Wheeled Mobile Robots
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Lecture - 4.3
Commonly used sensors - 1

Hello everyone, welcome back. So, in the last class, we discussed about the importance of sensors and sensing, especially for perception in mobile robotics. We talked about the classification of sensors, and try to understand some of the basic characteristics of sensors which are used in mobile robotics for perception.

Today, we will try to understand the working principle of some of the commonly used sensors in mobile robotics. Of course, depending on the application, depending on the requirement, we can choose various sensors. So, covering all the sensors may not be possible in this talk, but I will try to explain the basic working principle of some of the very commonly used sensors.

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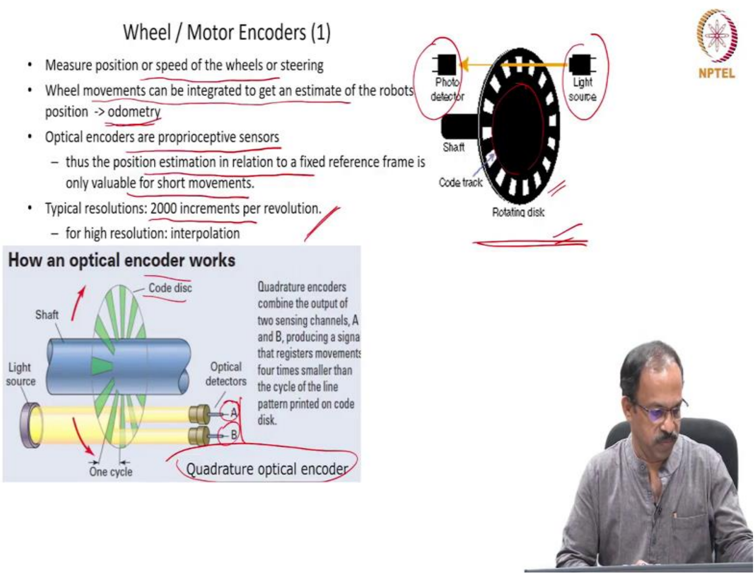

So, one of the most commonly used sensors is an encoder. So, the wheel or motor encoders are primarily used to get the position of the wheel or the speed at which the wheel is rotating. So, either the position or the speed can be measured using the encoders. So, normally the encoders are attached to the wheels in mobile robots, so that we can identify the rpm of the wheel, and then use this rpm to find out the distance traveled by the robot, and therefore, to locate the position of the robot.

So, normally we can use the wheel movements which can be integrated to get an estimate of the robots position. And the normally we call this as odometry. So, estimating the position of the robot using the encoder, one is for the position then we can use additional information, and then get the encoder data.

So, commonly used encoders are optical encoders and they are proprioceptive sensors that is they collect the information within the robot, and that is why we call them as a proprioceptive sensors. And because we are using that, we will not be able to get the actual position estimation because they will be erroneous. Because if you use it for a long time then the wheels will actually create wheels may slip or there may be some other problem.

So, the actual position estimated using the encoder may not be always correct. So, for short distance travel, we will be able to use this kind of encoders for estimating the position. So, only for short movements, we can actually use it. The typical resolutions of such encoders are roughly 2000, but we can actually have much more higher also up to 8000 also it is possible.

So, every revolution one rotation of the wheel can actually be resolved into 2000 pulses. So, you will be able to get a very good measurement of the position of the wheel as well as we can get the rpm also. So, as you can see here in this picture, the principle is very simple. You have a light source and a photo detector that is the optical encoder principle.

And then you have this rotating disk with some kind of a track which is cut on the disk which will allow the light to pass through, and then they pass fall on the photo detector. So, as the disk rotates and the light falls on the detector, you will be able to know so how many pulses are actually there on the receiver, based on that you will be able to find out the position as well as the speed of the disk.

And this disk is connected to the rotating shaft, and therefore, you know how much the shaft has rotated, so that is the basic principle of operation. So, as you can see here, so there are disk like this. So, you will be able to have a disk like this as you can see here.

So, this disk will be having lot of cut marks on it, and that will allow the light to pass through, and the lights will, light will fall on the detector.

And then the detector will actually identify the pulses, and then the pulse can be used for measuring the position. So, these are the typical disk, which are used in the optical encoders. Now, coming to the resolution, so you can see that if you can have only one round like this one set of disk you have a limitation and if you want to have large the increase the resolution, you need to have more number of this cut portions.

So, into improve the accuracy or the improve the precision of the sorry improve the resolution of the encoder, we can actually use something called quadrature encoders. So, the quadrature encoders will be having two detectors. You can see there are two detectors and a light source, and then there will be the coded disk. And by properly having this disk designed, you will be able to get different stages of input to the and detector, and that will actually increase the resolution of the encoder.

So, if you want to have increase the increase resolution, we can go for this quadrature optical encoder where you will be having two detectors and one light source, and you can have a disk in which the both the detectors will be getting a different input for the same position. And by resolving this, you will be able to get a much better resolution for the encoder.

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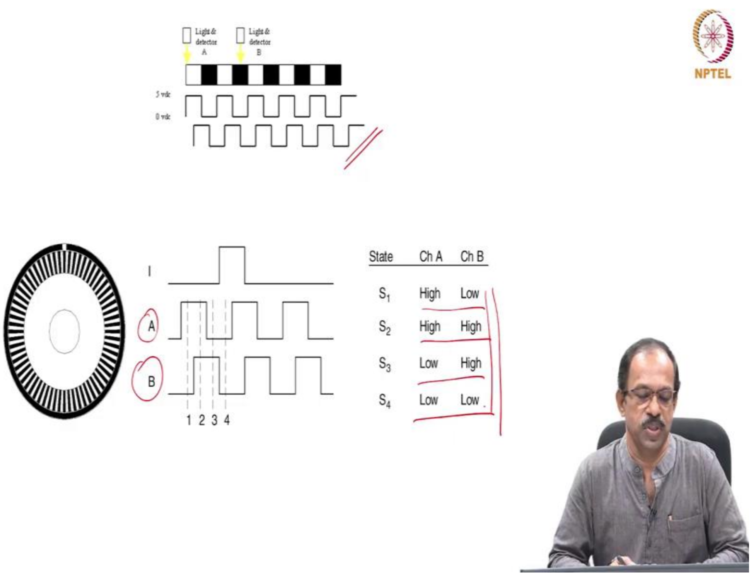

So, this one explains it. So, you have A and B are two detectors, and then both will be having different pulses. So, each one will be having a different pulse for the same position of the disk. As you can see here, so you have a disk I mean A and B are the two detectors, and you can see that there will be difference in the there will be a phase difference between these two pulses. And by looking at this, you can actually increase the resolution.

So, you can have four states; high-low, high-high, low-high, and low-low. And then that actually increases the resolution for times, so that is why these are known as quadrature encoders. So, the resolution actually can be increased four times in this case. So, that is the optical encoder, which are very commonly used in a mobile robots to find out the position or the speed of the wheel, and which will actually help us to get the position of the robots.

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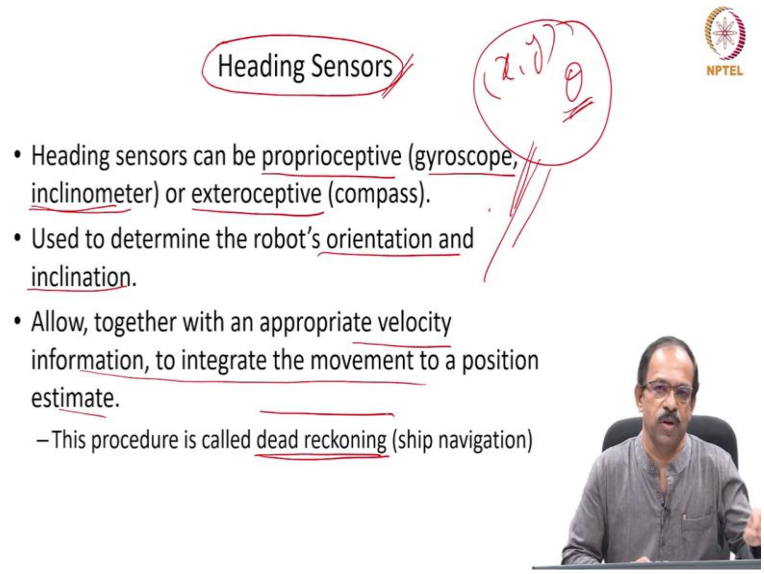

So, once you know the position, the next one what you are interested is known as the heading of the robot. So, most of you by now know that the position of the robot is normally given by (x, y) position, and the orientation is given by θ in normal planar motion.

So, x, y, θ are the primary interest for us. So, x, y can actually be obtained by looking at the encoder data, the optical encoder which are attached to the wheels will provide you the estimate of x and y position in the dead reckoning. Now, what we are interested is, knowing the orientation of the robot. So, that is basically we use the heading sensors to know the orientation of the robot.

What is the current orientation of the robot can be obtained by using the heading sensors. So, they can be either proprioceptive or it can be an exteroceptive also. Proprioceptive will look at the internal information, and then try to find out what is the orientation. Exteroceptive will look at the external references and then find out the orientation. So, both can actually be used.

So, gyroscope or inclinometer these are the commonly used proprioceptive heading sensors. And compass is an exteroceptive because it uses the magnetic field information to get the orientation. So, these are the commonly used heading sensors ok. So, the orientation and inclination.

So, inclination is inclinometer is primarily used for inclination, because you can apart from θ which is in the x, y plane, but you can have an inclination of the robot when the robot is traveling over a grid or moving over a slope then you want to know what is the inclination. So, you can that get you can get that one using the inclinometer.

Now, this information the θ and then the inclination, along with the position information that is the from the velocity information to integrate the movement to a position estimate, we will be able to get the complete pause of the robot the x, y, θ, and the inclination can be obtained, and that is we call as the dead reckoning of the robot. So, normally this is used for in ships and other mobile vehicles.

We can use the position information from the velocity. So, you get the measure the velocity of the robot and integrate it to get the position. And along with that, you use the heading information to get the complete pause of the robot and we call that as the dead reckoning of the robot. So, this is what commonly used in mobile robotics for primary information.

So, as I mentioned there will be lot of errors when we use this for a long duration and that is why it cannot be always relied on, but the primary information that you can get is from these sensors which will help us to get an approximate estimate of the cause of the robot.

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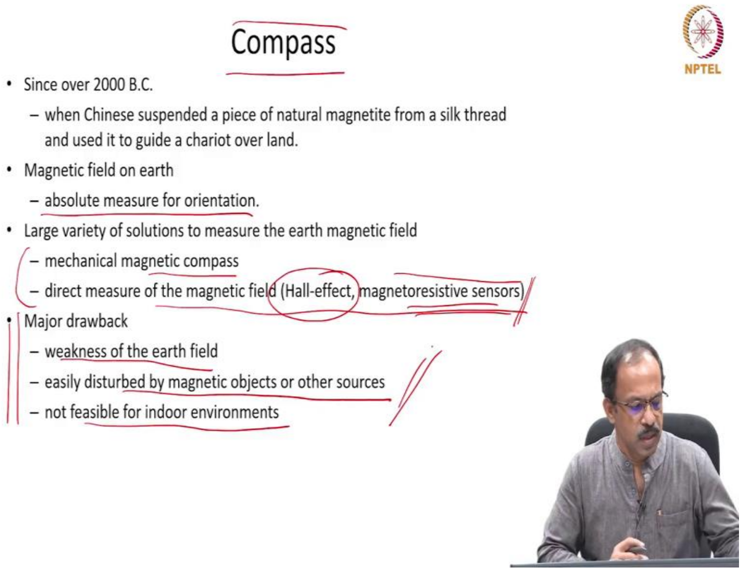

So, let us look at some of these sensors heading sensors. So, one is the compass which most of you are familiar ok. It has actually it depends on the magnetic field, and it is quite old. People have been using this magnetic field to identify the directions. So, we can always use this as a method to get the orientation. So, it actually gives an absolute measure for orientation.

So, always you know the magnetic field has got a particular direction, and therefore, that will give you an absolute direction whether it is north or east, or what is the direction which the robot moving can be obtained, it is an absolute information. And we have different methods to do this.

We can actually use the mechanical magnetic components, mechanical magnetic compass or you can directly measure the magnetic field using some other method like Hall-effect or magneto resistive sensors etcetera.

So, these are additional methods. So, one is you directly use the mechanical the compass which will actually depend on the earth magnetic field, or we can actually use something like a Hall-effect sensor which actually is a sensor which changes its voltage or a potential difference can be measured with the variation in the magnetic field. So, that is basically the Hall-effect sensors.

And similarly, magneto resistive sensors, where the resistance changes because of the magnetic field, so such sensors also can be used for getting the orientation based on the magnetic field. But there are many drawbacks to this because the weakness of the earth field, earth field need not be always the same in different places.

So, there may be variations. And it is easily disturbed by magnetic objects or other sources. Suppose, you have different source of magnetic field other than the earth's magnetic field that will actually interfere with the measurement, therefore, you may get a error in the measured value.

And many times may not be always feasible for indoor environments because of both the reasons. The magnetic field also may not be very strong, and at the same time your interference from other sources also will be there. So, that is got its own limitation, but for again for basic information you can actually use that is as a sensor which will provide the orientation.

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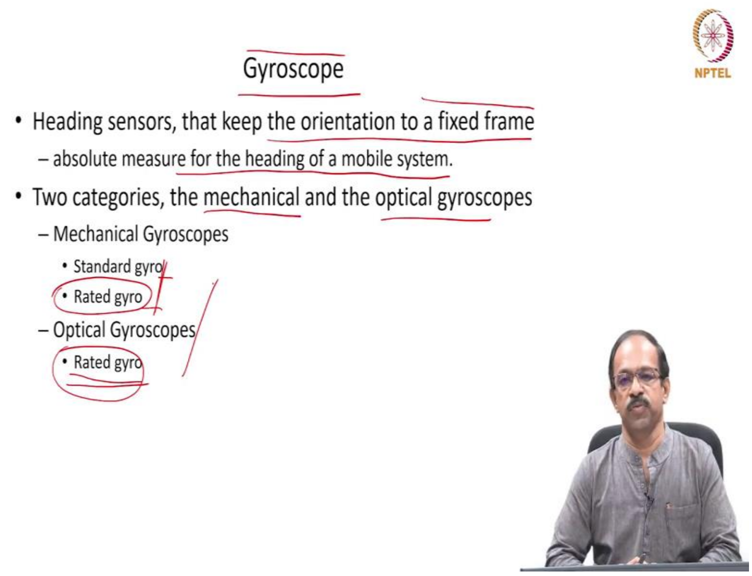

So, the other one which is commonly used as a gyroscope. Gyroscope is something which have been which has been there for a long time. Most of the ships use this gyroscope to get the orientation. So, the fundamental principle is that it keep the orientation to a fixed frame absolute measure for the heading of the mobile of a mobile system.

So, you can actually fix an axis based on some principle, and then any changes from that can actually be easily measured, so that is the basic principle of gyroscope. So, you keep the orientation to a fixed frame, and then any changes in that orientation can actually be measured. So, there are two categories of the gyroscope.

So, one is the mechanical system; other one is the optical gyroscopes. So, both can be used for getting the heading information, but not only heading you can actually even get the rate of change of heading also. So, that is where you can actually get something called a rated gyro.

A rated gyro is which actually gives you the rate of change of orientation. So, orientation is more like a static value measured, but how fast it is changing or you can say it is an angular velocity also can be measured using gyroscope. So, you can have two types. One is the standard gyro; the other one is the rated gyro.

Standard gyro will give you the orientation, and the rated gyro will give you the rate of change of orientation. In mechanical optical gyroscopes you will get a rated gyro. For the mechanical gyroscopes, both categories one is that you get the orientation, the other one is the rate of change of orientation also can be obtained.

In optical gyroscopes, we can use it for getting the rate of change of orientation. We will look at both and then see what is the difference and how they what principle they use for getting the orientation as well as the rate of change of orientation.

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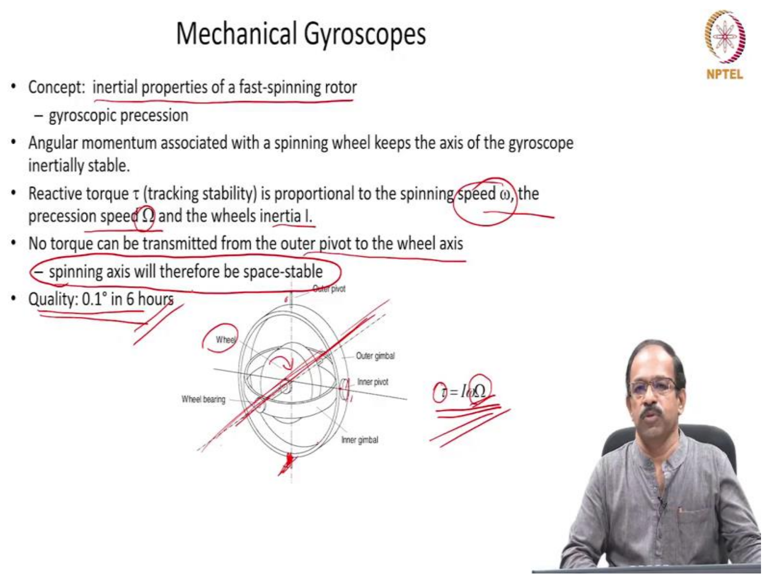

So, this shows the basic mechanical gyroscope. As you can see here, so there is a spinning wheel here, so as you can see this wheel this center wheel is actually spinning at a particular rate, and it is actually along this axis. So, it has got an axis. Now, if this is rotating or spinning at a particular rpm, that is basically the it will be having some inertial properties, and that properties are used to get the measurement ok.

So, this one this is rotating I mean it is spinning and it will be having an inertia to change its axis of rotation. When changes any change in orientation will actually be resisted by a torque, and that torque is known as the precision torque. So, it will be actually creating a precision torque which we called as $T = I \times \omega \times \Omega$. So, this I is the inertia of the wheel, and then precision speed is Ω and the small ω is the spinning speed. The spinning speed is ω and then we get a precision speed of Ω.

So, if you can get this, we if we know the I and ω, then the torque will be proportional to the Ω which is the precision. So, now, we can see that the reactive torque is proportional to the spinning speed ω and the precision speed Ω, and the wheels inertia I.

So, no torque can be transmitted from the outer pivot to the wheel axis. So, you cannot transmit any torque from the outer pivot, these are the pivots; inner pivot and outer pivot. So, you have two pivots. One is inner and the other one is outer. So, no torque can be transmitted from inner to outer, and it will always remain the same axis whatever may be the rotation of this inner and outer pivot.

So, now if you have a rotation of the inner or outer pivot, this axis will still remain the same whatever may be the original rotation axis. And therefore, if you connect this to a moving system and rotating system, we will be able to find out the orientation by looking at the changes in the orientation of this axis with respect to the pivot. So, the pivot this absolute axis will remain the direction of this axis will remain the same, it will not change ok.

So, the spinning axis will be always space stable. So, this would be a space stable. The spinning axis will be always space stable. And therefore, you will be able to identify how much the system has moved or the whole robot has moved with respect to this pivot by looking at the axis of the spinning axis. The spinning axis will actually tell you what is the change in the orientation, that is basically the basic principle of the gyroscope.

So, the this one will be rotating and when it is rotating there will be a precision torque $I \times \omega \times \Omega$. And then any you will not be able to change the this axis whatever may be the changes in the inner or outer pivot. So, whatever maybe the torque is acting on this one will not be transmitted to this. And therefore, this will always remain as the axis will always remain space stable, so that is the basic principle of mechanical gyroscope.

So, again there will be small errors in this one. So, the quality is around 0.1 degree in 6 hours. So, it is continuously rotating for 6 hours, there may be small changes in the orientations, but that can actually be that is need to be compensated by some other means. But otherwise for shorter durations, you will be able to use this mechanical gyroscope to find out the change in orientation, so that is the basic principle of mechanical gyroscope.

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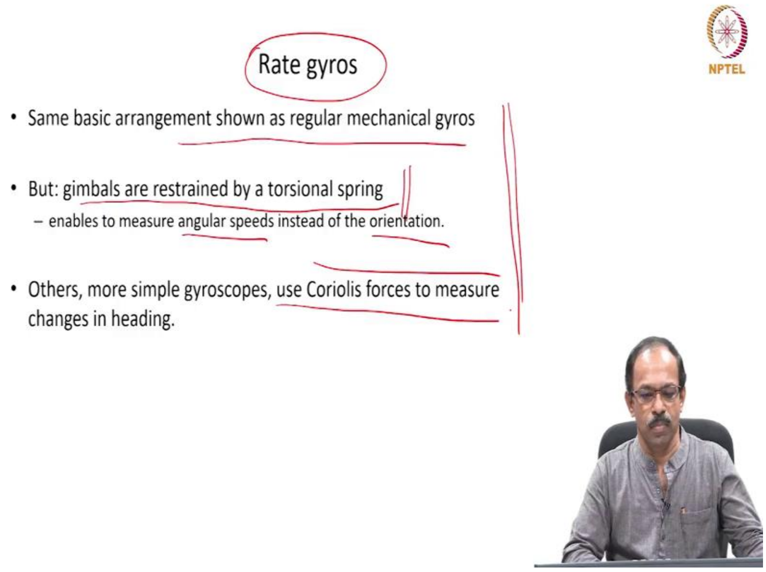

So, this can actually be converted to a rate gyro. So, rate gyro is basically the rate at which it is changing. So, the conventional one will give you only the change in position, but the rate at which it is moving can be also obtained by making some basic arrangement with mechanical gyros. So, you can actually restrain these gimbals by torsional spring and then we can actually get the angular speed instead of the orientation.

So, the torsional spring if you restrained, then the how much the string is actually getting extended that actually gives you a rate of change of the orientation or the angular speed can actually be measured using that kind of an arrangement. So, you connect this to a restrain it by a torsional spring, and then you can measure the spring extension that will give you a value of the angular speed, or some cases you can use Coriolis forces also to measure this changes in heading ok.

So, these are the ways in which we can actually use the mechanical gyros to get the orientation or the rate of change of orientation. Most of the robots nowadays do not use mechanical gyros because of the difficulty in maintaining the mechanical gyros in mobile robots. They were primarily used for big vehicles or ships and other bigger vehicles, but nowadays not many mechanical gyros are used in the robots.

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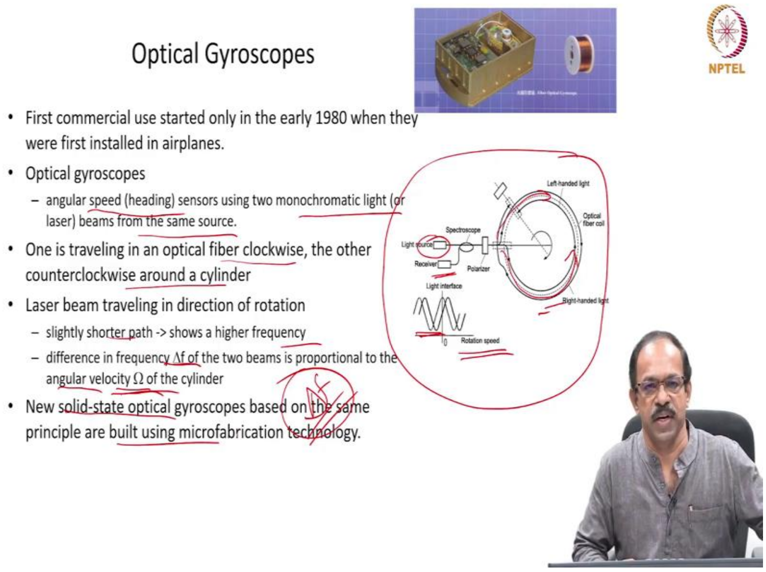

So, the (Refer Time: 20:22) is the optical gyroscope, as I mentioned optical gyroscopes are used for measuring the rate of change of orientation. So, the principle is simple here. So, you have a light source. A light source is actually passing through a ring. So, you can see the there is a ring. And then there will be a one light will be passing in one direction, another one will be passing in another direction. There will be two light beams traveling in opposite directions. And then they will come and received at the both at the receiver.

Now, if the this ring is stationary, then both will be traveling at the they will be traveling the same distance, and then it will be reaching at the receiver without any phase difference. If this ring is rotating then because of the rotation of this ring, there will be a small change in the phase between these the two received signal, so that can actually be used to measure the speed of rotation of the ring, so that is the basic principle of optical gyroscope ok.

So, the angular speed using two monochromatic light source beams from the same source. Then one this traveling in clockwise, the other one is in the anticlockwise direction around a cylinder. And then laser beam traveling in direction of rotation of the cylinder will be slightly shorter paths shows a higher frequency. And the difference in frequency Δf of the two beams is proportional to the angular velocity ω of the cylinder.

So, the, this can be used for the measurement of the cylinder velocity. So, that is basically if the cylinder is rotating, you will be able to find out the velocity of the cylinder using the change in frequency. The Δf will be the change in frequency can actually be measured and that basically gives you the rate at which the cylinder is rotating. So, that is basically known as the; that is the basic principle of optical gyroscope.

So, nowadays you do not need to have such a big setup. You can actually use simple solid state systems to get the optical gyroscopes assembled. So, it can be very small size. You do not need to have very big size for the cylinder and other thing. You can have very small MEMS based optical gyroscope for getting the rate of change of orientation that is one way of measuring the heading rate of change of heading ok.

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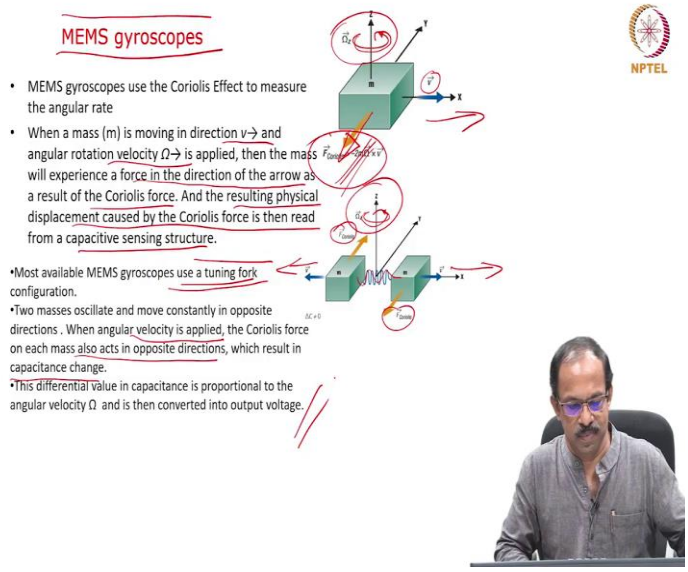

So, as I mentioned the mechanical gyroscopes are big and difficult to use, and therefore, now we have the MEMS based gyroscopes that is micro electromechanical system gyroscopes. The, the principle of mechanical sorry the MEMS gyroscope is based on the measurement of the Coriolis force or the effect of Coriolis force.

So, assume that a mass m is actually moving in the direction v in the in moving this direction with a velocity v, and it is rotating with an angular velocity ω with respect to the z-axis, then there will be a force the Coriolis force will be acting in this direction. So, this is the basic principle of Coriolis force. So, it is moving in one direction and then trying to having a rotation with respect to a normal direction, then you will be having a Coriolis force acting in this direction, so that is the basic principle.

Somehow if you can actually measure this force or the effect of this force, then we will be able to know what is ω. Because we know this v, and therefore, this course is this is proportional to the v and ω, and therefore, we will be able to get what is this ω if we can measure the Coriolis force or the effect of Coriolis force at the displacement of the mass because of the Coriolis force. So, that is the basic principle of MEMS gyroscope ok.

So, when a mass is moving in a direction v and angular rotation velocity ω is applied, then the mass will experience a force in the direction of the arrow as a result of the Coriolis force ok. The resulting physical displacement caused by the Coriolis force is then read from a capacitive sensing structure.

So, you can have a method to measure the displacement using some capacity measurement or something like that. And that can be used to identify what is the value of ω or what is the rate at which it is rotating, so that is basically the principle of MEMS gyroscope ok.

So, it is difficult to have a mass moving like this in a sensor, and therefore, we use a tuning fork configuration to design the MEMS gyroscope. The principle is this one, but the actual design is based on a tuning fork configuration. So, what is it? So, you will have two masses m as you can see here, they are separated using a connected using a spring, and then they will be vibrating as if it is trying to move in this direction ok. So, both are trying to move in the opposite direction. And then the whole system is having a angular velocity ω like this.

And then it will be experiencing a Coriolis force, both the mass will be experiencing Coriolis force. And now you measure the displacement of this mass using some other method and that will be a measure of ω, so that is the basic principle of MEMS based with a tuning fork configuration MEMS based gyroscopes.

So, when angular velocity is applied, the Coriolis force on each mass also acts on opposite direction which results in capacitance change. And this capacitance change is a measure of the angular velocity. So, you will be able to get the angular velocity of the system based on the measurement of the capacitance change, so that way you will be able to get the rate of change of the rate of change of angular orientation using this sensor ok.

So, the differential value in capacitance is proportional to the angular velocity ω and is then converted into an output voltage that is what actually happens in the sensor. So, the gyroscopes are very small chips. So, you can actually you will be able to get it in a very small chip, and use it for use it in your system to get the angular velocity ok.

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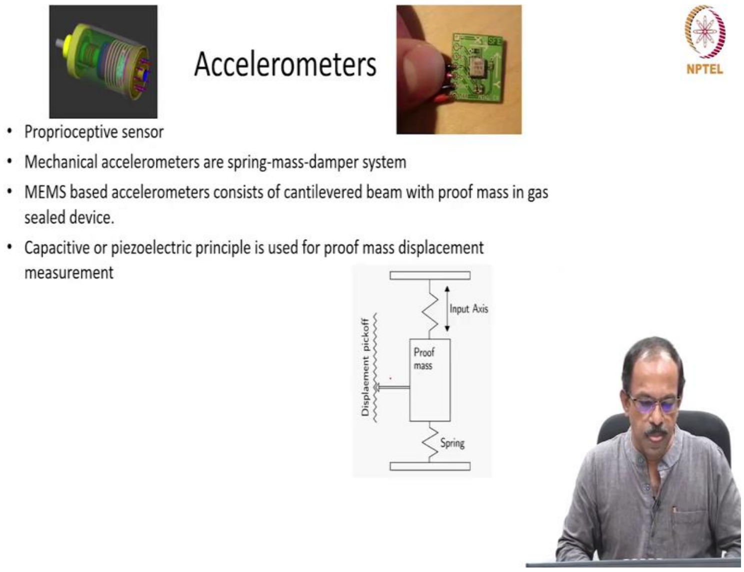

So, we will discuss this in the next class, accelerometers and other kind of sensors will be discussed in the next class.

Thank you.