 0 velocity, picks up the speed, and brings it down; that is why a tachometer is used. Sometimes the tachometer information is obtained from the encoder itself; these are fairly rugged tachometers used in the industry.

Like a motor and a generator dc, we have to make it. Here it is linear speed versus voltage. This is an encoder used in some other tinier, smaller units, but there are rugged encoders, which are larger than this. So they come in a variety; I have just shown you a few of these.

Then we have the cameras, vision systems, the proximity sensors—when something comes near, the infrared light is bounced off. The list is endless; it's all your imagination that limits you.

(Time 44:05 min) The potentiometer for example gives an analog signal. This has to be converted into a digital signal because most of the controllers today are digital electronics; in the past they used to be analog, because digital electronics gives you requisite features.

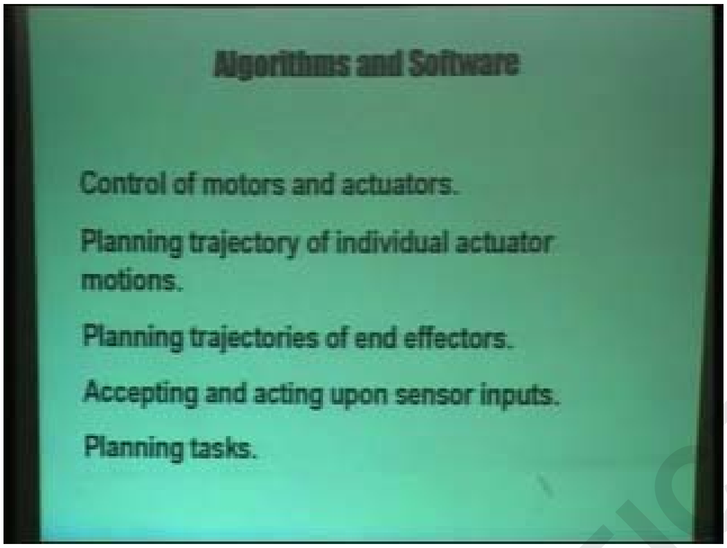
So you have to convert this signal: 5 volts equal to this eight bit word; 10 volt equal to another eight bit word.

So there are analog to digital signals and the reverse is also there. Sometimes the controller gives out the digital signal and that may help in converting it into an analog one to drive some systems.

Then there are microcontrollers—very small, whole computer in a small thing—there are power electronics. I told you about the pwm amplifier; the whole thing comes in a small chip of this size, and in many of these, MOSFETs are required in order to drive the motor.

We can see what we had built for Natraj robot (Refer Slide Time 45:19 min), a walking machine. These are the servomotors and you can see the various electronic boards, which are out there. These were built in our laboratory by our students and were tested by engineers.

Last but not the least, in order to put all these together and make them work, one has to think. That's where algorithm and software (Refer Slide Time 45:33 min) come in. They occupy a very specific



position as important or even sometimes more important than the rest.

You cannot have a machine sitting there if it doesn't know what it has to do and how it has to do—all that is through the software,

the control of motors and actuators. There are various equations to be written. You want the motor to rotate in a particular angle, get information from the encoder, from the tachometer. How to put all these together and control it? It goes in and stops where you want it to; control algorithms are required for these.

Planning the trajectory of the individual actuator motions: do you want it to accelerate; do you want a straight line; do you want a uniform velocity (once it accelerates the uniform velocity comes down); or do you want the velocity to move around some polynomial, some curve of the motor—the motor of the shaft as it is going through 90 or 100 degrees? All these have to be planned by somebody. Today of course as I showed you many of the systems sit on the back of the motor. You just tell the motor to go through 90 degrees and it takes over; so everything is distributed electronics.

You communicate or command to the motor and the chip on the motor, the controller chip on the motor, takes care of all these things. That will look at the load, the disturbances and how to compensate for them.

When you want the robot, say an industrial holding a welding gun, to move along the trajectory, somebody has to plan the trajectory. You will typically give some points on the trajectory and somebody has to plan. Somebody has to plan the velocity along the trajectory. If you are welding along a curve, you should move at a uniform velocity on the curve; somebody has to plan, somebody has to calculate work; they should be the individual motions in order to get that. So, all these are there: planning trajectory of individual actuator motions, trajectories of end effectors, and so on.

We have the so-called kinematics of robots or we have the motorized vehicle behaving autonomously; it has to reach some particular spot and it has to avoid some obstacles. We plan a wheeled vehicle. What is the path it should take? You have got the path; what are the velocities it should maintain or what are the individual velocities and the individual wheels? In case all the four wheels are independently or individually driven, all these are done by the software.

Accepting and acting upon sensor inputs: there is a rock in front as my robot, mobile robot, moves. What should it do? How should it avoid it? How much of a gap should be there? Sensors will tell it where the rock is, how far the rock is. The vision sensor or just a simple proximity sensor in a software environment might be able to sense it, because everything there is known. We know where things are, unless of course something unexpected happens. When a horse is walking along, it has to choose its foothold—where shall I put my feet and at any instant, am I on my two feet or three feet? Am I on four foot or one foot? It will just topple over if you have not controlled all these things. So all this controlling is done

In nature, of course, it is far more sophisticated. When you look at a movie of a lion or tiger running, you see the way the body moves; it is not just the feet running. The head moves, the tail moves, and the body reflexes. All this is done. That means there are a lot of actuators all over the place, which control and simultaneously it watches, it senses, it feels.

So all these tasks have to be planned by somebody and that is where the controller, computer controller, comes in and looks after all these particularly.

(Time 50:26 min) So with this I conclude this lecture just by summarizing that today we have seen the various subsystems used in robots. We have gone from the component level more or less to a broad level. From the next lecture onwards, we will be going into industrial robots, which are used as vehicles, as a means to tell you about robotics to a great extent and later on to touch up on mobile robots, washing machines, and others. Thank you.