NPTEL Online Certification Courses
Industrial Robotics: Theories for Implementation
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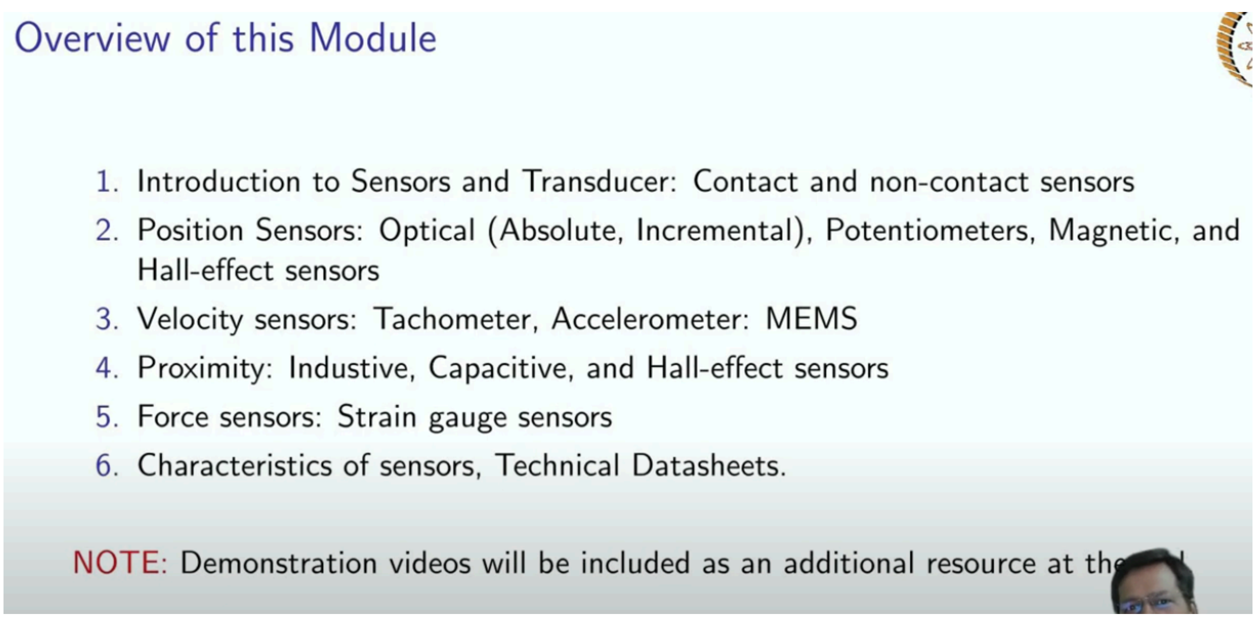
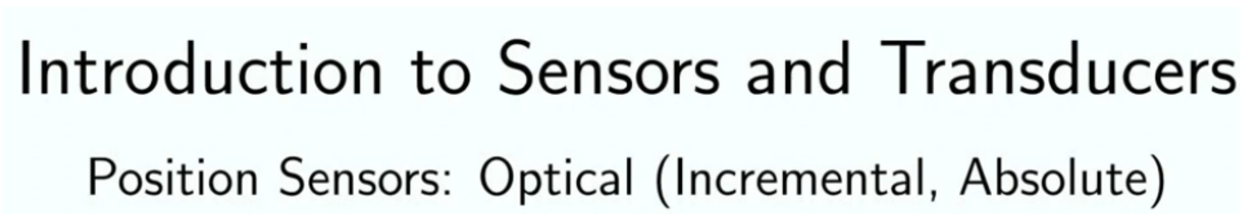
Lecture: 11

Introduction to Sensor and Transducers. Position Sensors

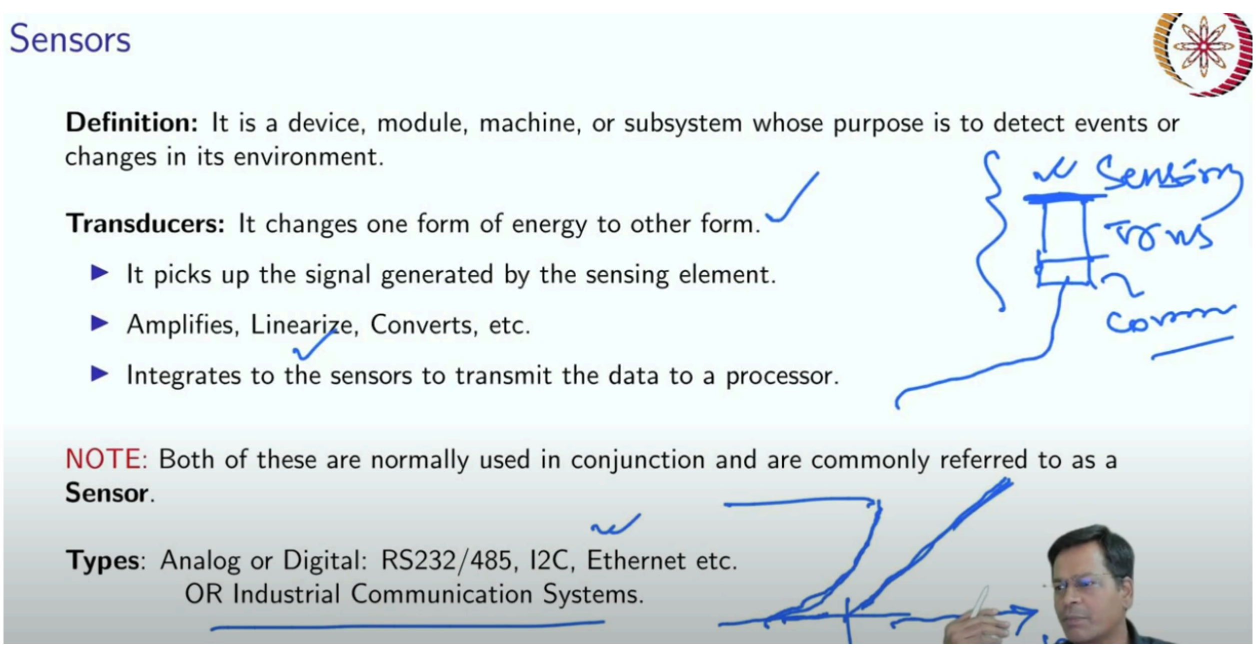
Hello, everyone, welcome back. So, we have already completed the actuators. Now, you are ready to run your mechanical system. Your robot arm can now move, so it should not move blindly. So, yes, you now know, now that you have also seen the type of control systems which were there to do at least position control. So, you see, you require having joint angle sensors at times so that you can give proper feedback. So what is that required? Because once you reach a place, you have to stop there right. Either in a limited case, like you just have to reach there and stop, or maybe you have to go in a trajectory that you saw in the application also. So, yes, now that things are moving, you have to have some sort of senses, not just to move, not just to have a constrained motion or some sort of control in motion. You also should have many other parameters which are to be continuously monitored. At times, Let us say you don't want to. If your robot gets overheated, then your temperature sensor is required, right? So, for various reasons, you need sensors. So without sensors, even humans are incomplete, so with the robot also. So yes, now, at least, you understand you need sensors. So, let us begin with the module called sensors here. That is the third module of this course.



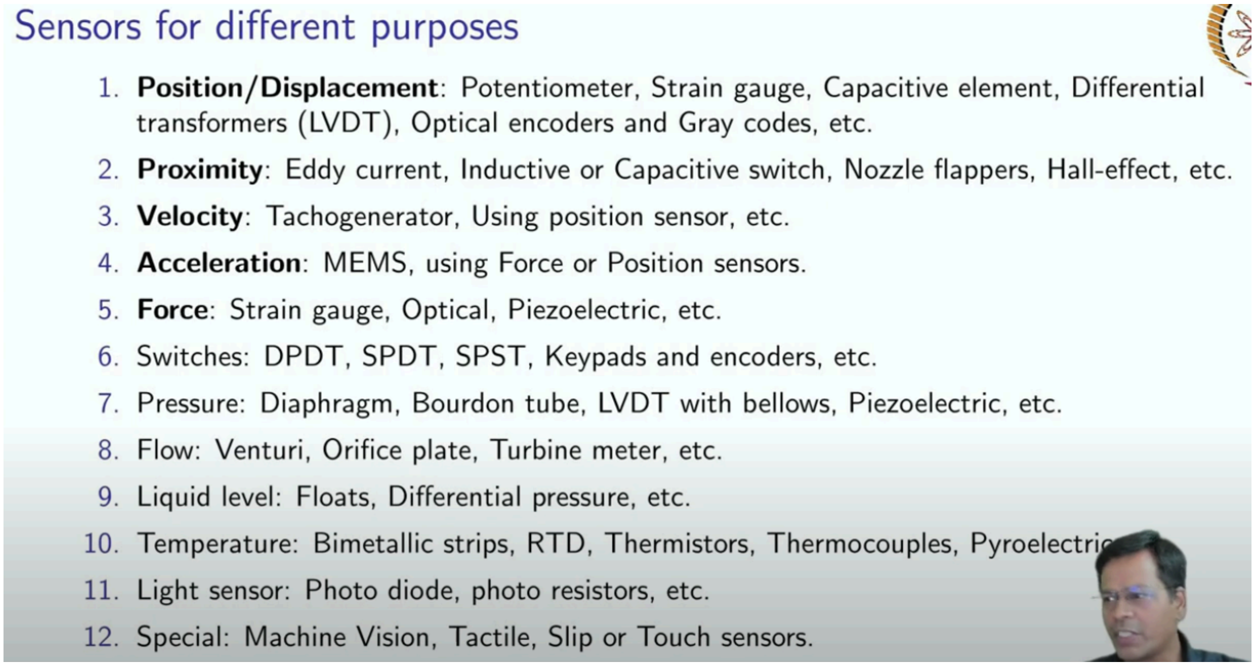
So, in this module, we will be covering sensors and transducers. There is some difference between them. We will discuss that. Contact and different types of non-contact sensors. Position sensors, very, very specific to industrial robots: absolute and incremental optical sensors. Those are very, very popular in robotics. We will discuss potentiometer sensors, magnetic sensors and hall effect sensors, which were very much required, even in the BLDC motor that we have covered already. Velocity sensors, that is, tachometer accelerometer accelerometers, mostly of MEMO type, we will discuss in detail. We will also discuss proximity sensors: inductive, capacitive and hall effect sensors. Force sensor: you have to have some feedback of the forces and torques also, as you have seen already, Yes, force sensor specific kind of force sensor, that is, strain gauge-based sensors. We will discuss and characteristics of sensors that will characterise a type of sensor if it is in our hand. We have to see different properties which it can give us. So, that is what is mentioned in the technical data sheet also. So, all these will be covered in this module. The demonstration video together will be covered as a resource video that I will be sharing with you all at the end of this module.



Let us start with sensors. First, I will introduce you to sensors and transducers in this lecture, and specifically, I will cover position sensors, optical sensors, to be more particular, of two kinds at least, that is incremental and absolute optical sensors, that is, to sense the position.



A sensor is a device or a module. It comes as a module, not just a device. It may be a machine. It can be a subsystem whose sole purpose is to detect events or changes in its environment. If it is an environment, let us say temperature, I have to monitor how it varies over time. Sometimes event, let us say something, is every time it is coming and going back. Coming and going back, I have to count how many times it has come, and it has gone back. So, that is the event number of events I want to count. These are just a few examples. There are many. So, yes, what are transducers in that case? If this is a sensor, what are transducers? It can change one form of energy to some other form. Let us say I am sensing pressure, But pressure actually cannot be fed back to a computer sometimes. So, in that case, you have to convert temperature to other forms, that is, electrical energy form so that it can be taken up by the computer system. It picks up the signal generated by the sensing element. So now you have something which is a sensing element, you have a converter which converts from one form to another, and then you may have some communication device which can transmit it to a long distance. So you have a sensing element, you have a transducer, you have a communication unit. So, all together, a pack will now be referred to as a sensor. So, sensor as such from now on, if I say sensor means it includes everything. It includes the sensing device, it includes the energy conversion device as well as the communication device. So, it picks up the signal generated by the sensing element it amplifies. Sometimes, it amplifies if the signal is very, very, very, very weak. So you cannot have that value directly to the. Even in electrical form it is not acceptable to many of the devices. So you may be required to scale it up, transmit it, then appropriately scale it back and use it. Sometimes, things are not linear. You have to linearise the thing. Your, let us say, barometric pressure varies with height, something. So as you go down into the atmosphere, go down from a certain level, from the ionosphere, so as you come down, your pressure goes like this: So that is non-linear, so it is very difficult to interpret when it comes to your system. So maybe your sensors would give you something like this straight line fashion: so as you are going down from a higher level to a lower level near to the earth, the pressure is increasing. So this is going down, down, down. It is the negative scale, to say negative times of h, and then this is your pressure. So you have converted your signal, which was initially like this, now it is like: so that is something which is known as linearisation, and then it can convert from one form to another. Sensors now integrate a device which may be useful to transmit data over a long distance. Sometimes, they convert the data to an acceptable form which is taken up by, which can be easily taken up by the processor. So what kind of data that your processor can normally take is a digital signal, normally in the form of RS-232/485, I2C, or Ethernet. These are some of the kinds which were there in your microcontrollers. There are industrial communication systems are also there. Now, you are already, you are aware of Profinet, EtherCAT, Profibus, and various kinds of industrial communication systems.



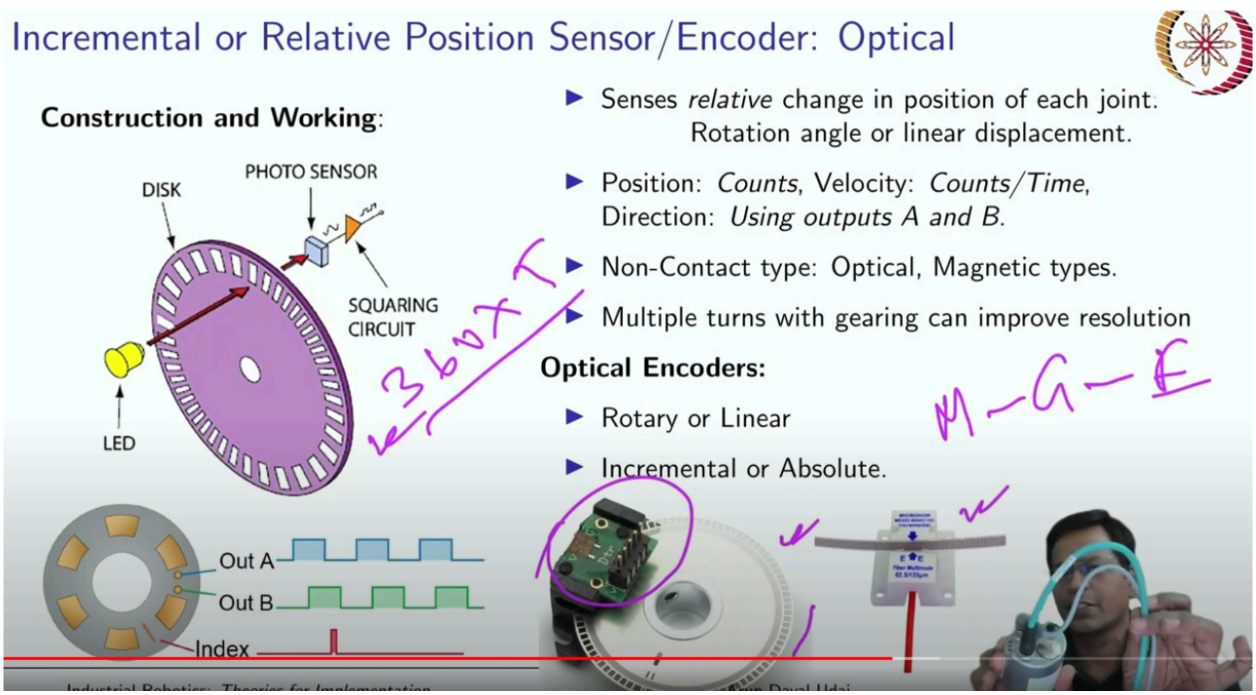
Let us move ahead. So, what are the different types of sensors that are there in the industry? One of the very common one that you know is now, at least, you have to have joint angle feedback. So, angle feedback, your joint is moving, and you want to know where I am, so that is to be sensed. So, at least position or the displacement sensor is required. There are various types of those sensors. It can be a potentiometer sensor. It can be a strain gauge sensor, capacitive sensor, or differential LVDT transformer. Are there optical encoders? Is there a Gray code? We will see a few of these in this module also. So, that is position sensor, proximity header, current inductive, capacitive. At least these two will be covered in this module.

A Nozzle flapper is a pneumatic type of sensor. The hall-effect sensor will be covering this also. So, velocity sensor, cogenerator velocity. The sensor is there in your speedometer also of your vehicle so that it can detect the velocity, and using the position sensor, also-you can just take a derivative of that can obtain velocity. That we will see. Accelerometers are there, that is there in your mobile phones also so that we will see that also. So, we will see a type of accelerometer, which is a MEMS sensor and may be using a force sensor. Also we will be covering in this module. That can be converted to an accelerometer also. So, the force sensor, strain gauge, in particular, will be covering optical and piezoelectric is also there. So, these are mostly used in industry. Apart from this, switches are definitely there. That is very, very common.

Even switches like the keyboard. Your desktop keyboard is also a sensor. It can detect what you are pressing. So, that also is a sensor. So, there are various kinds of it: DPDT, SPDT, SPST, or keypad, your encoders. All these are just switches. So, we won't be covering switches as such, so that we will be covering till 5. Others are special sensors which are also there in the industry, but not specifically. It is always there in the robot, so we are skipping those, at least for this module. So they are pressure sensors of various kinds, which are mentioned here: flow sensor, liquid level sensor, temperature sensor, light sensor and special sensors like machine vision, tactile, slip or touch sensors. These are various types of sensors.

Let us start with the position sensor. Before we actually start, let me just expose you to your mobile device. Even I have this now. So, just see this one and what it is showing. This is the number of devices which are there in my tab, at least the one which I am using. So, you can download a similar one for your mobile phone also, and you will be surprised to see this kind of data. So, it has so many sensors. I am sure you are aware of this, but yes, at least a few of them I will demonstrate here. So, this is the accelerometer which is there. So, if I move it to one axis, you can see this. It gives you some kind of acceleration in one direction. If I am moving in some

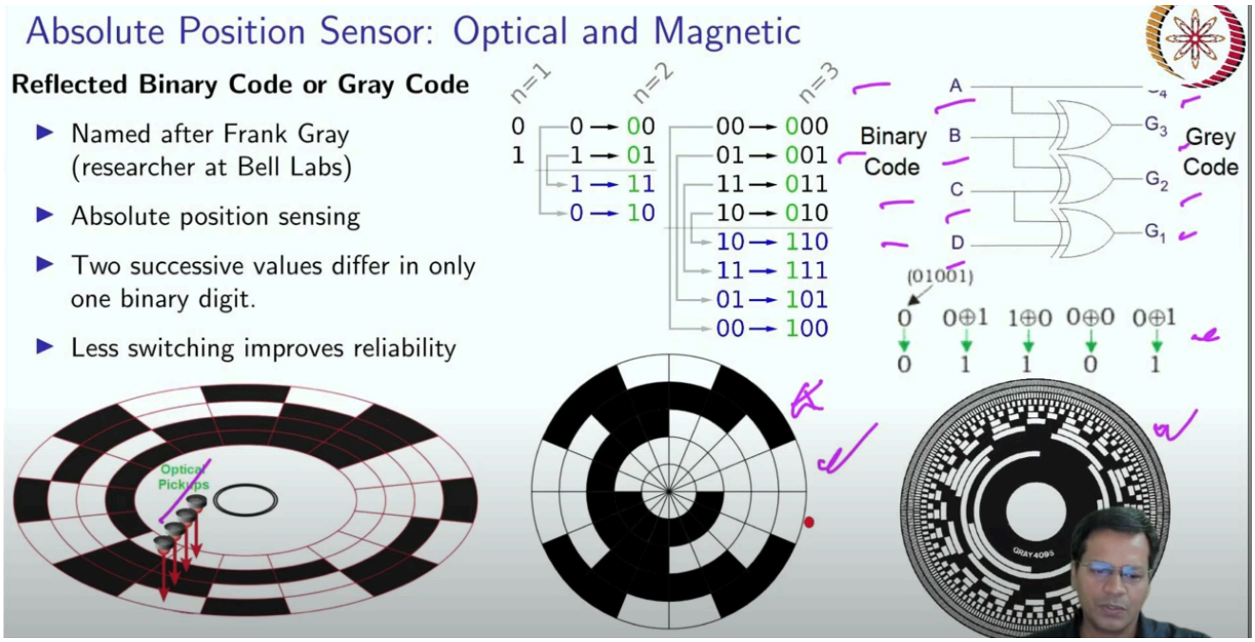
other direction, it shows something else. If I move along this, yes, it gives me some other plot. So, all three axes have accelerometer sensors. So yes, it gives me.
So linear acceleration is also made up. So if I keep it flat, you see, one of them is going to zero. So that is the Z1. So that is the linear, that is the acceleration, actually not the G value. So, it is just the static acceleration, it is just the acceleration of your device. So, if I am not moving continuously, it won't go. But yes, at least you can feel the difference. Something is there if I am shaking it. So, the magnetic field sensor is there, the gyroscope is there, which can measure the angular velocity, and gravity is there. So, at least you can see it is going up to 9.8 and 9.9 along the Z axis. If it is kept flat, If I make it like this, so you see, it becomes a Y axis 9. 8 If I keep it like this, it becomes a Z axis almost 9.8. So, this is the gravity sensor. So it has a magnetometer, it has a gyroscope, it has many, many other sensors also. You see, there are many. So, you see, you have already preloaded with a good amount of sensors in your devices. My touchpad is a device which is a sensor, again, that is a capacitive sensor. My camera is also a sensor, that is, a vision sensor. So, you see, you are flooded with sensors nowadays. Just keep your eyes open. You will find them.



Now, let us move ahead with the position sensor. That is an optical encoder, incremental we will start with, and we will go to absolute also. So, yes, how does it work? So, this is very, very simple. You see, there is a disk, there is a disk over here with Windows. You have a disk with a window. Those are holes in this disk. So, if you have an LED light from one of the directions and you have a photo sensor over here, this light will pass through whenever it encounters the window. Otherwise it is obstructed by the walls which are here. So, the photocell which is there will give you a high signal when it sees a window, and when it is obstructed, it will go to zero. When it is obstructed, it will go to zero. So, got it. So, what are we going to do here so effectively if the wheel keeps on rotating continuously? What you will see? You will see a square wave kind of thing, Not necessarily because the light is not 100% or 0%. Sometimes, it is a partially opened window. In that case, you won't see 100% high. You may see a little less of a high so that you can set a threshold. So, that thresholding circuit is here, which is known as the squaring circuit. That basically converts it to a complete square signal. So, it is nothing but a comparator, beyond which it will show it as 1, below which it will show it as 0. So, it will give you a square wave. So, at least now, you see. So, if this wheel keeps on rotating, what you will get is a square wave.

So now, is it sufficient to measure the angle? Yes, it is sufficient If you know the slot. What is the width of my slot and the total number of slots? So, if you just count the number of slots, you can understand. Yes, my wheel has rotated by this much of an angle. Let us say there is every slot is 1 degree and 1 degree blank. So, overall, you can have as much as a total of 360 divided by 2. That is, 180 independent slots will be there. So, if you see 180 counts of high signal, you understand. My wheel has rotated by one full revolution. So, that is OK. But whether it rotates clockwise or anticlockwise, it will give you the same kind of square wave. So, how will you know that? In order to do that, there is a trick. You have two different LEDs and two different sensors. So if one of them is going high, the other one goes high after a moment. If this wheel is moving, otherwise, it will remain there. So you will get a shifted waveform over here. So, there is a shift in between. So if this appears first and this appears second, it rotates along the clockwise direction. So, if it is in an anticlockwise direction, you will see a reverse pattern, and that is how you can measure whether it is rotating clockwise or it is rotating anticlockwise. And just by measuring a number of counts, you can get the angle. So, you now get the complete sense of it. But yes, it is not absolute. If I say how much it has turned from a reference line, you cannot say because you might have already rotated and then switched on your circuit. So, it just measures a number of counts of slots from the point where it has started counting. So, it is a relative position. So, you can keep on adding if it moves clockwise, and you keep on subtracting if it moves counterclockwise. So, that is how it can be measured. But yes, it is a relative sensor. That is the reason it is known as an incremental sensor.

Now, there are many other ways of getting more resolution and other stuff. So, maybe you can count this rising edge, falling edge and again rising edge and falling edge, So, one complete window-to-window transform. You will get at least four counts. So, you can increase just one high for one angle turn one slot turn is converted to at least four different kinds of signal, which you can use to resolve four independent instances further. So, just one slot is further subdivided. So anyway, that is a bit. It is not very complex, though, but yes, this is the way you can even have more resolution of a just-out-of-one-window count. So, yes, what all things that it is giving is, it is giving a sense of relative change in the position of each joint and rotation angle, and it is, it can be. The slots can also be made on a linear rail kind of thing. So, you may have slots like this, slots, and you have an LED, you have a sensor over here, photocell, and you can count the number of slots if something is moving, even linearly. So, that also is possible. And then what all things that you got out of it is a count. The count will give you. It has a direct relation to the angle or displacement. Velocity is nothing but a number of counts appearing per unit of time is its velocity and direction; using the two inputs, A and B, you can get direction. So, in this case, you have an additional slot of a very small width that is known as an index width. That is just one signal that you are going to get after every one complete revolution. So, it will. If you count this one, it will directly give you a number of complete revolutions per second. You can directly get that. So this will also save. Instead of counting, let us say, 360 high signal for one complete revolution. So, for every five revolutions, 360 into 5 number of counts is going to counts are going to appear. So, to avoid that huge number in your variables, you can just keep track of your index. So, if you have one index, one index plus, let us say, five counts so that, you can have counts like that. One index means one complete index to index is 360 counts. So, just keep track of the index count and then the number of independent counts that you are getting. So this is the way it can save your space, variable space also. It is a non-contact type of sensor, so it is an optical sensor, It can be magnetic type also, magnetic types also. So what is magnetic type? Basically? You must have seen older days when you had a magnetic cassette. So, it has data written at every location. So, you have a pickup head that can read those data. So, you can have 1, 2, 3, 4, 5, 6, like that. You can have n number of. So, it can be very, very dense. So, these kinds of sensors are also there. That is also a non-contact magnetic type. Multiple turns with gearing can improve the resolution. Let us say your motor has rotated by just one turn, but you have a gear attachment that can rotate this disc by, let us say five turns. So, 360 per turn into five total counts you will get out of just one turn of that motor. So, your motor has a gearbox, and then you have an encoder. So, the gearbox maybe 100 times, maybe any time. So, that is the additional resolution you can get. So, optical encoders can be a rotary type, it can be a linear type. So, one close-up view of the real picture is shown here when this is a disc, and you can see clearly. You have slots here. You have slots here, and these are the circuitry to do the pickup operation. So, one side of it has an LED. Another side you have a photocell And similar is one of them. This is for linear displacement sensors. So, it is nothing but like a tape which I am holding in hand. I don't know if you can see it very clearly, so I cannot see it. It just appears Gray to me. I cannot count the lines. They are so fine, so fine. So, this type of tape is there so that tape can measure also. So, this is a type of counter for linear motion. So, there are many advanced types. So, one of them. It looks like this. I am sure quite a lot of you have seen this earlier, also. So, if you see this, it looks like this. It has a counter rotor which is here that effectively rotates the inside wheel that has slots. That is all it looks like. It has a flange, and it can be coupled with any other link which goes next to it, and it has how many wires you just count. So, it is a four number of wires. One goes to VCC, which is the supply, other one to the ground, so those are the supplies for LED. Then, you have two output signal phases, A and phase B. There are many advanced types of such sensors also which do all these counting things inside the sensor only. So, one a similar one I have in my hand. It is a very expensive and quite high number of count. It can get something around 10000 counts it can give. So yes, this is from SICK, it is a company, so you still again have this type of rotor. Inside, there is a disk, and you see there are many wires here. One of them is to power the device, other one gives you a ready-made signal at the end. So it looks like this. So, in the end, I can directly get something which is like an Ethernet cable. So you see, it is very much like an Ethernet cable. So, it gives me an output directly in the form of an Ethernet signal. so, you can interface directly with your advanced devices like PCs without having any type of acquisition system got it. So, that is a very advanced type of encoders. So yes, this is the incremental sensor.



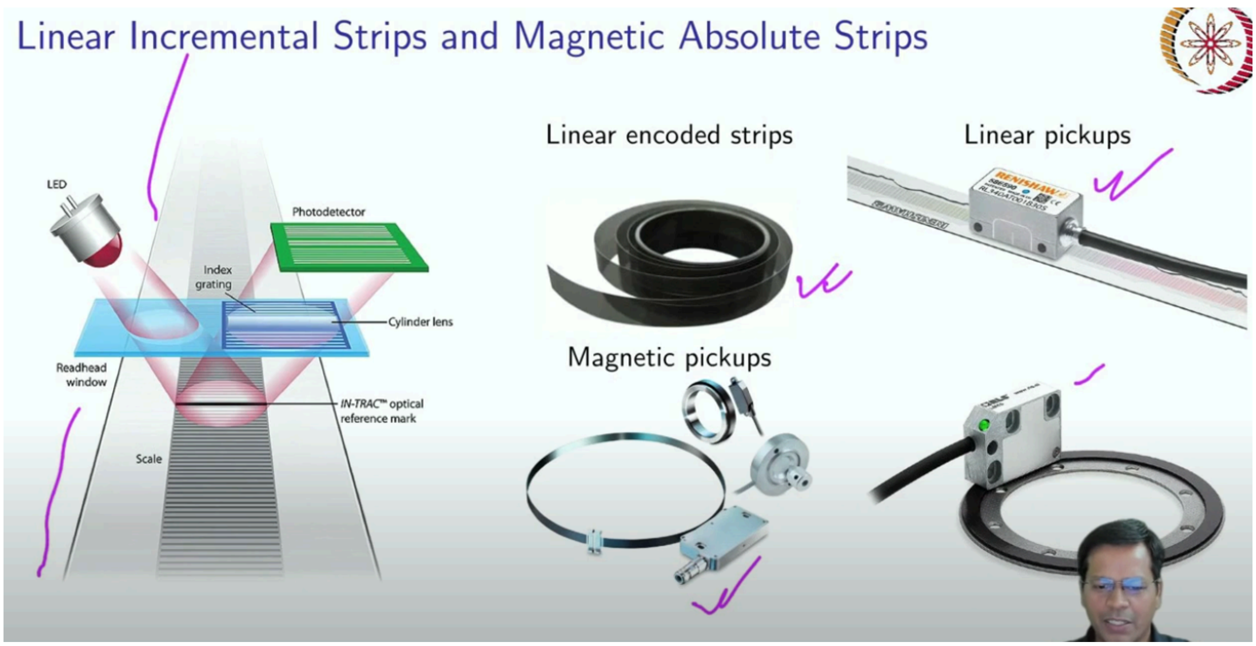
Now, you see how an absolute position sensor can be made, which can store the value, at least the starting value. So, if it moves even when the system is shut down when it starts, it can directly get where I am. Initially, if you remember your printer, whenever you start your printer your head goes to the home position. Why So? That is the incremental encoder probably, which is there, the strip which I showed you. It is the pull-out from such printer only. So yes, it is an incremental sensor. So, your cartridge goes to the home position as soon as it reaches home. There is a limit switch which says: yes, now you have to start counting. Wherever it is, bring it, keep moving it, moving it until it comes to the home position and triggers that zero-limit switch. When that limit switch is ON, start counting when it moves here, and keep on adding. When it moves back, keep on subtracting, and that is how it keeps track of your head. Position, got it? So yes, That is incremental, but still, by homing operation, you can maintain that.

But if you have an absolute position sensor, you don't require that. So one of them is reflected binary code or Gray code sensor. It is named after Frank Gay, a researcher at Bell Labs. It is the absolute position used for absolute position sensing. Two successive values differ only by one binary digit. So, two successive values should differ only by one binary digit. So, let us say I have coded this disk by binary digit of 3 bits. So what do you see? 0 0 0, 0 0 1, 0 1 0, 0 1 1, 1 0 1, 1 1 0, 1 1 1. So, I think I am right, I don't know. I have missed 1, that is 1 0 0 here. So, 2 to the power 3, that is eight independent values you can store. So yes, what do you see? Here is at a particular location, you may if you code your disk like this. So, from here to here, just one bit is changing. You see, just one bit is changing. That is fine. But from here to here, even this is changing. So, two wires are changing at a time. Two wires can change at a time. Sometimes, one wire is changing. One wire is just changing the other one. You have two wires. Which is changing? What do I mean? I will tell you. Let us say this is an arrangement. Your disk is coded like this: you have optical pickups, which are here so that you just see the reflected light. If it is black, there would not be any reflected light. If it is white, you will see a reflected light. So, this will, these four pickups will pick up what is written on this disk in these four bits: 1, 2, 3 and 4 bits. So, all the four bits. It will turn on 0 0 0, 1 0 0, 1 0 0, 0 1 1, like that. So, it will directly give you the values which are stored there by just checking the values in these wires.

So, that is what I am talking about. So, you see, if two wires are changing and one of the wires is faulty, you would not come to know whether it is just this change because of rotation or because of some faulty wire. So, in order to avoid that, Gray has come up with a new idea: you shuffle this in such a way, this binary-coded decimal in such a way that at a time, only one of the bits will change. So, if at all, by any cause of fault, if you see two wires changing, that means your device is faulty. It has fault tracing capability immediately within the device itself got it. So, you should not see two wires getting changed at a time. If it is changing, your device is faulty. So that is the beauty of having Gray code instead of binary code. So, less switching improves the reliability. So that is the beauty of having gray code. So, see how it is generated. So, let me draw it once again here. So how can you make, let us say, a three-bit of Gray code without actually doing some sort of shuffle operation? So, three bites of binary you can quickly make. So, let us say the binary is 01, so next time, when you do, you have to do 01 and 10. So, this is just, and you just have to mirror a.Bout this. And then you add 00 here and then 11 here. So, this gives you a Gray code of two bits.

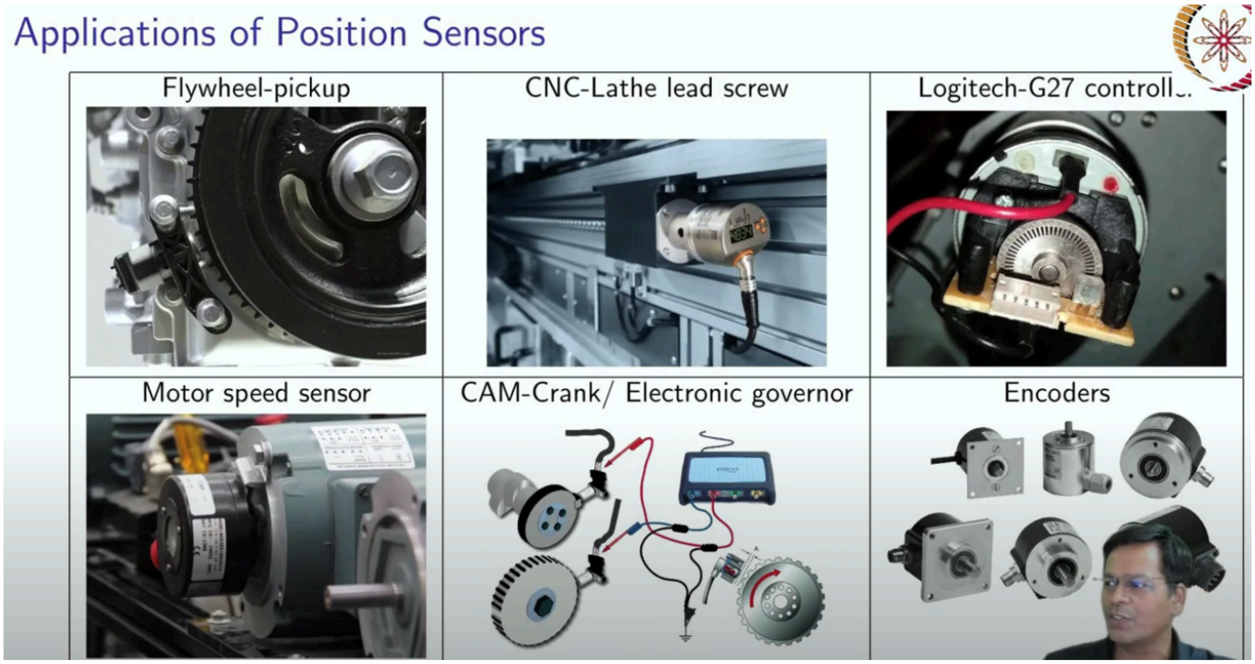
Now, how to generate three bit gray code? So you just copy this. So, 00, 01, 11, 10. Now, I will mirror it about this line. So, I will write 10, 11, 01, 00, Got it. So, it quickly comes from here. Now, I will do it. I will add 0 like this and 1 for all of them. So this gave me a Gray code of three bites. So, that is the way it is generated. There are other ways of generating it: electronically also, or by programming you can do it. So, this is how I have generated this three-bit Gray code. So, you see, in any of the two consecutive data, only one bit is changing. So this is changing from here to here, from next one, you see only this is changing. Next one, you see this is changing. And then you see this is changing, this is changing, this one is changing, and finally, this is changing. So, you see, only one bit has changed. So that is how it improves the reliability.

Another way of generating is electronically, using the NOR gate something like this: you simply input the binary code here: 0000, 0001, 0010, 0011, 0100 and like that, so you can just keep on feeding here, and you will get Gray codes here in this four wires. So, this is just an operation which is happening here, which is explained, and this is a disk, which is something around 4096 data which is saved over here. So, that is how you can have a disk with so many values. But things are very, very complex here. You have a very good number of wires that have to pick up this signal. You have so many LEDs. That, again, makes things a little unreliable. So, at least for this many counts, it is quite good enough. So, that is your optical sensor, non-contact sensor and absolute also. So, the change in data per unit of time is the velocity. The position you are directly getting. Each position has a unique value. If you get that value, that means you are in that position and direction. If that value is going right-hand side or left-hand side, you can directly detect them. So, direction, speed, position, everything is obtainable using this. So this is there.



And then this is a linear pickup arrangement, which is there. You see, and if you know, I don't know mouse also has got an optical sensor. Optical sensor at the bottom. So, if I do some cursor movement, that is because of this sensor. So, that is an optical sensor. So, that has a similar arrangement. It has a light that is thrown out, and it is thrown on the table on which you are swiping your mouse, and then the reflected picture is taken, and the change in that image is analysed to find out which direction you are moving. So, that is an optical sensor, non-contact, and it detects displacement, I tell you. So, that is a very good displacement sensor that you can get something from the self of your mouse. You can just pull it.

So, this is a linear encoded strip, the one that I showed you out of my printer. Magnetic pickups are very, very similar, but instead it has a ferromagnetic tape which can store data. This is magnetic pickup and linear pickups are like this. So, yes, that is. What are magnetic absolute strips?



So, these are some applications. When you see, a Flywheel has a kind of reflection mirror placed here. So, every time that mirror comes in front of that LED and photocell, it will count as 1. So, every time it goes there, it will simply say the number of revolutions per minute or whatever is encoded there:

CNC-Lathe lead screw. So, this is the encoder which is fitted so as many number of count, this shaft will rotate. That is, the tool post will move along this path. Got it? So, that tool is going to move like this. So by measuring precisely this angle here, you can easily calculate how much turn my lead screw has rotated and what is the displacement of my tool post. So, this is how it is used in a CNC lathe or this kind of machine, your Logitech or any manufacturer gaming controller. You see, you have a joystick. How did it come to know what is my rotation? Maybe you have a steering wheel that is used to play various games. So, that is steering wheel rotation. How much you have turned is also sensed using this kind of arrangement. So, you can clearly see the slots which are here. There is a photocell and pickup arrangement which is here and this is nothing but a motor. The aft side of the motor is fitted with the encoder here. The one which I showed you, very similar to this one, is fitted here so that it will give you directly the speed of your motor also and sometimes position if it is position controlled. If you are interested, you can get that.

And what is this? This is a CAM-Crank Electronic governor system. Electronic governors basically is used in alternators or generators which generate electricity for you because you have to maintain the constant speed of your shaft, to maintain, let us say, 50 hertz, the frequency of your output. So, let us say you have to maintain, let us say, 720 rpm for that. So, that is measured continuously, and it is velocity fed back and maintained using a type of controller using an electronic governor system. The electronic governor continuously takes feedback on speed and maintains your speed using a fuel rack system. So, that is what is there in an electronic governor. These are various types of sensors that I have shown you.

That is all. Thanks a lot for this lecture. In the next class, I will be discussing more about absolute sensors, that is, a potentiometer is there. So, I will be discussing on potentiometer. Magnetic sensors and a special kind of magnetic sensor are the hall effect sensors I will be discussing in the next class. That is all. Thanks a lot.