Wheeled Mobile Robots
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Lecture - 4.6
Sensor Errors and Error modelling

Hello everyone. Welcome back to the discussion on Sensors commonly used in Mobile Robots. In the last few classes we discussed about the basic principle operation principle of some of the sensors. So, before closing the discussion on sensors let me briefly talk about another class of sensor which are very commonly used though they are not very very much needed in localization and other aspects, but they are used for many other applications in mobile robots.

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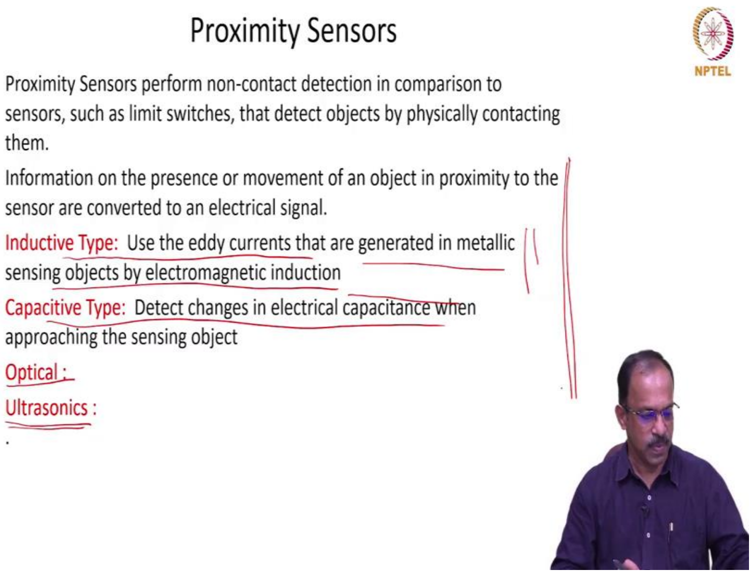

So, they are basically the proximity sensors. Proximity sensors do a non contact sensing compared to the sensors like limit switches which actually depend on contacts to sense objects proximity sensors do a non contact sensing. So, the presence or absence of an object or momentum of a object proximal to the sensor can be detected by this kind of sensors.

As you can see here there are different kinds of proximity sensors one is basically the inductive type which uses the eddy currents that are generated in metallic sensing object by electromagnetic induction. So, that is one basic principle where they go for the inductive principle. When the metallic objects are close to the sensor because of electromagnetic induction there will be a eddy current formation that will result into some kind of changes in the sensor.

And that can be used as a detection of some objects proximal to the sensor. So, that is basically the inductive type sensor. Another one is capacitive type basically again this also will be having a non contact type. So, the detect changes in capacitance. So, here the variation capacitance is measured when the sensor is close to an object and there are other types also like optical and ultrasonic sensors.

Optical sensor as you know when it is reflecting a light or the light is getting objected or obstructed by some objects in the vicinity that actually can be given as a sensing of the presence of object near to the sensor that is the optical.

Similarly, ultrasonic also ultrasonic will be emitting ultrasonic waves and then that will be reflecting from a object and that can be used as a measure of or as a sensing of objects near to the sensor. So, any one of these principle can be used either it is inductive capacitive or optical or ultrasonic can be used to detect object proximal to the sensor.

So, when you attach this sensor to the robot and the robot is moving, it will be able to tell you whether there is an object near to the robot or not. Do you want really tell you the distance of the object or the type of object etcetera which purely tell you whether this the object is close to the robot or not that is basically the proximity sensor.

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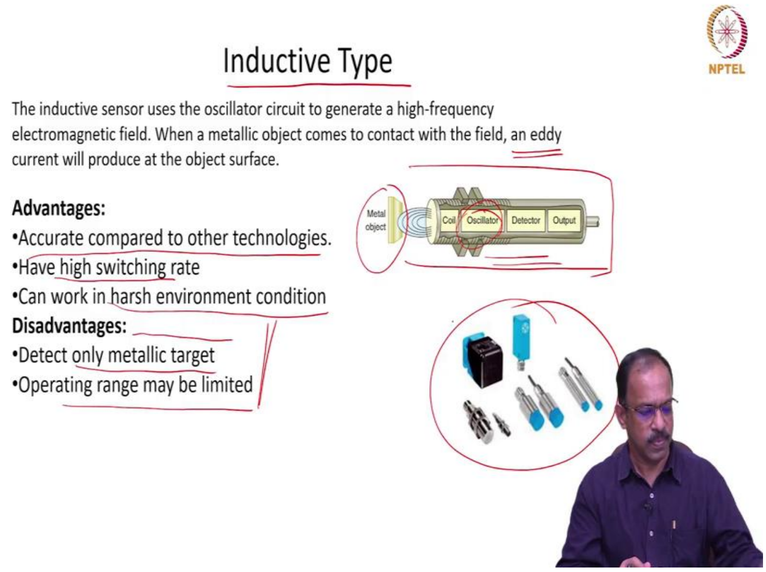

Let us look at the working principle of this happens sensors or the inductive type. So, this is the basic construction of an inductive type sensor. So, there will be a coil which will be actually actuated through electrical supply and there will be an oscillator which will generate high frequency electromagnetic field and any metallic object comes close to that will get an eddy current on the surface.

And as the sensor is closer to this the eddy current increases and that will actually lead to some changes in the oscillator and then oscillator will actually will not be able to provide the necessary oscillation as a current increases and that can be used as a measure of object close to the sensor; that is basically the principle of inductive type sensor ok.

So it is very accurate compared to other technologies because the variation in the oscillator circuit only need to measure and the once we can measure that it will actually tell you whether there is a change in the oscillation and that will tell you whether there is a presence or absence of object.

And have a high switching rate. So, it can actually do very fast response and very harsh environment also this can work, but the disadvantage is that it can only for metallic targets. So, currently there they are actually used for metallic there are non metallic sensors also, but most of the inductive fund which actually fall over the metallic target only. And the very limited range if the object is far away then it you would not be able to create the necessary eddy current.

And therefore, it will would not be able to get the sensor. So, out of few disadvantages are there over the inductive type sensor. So as we can see there are lot of commercially available inductive type sensors in the market and they are not very costly you can actually get in to a low costs these kind of sensors and the output is only a presence or absence of an object, that is all it will tell you.

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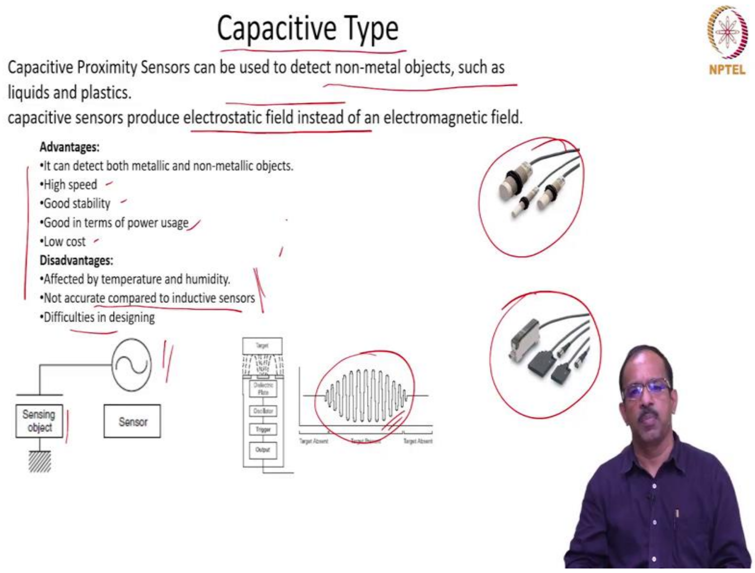

Coming to the capacitive type as I mentioned the variation capacitance is basically measured in this case ok. So, they can be used for non metal objects because it is not the on inductive principle. So, you can actually use for non metal also you can use this capacitive principle and they produce electrostatic field instead of an electromagnetic field.

So, electromagnetic instead of electromagnetic field you can go for electrostatic field and then as you can see here the sensing object and this is the sensor. So, you will be able to see the variation in the signal when there is a presence of an object. So, this variation can actually be observed in the sensor and that can be interpreted as the presence or absence of an object.

So, that is the principle of capacitive type sensor. Again you can see they are very commercially available sensors are there can be easily attached to a robot and then can be used for checking the proximity of a robot close to any object. So, it can detect both metallic and non metallic objects and high speed good stability good in terms of power usage and low costs are the benefits.

So, it may get affected because of the temperature and humidity and very not and not accurate compared to inductive sensors and difficulties in designing. So, accuracy wise the capacity may not be so good and maybe bit difficult to design, but otherwise they are a very good and high speed and stabilities.

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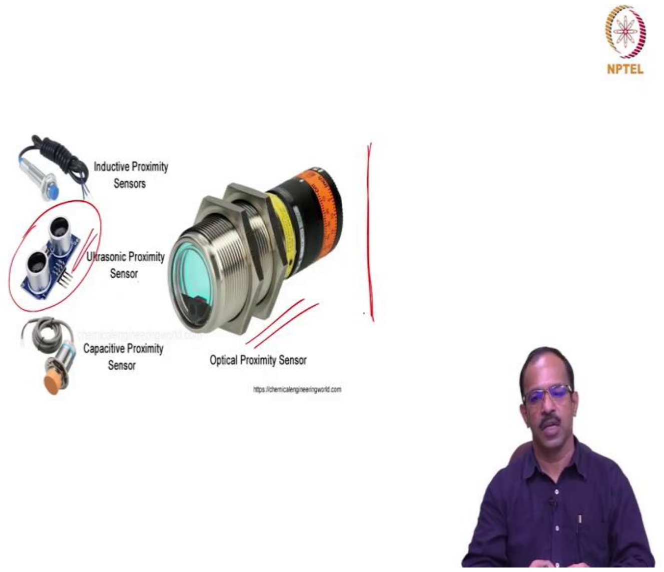

Therefore, sensing using the capacitive type sensors and these are they are actually like ultrasonic. So, I am not going into the details of all these sensors ultrasonic basically provide you I it will produce an ultrasound ultrasonic wave and then there will be a receiver which will actually receive the reflected signal and whenever there is a reflection coming to the sensor that will that can be interpreted as a presence of an object near to the sensor.

That is basically the ultrasonic and similarly you have the optical proximity sensor optical proximity also with the reflection of light or there is a receiver at the other end that also can be used for checking whether there is any object in the near to the sensor.

So, we can go for inductive capacitive, ultrasonic or optical proximity sensors in robotics. As I mentioned they have just provide you the information whether the robot is close to an object or not now further qualitative information quantitative information will not be available from the this kind of sensor.

But still they are they have wide application because in many cases you just want to avoid some obstacles or just want to check whether it has reached a particular end of path or something like that. So, in that situations, these kind of sensors are quite good and they are cheap and then easy to integrate and therefore, they have lot of applications in a mobile robotics.

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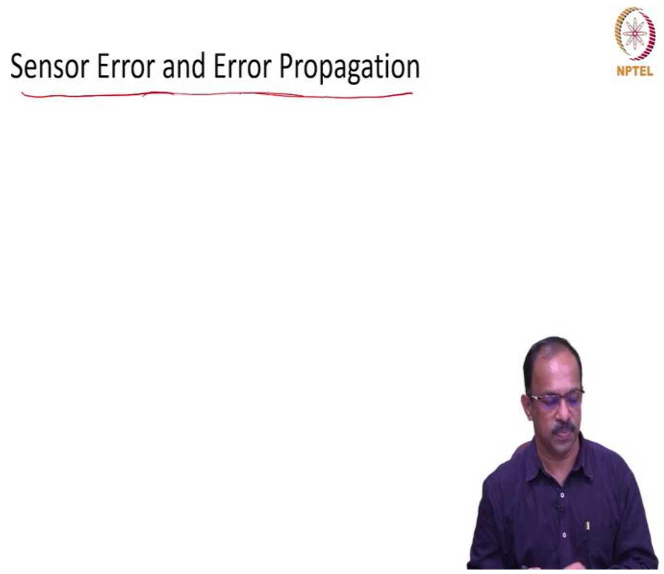

So, that is about the different types of sensors we use in robots. But before closing the discussion on sensors I just want to highlight one important point which I already mentioned few times about the sensor error and the error propagation. So, as I mentioned the sensor arrays are when there can be arrays which are which can be compensated using calibration and there are random errors which cannot be really modeled or predicted.

So, we need to have some understanding of what is the error in the sensor and how this sensor error will lead to additional errors in the estimation of sensor the robot pos or other characteristics of the robots. So, this is why we need to know what is the error propagation model that is normally used in robots.

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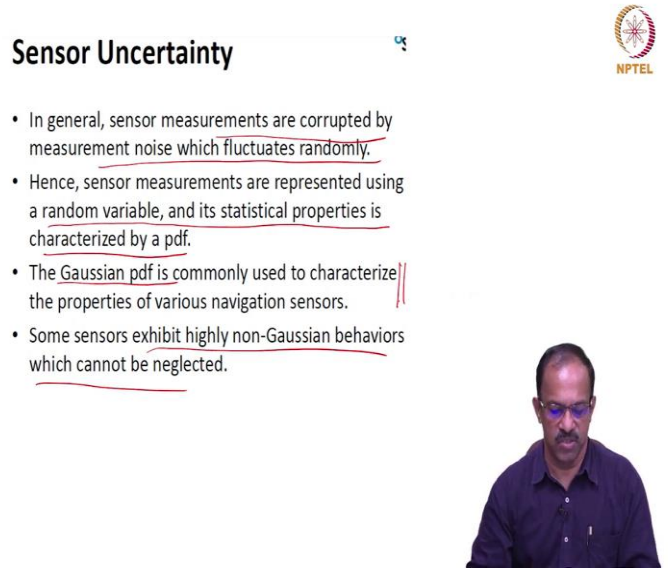

So, as I mentioned the sensor measurements are corrupted by measurement noise which fluctuates randomly and where we have to represent them using random variable and the statistical properties are characterized by pdf that is the probability density function.

And normally we go for the Gaussian pdf where I mentioned that it is a; it is a; it can be presence as a Gaussian distribution with the mean value and a standard deviation. But there are sensor which represent non Gaussian behaviors also, but in general master sensors can actually be classified under this category and then we can use it for predicting the errors and estimated cause of the robots when there are errors in the sensors.

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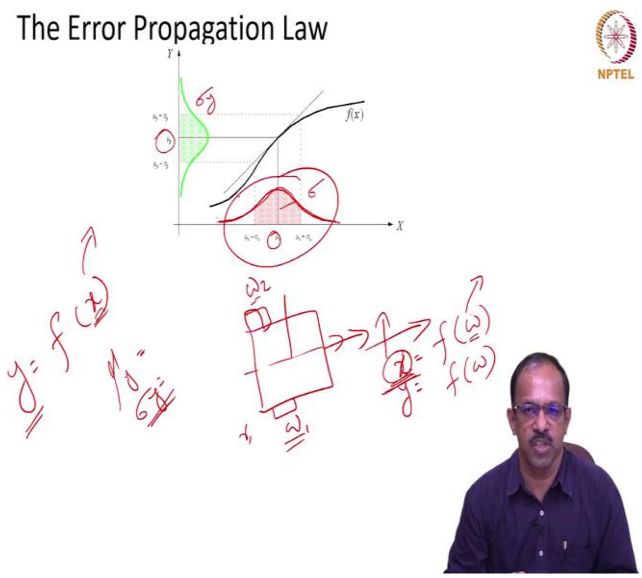

So, to explain this please have a look at this diagram; it shows x vs y plots now assume that ok. You take an example of a mobile robot and we have 2 wheels the robot is moving and then we say that this is having a speed of ω_1 this is having a speed of ω_2.

Now, we use this we used 2 sensors to get the values of ω_1 and ω_2 or we use a sensor to get the speed of the wheel or the angular position of the wheel based on the sensor reading. So, we take this and then we want to know how much the robot has traveled in this direction in its x direction.

So, we want to write get the x position of the robots and we know that if we know the radius of the wheel and the rpm of the wheel and once we have these parameters and then some other robot parameters if we can have then we will be able to get this x and y as a function of this ω.

So, we will just say it is a function of ω of course, it may be function of many other parameters, but for the time being let us assume that it is a function of this speed now I have a sensor which actually measures this ω and then I use that one to estimate the position of x.

Now, the question is if I have an error in ω measurement if there is an error in ω measurement what will be the error in x estimated position x. So, this I need to estimate because I know only about the sensor and the sensor characteristics and based on that I need to find out what will be the approximate error in the position x if I calculate the position x using the value of ω.

So, this is basically what we need to know or this is known as the propagation of error from the sensor to the estimated position x. So, we have a propagation of error from the sensor reading to the estimated position of the robot x. So, now, if I represent this as a f(x). So, in this case as I write this as y = f(x) that is I am estimating y is a f(x) and then I have an error in x.

So, that is what actually plotted here. So, if I am measuring this x and the error in x can be shown as a distribution like this with the mean value μ_x and then a σ which is the standard deviation if this I know. If I know the sensor mean value and its standard deviation can I find out what will be the error in y μ_y and the σ_y.

So, if I can estimate the μ_y and σ_y then I know what is the error in y because of the error in x. So, this is known as the error propagation model and we need to have a relationship between the μ_y and μ_x or we need to know what is mu y or how can I x estimate μ_y or σ_y.

A signal y is important because that actually shows the how much error will be there variation in the error. So, if I can estimate this σ_y if I know these parameters then we call that as an error propagation model and this is basically the error propagation law which states that we can find out the error in the estimated value if we know the error in the sensor or the measurement. So, that is basically the error propagation law.

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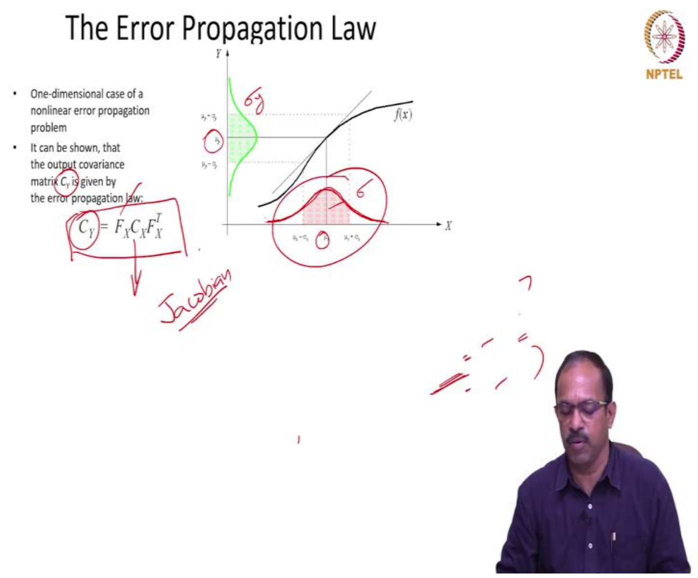

And what it states? So, we will take a one dimensional case that C_Y which is a co variance in Y co variance even it is a multi dimensional one you will have a co variance. So, C_Y; so, $C_Y = F_X C_X F_X^T$; where C_X is the error co variance in X if the error co variance in X or the μ_X or C_X is known then we can actually get $C_Y = F_X C_X F_X^T$ where F_X is known as the Jacobian which is a; which is a which depends on the function y(f(x)).

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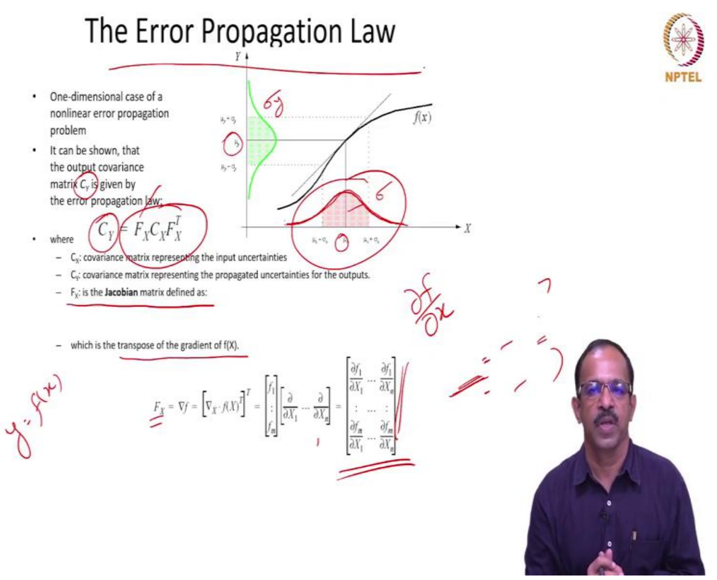

So, we can write it as C_X is the co variance matrix and F_X is the Jacobian which is defined as a transpose of the gradient of F_X and is given as. So, if y = f(x). So, if you have is equal to f(x) then Jacobian F_X can be given as a fund by partial derivative of f with respect to x_1 x_2 x_3 etcetera.

$$F_X = \nabla f = \left[\nabla_X \cdot f(X)^T\right]^T = \begin{bmatrix} f_1 \\ \vdots \\ f_m \end{bmatrix} \begin{bmatrix} \frac{\partial}{\partial X_1} & \cdots & \frac{\partial}{\partial X_n} \end{bmatrix} = \begin{bmatrix} \frac{\partial f_1}{\partial X_1} & \cdots & \frac{\partial f_1}{\partial X_n} \\ \vdots & \cdots & \vdots \\ \frac{\partial f_m}{\partial X_1} & \cdots & \frac{\partial f_m}{\partial X_n} \end{bmatrix}$$

So, if its a multi dimensional one then we will be able to get this elements as partial derivative of f with respect to x. So, if we have multiple variables x_1 x_2 x_3 etcetera then you will be able to get this as a variable like this.

So, this is the Jacobian which can be used for calculating this. So, $F_X C_X F_X^T$ will be the co variance of co variance in y when there is a co variance x in the measured band gap. So, this error propagation law is widely used in estimating the position of the robots when we are using sensors to get the parameters.

So, when the when a sensor is used to get the distance to an object and then using that distance you are estimating the position of the robot we need to know how much error will be there in the position when we have some error in the estimated over a sensed distance that is basically the requirement in localization of robot.

So, we will be using this error propagation law in order to get the estimated position of the robots and as the robot move this covariance keeps increasing and therefore, you will be having lot of uncertainty in the because estimated position of the robots with this kind of measurements.

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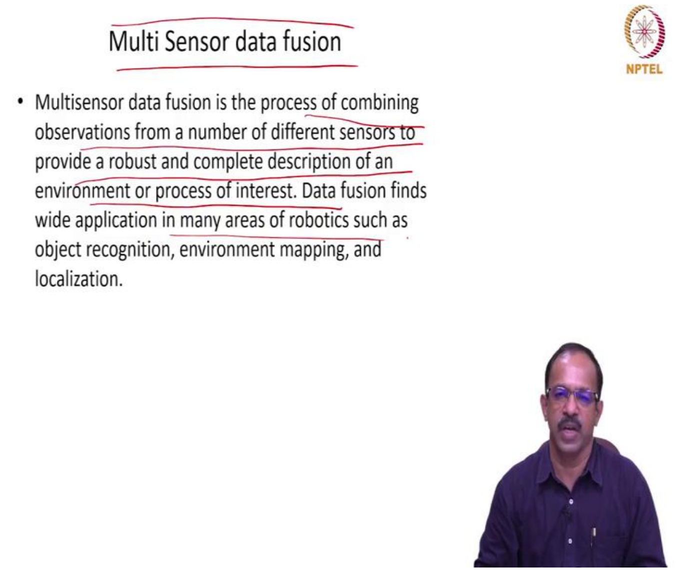

We will see this how to use this one in the localization as when we discuss about localization of mobile robots. So, that is about a single sensor issues when you have a sensor and we used that sensor for estimating position or the velocity or some other parameter of robot you will be getting errors.

So, how do you actually avoid that kind of errors? So, one way is to go for multi sensor data fusion. So, you do not depend on a single sensor you use multiple sensors and then fuse this data and then have a better estimate of the position of the robots. Though there is error propagation still you will be able to correct the errors or to bring down the errors to some extent by having a multi sensor data fusion.

This is the process of combining observation from a number of different sensors to provide robust and complete description of an environment or process of interest. So, you will be able to combine data from different sensors and then use it for describing the or use it for getting the estimated position when the with much more accuracy. It actually has got wide application in many areas of robotics object recognition environment mapping and localization.

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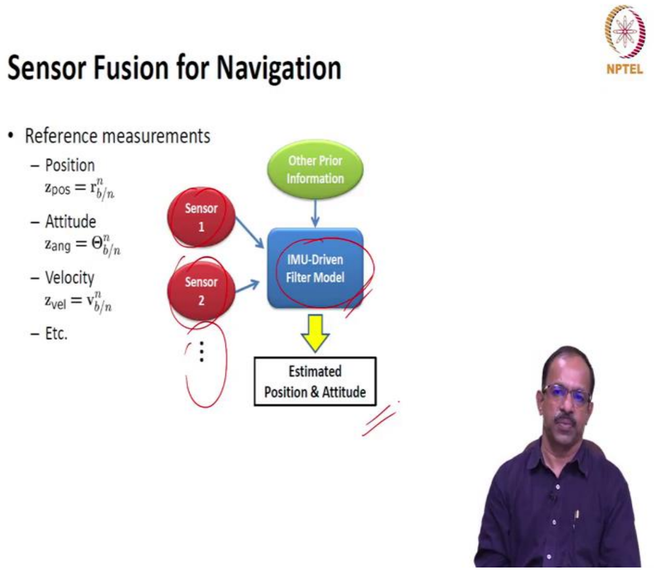

So, how is it done? So, you take the sensor data sensor 1 sensor 2 etcetera and then there will be some kind of sorry filter algorithm. So, we use some filter algorithms to fuse this data and then reduce the error. So, as the robot moves the that error keeps increasing. So, to avoid that we use multiple sensors and then fuse this information using some filters and we will estimate the position of the robot that is the way how we keep on doing the estimation of the position and attitude of a mobile robot using sensor fusion.

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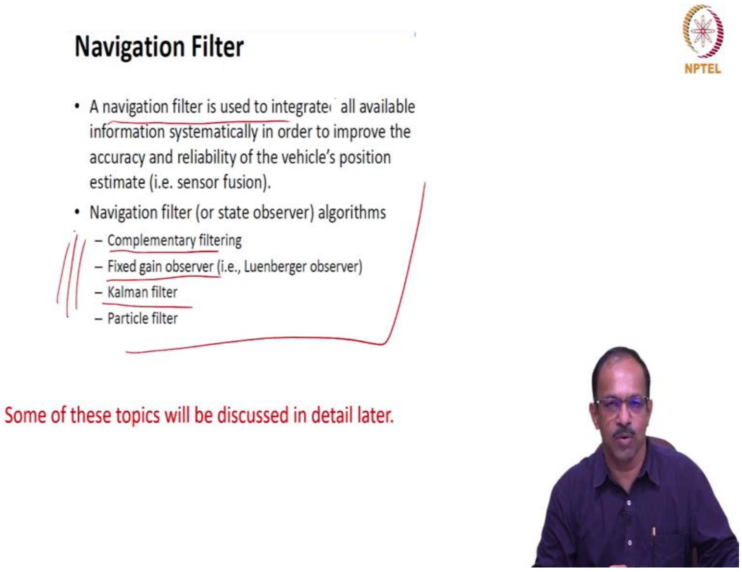

And we have many filter like navigation filter to that the navigation are related data and these filters will be having a different features. So, it can actually go for complementary filters or fixed gain observer or Kalman filter or particle filter. So, there are many such algorithms available and some of these we will be discussing later as when we talk about robot localization mobile robot localization we will be talking about this.

Some of these filters not all the filters, but at this time will be discussing one or two filters and see how these filters can be used to fuse the information from sensors. And then estimate the position of the robot in a much better way by reducing the error propagation or reducing the error in the estimated pose and position and attitude of the robots. That is what is going to be the that will be discussed in the next few classes ok.

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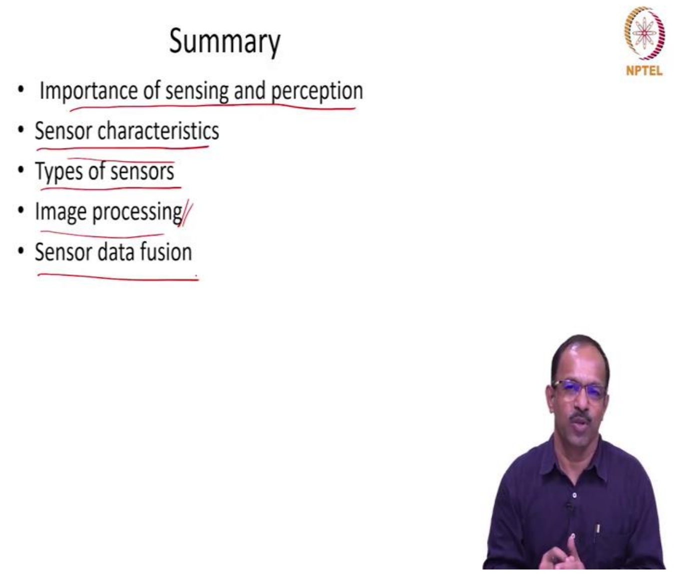

So, let me conclude the discussion of sensors with that. So, we talked about the importance of sensing and the perception in mobile robot what is the reason why we need to learn about these sensors the sensing and perception is an important aspect of mobile robots.

And then we talked about the characteristics of sensors like the repeatability, resolution , bandwidth etcetera and then we talked about different types of sensors we talked about position sensing I mean encoders, we talked about velocity sensing and we talked about accelerometers I and μ_s etcetera etcetera.

And briefly talked about vision based sensors or the image based sensors where we can do image processing collect the image using camera and process the image and then use it for some information to collect some information and that information can be used in mobile robots and finally, we talked about fusion also.

So how to fuse result data? Of course, we did not go into the detail, but just mentioned the importance of sensor data fusion and how that can be used for improving the position or the estimated position and attitude of mobile robots ok.

So, with this I will conclude the discussion on sensors from next lecture onwards we will talk about mobile robot localization especially for autonomous robots how do we do the localization and then how can we use the sensor fusion to improve the accuracy of localization.

Similarly, how to use the localization and mapping in order to create map for robots that will be the discussion in the next few classes. And we need to discuss little bit about the kinematics also and how can we use the kinematics to of course, you already have some information about the kinematics. So, I will not be going to the details of kinematics, but I hope that you will be having the basic knowledge of kinematics to when we use this information for localization ok.

Thank you.