Wheeled Mobile Robots

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Lecture - 4.5
Commonly used sensors – 3

Hello, everyone. So, let us continue the discussion on sensors. So, we saw about we saw a few sensors and their functioning working principle, we looked at the encoders, we looked at the gyroscopes, we looked at the accelerometers, we looked at IMUs. And, then we discussed about the beacon based sensing also for localization of robot, how can we use active beacons and as a special case we looked at the GPS based localization also.

So, in this lecture, we look at the sensors which are used for identifying the distance to different objects in the inner environment or obstacles in the environment and how do we use that one for localizing the robot. So, not only for localizing we can actually use that one for obstacle avoidance applications also.

So, there are many sensors which can actually identify the distance from the robot to the to an object on its path or in the surroundings. So, there are different basic different sensors based on various sensing principles. So, we look at some of them and how they are used in mobile robotics.

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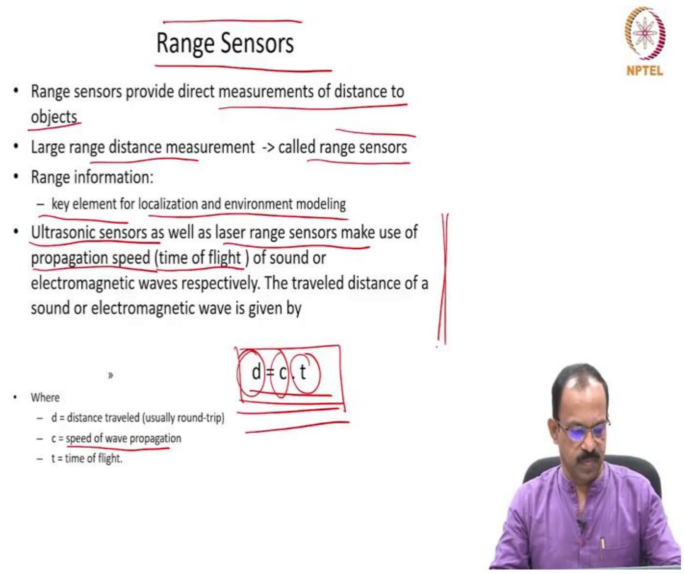

So, these sensors which are used for distance measurement are commonly known as a range sensor. So, it will measure the range or the distance to the object. So, it measure the direct measure of distance to the objects and the large distance measurements we call it as range sensors and otherwise we call it as the proximity sensor which are actually basically to just identify whether they are very close to something or far away from that one.

So, you want to measure the distance then we call it as the range sensors and they are very key element for the localization and environment modelling. So, localization is basically you want to know the position of the robot based on this measurement we can actually do that or we can actually use this one for creating the map of the environment also by measuring the distance to different objects you will be able to create a map of the environment.

So, there are two types of sensors used commonly used – one is the ultrasonic sensor and then other one is the laser range sensor. So, ultrasonic sensor and laser sensor both the both measure the distance, only thing the principle of sensing is different. So, it actually the ultrasonic sensor emits the sound signals and this sound signal go and hit on the object and then it will return then the reflected signal will be received at the receiver. And, then look at the time of flight how much time it took the center the signal to come back and based on that the distance can be measured. So, that is basically the ultrasonic sensor principle.

The laser range sensor instead of the sound signal will be sending a laser signal and then measure the distance based on the received signal. So, these are the this is the two type of these are the two types of sensors and as you know that the principle is that $d = c \times t$.

So, there is a sound signal or a laser signal you will be using this principle to measure it that $d = c \times t$, where c is the distance d is the distance travelled and c is the speed of wave propagation. So, as you know that sound wave or electromagnetic wave or I mean a light source or light signal will be having the frequency it is on frequency in the in the medium sorry, it is on speed in the medium.

And, that speed if we know the speed of that wave propagation then by looking at the time of flight how much time it took for the signal to return back after hitting the object you will be able to get the distance. So, d is given as $d = c \times t$, where the c is the speed of wave α and t is the time of flight. So, both the laser range sensor and the ultrasonic sensor use this principle for measurement.

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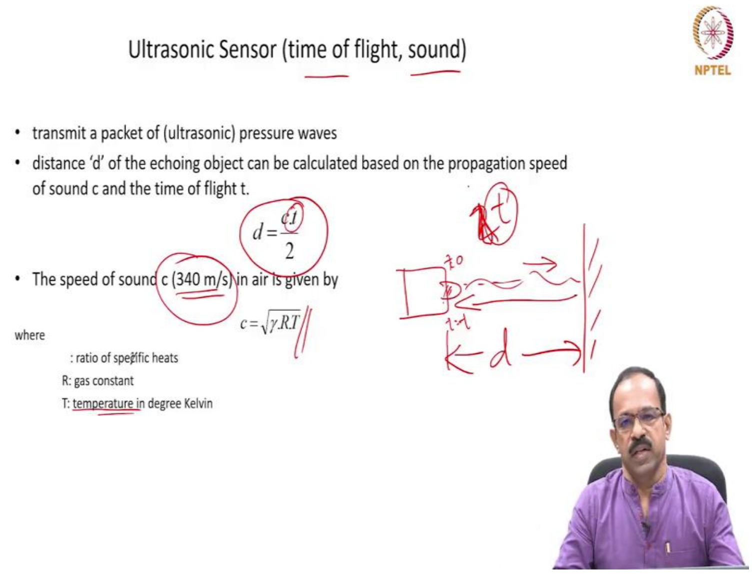

So, let us look at the ultrasonic sensor first which again the time of flight and the sound signal. So, we know the speed of sound in the air and once we know that we know that the sensor will be sending a signal and suppose this is the object. So, it will be sending a signal and this will actually reach go in this direction and then it will reflect and then receive here.

So, this should be a transmitter and receiver a transmitter will send a signal if the transmitter will send the sound wave it will go to the object travel to the object and reflect and then come back and at the receiver. So, we know that this is the distance d and it takes time 2t for to and fro motion and therefore so, $d = \frac{c.t}{2}$ that is if this is.

So, if I say it is t is the time taken for it to come back suppose t is the time taken for the signal once after the transmission t = 0, then it is equal to t is equal to t then it is $\frac{c.t}{2}$. So, that is the way how you get the measurement done. And, we know c = 340 meter/second in air of course, it varies with respect to the temperature in temperature and the gas constant, but assuming that normally there is not much of variation we can actually get the distance measured.

And, the error may be mainly because of the changes in the speed because of variations in the parameters, but in general we can say it is 340 meter/second and therefore, if we know the measurement of t we will be able to get the distance. So, the primary challenge is how do we actually measure the distance this time t. Once we can once we have the method to measure the time t, then we will be able to get the distance measured.

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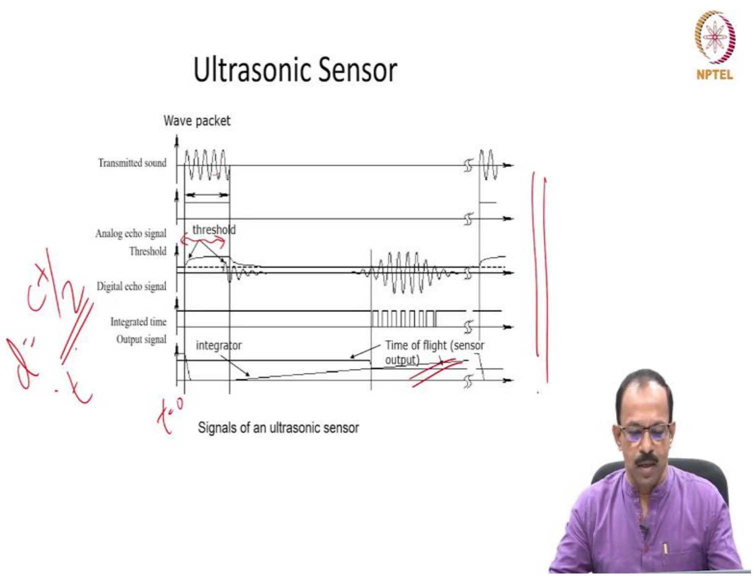

So, this is the way how it actually happens. So, the transmitted sound will be travelling at this is t = 0 initially and then this in the receiver there will be a signal which is coming back and then receiving.

But, the if the receiver and transmitter are kept close to each other and therefore, there will be a set at threshold that during a particular period you should not measure the reflection because otherwise you will be measuring the same signal what is transmitted. So, there will not be any time the time will be too small between the transmitted and reflected measurement and therefore, the error will be there.

So, initially a threshold will be set and after that threshold then you will see that if anything comes back that signal will be received and the time will be calculated because we will be sending a time setting up a time signal also. And, the time will be integrated and the moment it reaches the moment the receiver get the signal and that time will be measured and that will be taken as the t and then you use it $\frac{c.t}{2}$ as the distance d. So, that is basically how do you get.

So, the time of flight the sensor output will be there, the time will be measured and the moment it the receiver gets the reflected signal and the time signal will be stopped and that will be considered as the time of flight. So, that is the way how this will be set in the sensor. So, you will be having the transmitter and receiver close by and a time signal will also will be started along with the transmission. So, this principle is used for measurement ok.

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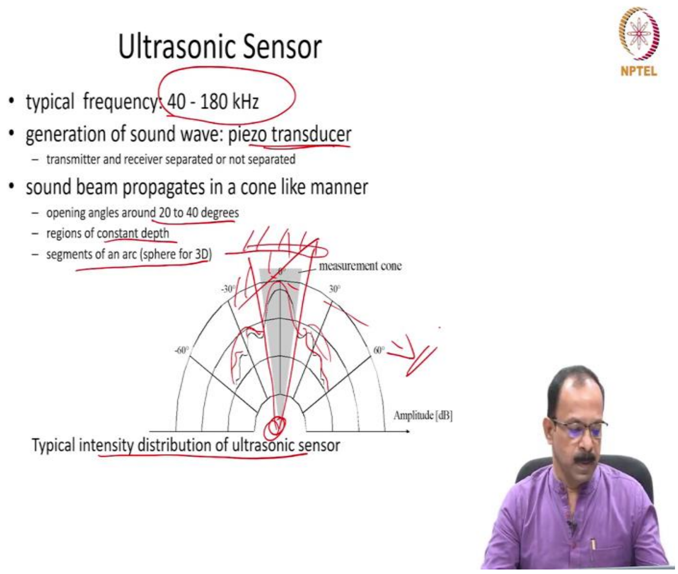

So, typical frequency is around 40 to 180 kilo Hertz in this case a piezo transducer will be used for generating the sound wave and normally the sound will be actually travelling in a cone like fashion. So, if the transmitter is here. So, it will be moving in this and it is having the amplitude highest amplitude in this cone. Of course, there will be signals in this other angles also. So, 20 to 40 degrees and regions of constant depth and segments of an arc sphere or for 3D.

So, you can have a 2-dimensional or 3-dimensional measurement, but in 2D you will be having a cone like this. This is the way how the intensity will be distributed. So, the highest intensity will be in the 20 to 40 degree cone ok. So, that will be the way how it will be transmitted.

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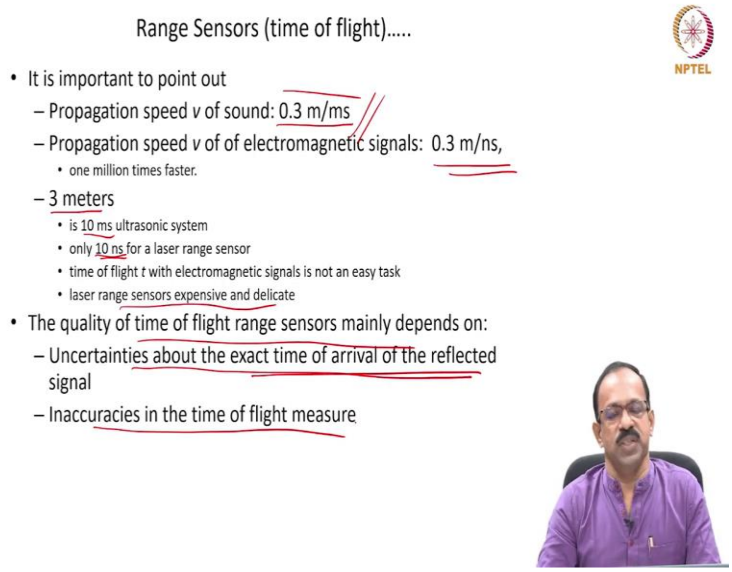

But, some of the challenges are that you will be having one of the one of the challenge is that there may be some reflection coming from somewhere here also. And you are trying to measure it some object here. So, it may be coming here or there may be some kind of a reflection if the object is something like this it may get reflected like this. So, these are some of the challenges and some of the surfaces will absorb the sound wave. It would not really reflect.

So, though it is a very good method of measurement of distance the challenges are the environment may not be same there will be many differences in the environment or there may be objects which are either not reflecting or the reflection may not be in the normal direction. So, all those will change cause some challenges and that is why you will do not get a proper measurement always if you do the measurement 3-4 times you may get different readings because of this kind of issues. But, still it is a good method of measuring, you can get a reasonably good measurement using sound based or ultrasonic sensor.

Now, if you look at the sound based and the laser based sensors you can see that the propagation of sound is 0.3 meter/millisecond. So, the propagation of the propagation speed of sound is around 0.3 meter/millisecond. But, if you look at the speed of ultra electromagnetic signal basically the light based or laser based signal it is 0.3 meter/nanosecond. So, you can see it is much much faster than the sound wave.

So, if you are using a sound wave to measure a distance you will be getting a time, but this is the same distance is measured using a laser based sensor the time gap is very very small. So, you will get a very very small time difference between the transmitted signal and received signal because if you are measuring 3 meters distance it is 10 millisecond for ultrasonic system, but it is 10 nanosecond for a laser range sensor.

So, you can see you can measure 10 milliseconds using the transmitter receiver the difference in the time of getting the signal back. But, in the case of a laser it is only 10 nanoseconds. So, it is very difficult to measure the time of flight using the conventional method which is used in the ultrasonic sensor. Because ultrasonic sensor starts a time signal and then integrate the signal and that point over actually it receives the signal the sound signal at the receiver you stop that time signal and measure that time step.

This is not possible in the case of laser range sensor because the time is too small and therefore, we need to have a different method of a measurement ok. So, we need to have more expensive way of measuring the time gap between the transmitted signal and the received signal. And, the quality of time of flight range sensor mainly depends on uncertainties about the exact time of arrival of the reflected signal ok. So, if you make any error in that measurement then the whole sensing is gone.

So, you cannot have a good sensing using that sensor ok. So, the inaccuracy in the time of flight measure is leading to a lot of errors in the sensor. So, you need to have a very good way of measuring the time of flight. And, it becomes complex in the case of a laser range sensor because the time of flight is much much less compared to the ultrasonic sensor. So, we need to have a different way of sensing it.

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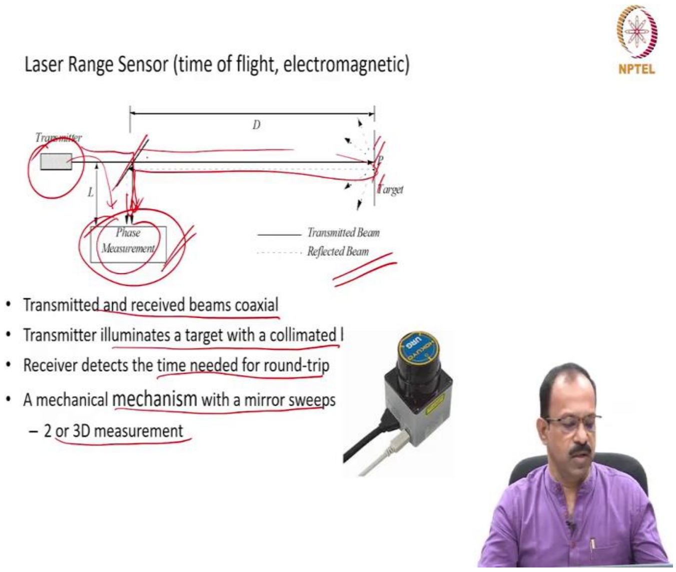

So, let us see how the laser range sensor works and then we look at how the time of flight can be measured. So, the basic principle of a laser range sensor as you can see here. So, you have a transmitter which sends the laser signal and it travels to the target and then reflects back. And, now we will use a mirror to reflect this or to divert the signal to a receiver here.

So, in this receiver what we do is we do not measure the time of flight, but we look at the phase difference between the transmitted signal and the reflected signal. So, why there is a change in phase because we will take both the transmitted signal and the reflected signal, since the reflected signal has travelled a distance it will be having a phase difference with the transmitted signal.

If we can measure this phase difference and then that phase difference can be considered as a measure of the distance travelled by the sensor. So, that is the basic principle here. So, the transmitted and received beams are coaxial a transmitter eliminates a target with a collimated beam and receiver detects the time needed for the round trip a mechanical mechanism with a mirror sweeps 2 or 3D measurements.

So, you can actually have a 2D or 3D by having a sweep of the laser also that is basically if you want to have a 3D laser range sensor you can actually the signal can actually be sweeped using a mirror, so that it can actually go in the 3D surface and then get the measurement that is the basic principle. So, you have a transmitted signal and a reflected beam. So, the transmitted signal comes here and the reflected signal also comes here and then we look at the phase difference and then use that one for measuring the distance.

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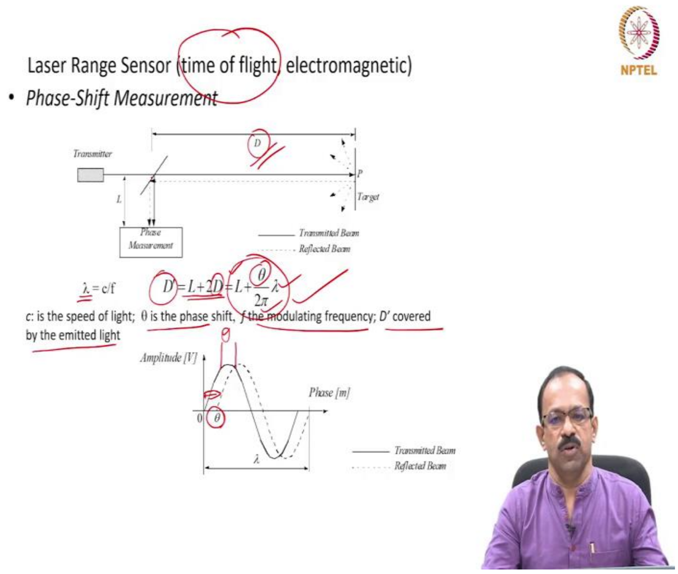

So, how much the distance is travelled by the signal? So, you can see that it travels the distance D'= L + 2D, this is D and this is L. So, this the additional distance travelled by the this is L + 2D. So, you can say that $L + \frac{\theta}{2\pi}\lambda$ = D' that is travelled by the beam.

And, here $\lambda = \frac{c}{f}$ which is the wavelength. So, so θ is the phase shift 'f'' is the frequency and D' is the covered by the emitted light. So, D' is the distance travelled by the or covered by the emitted light.

Now, we can actually plot the phase difference and then we will see that there is a θ shift between the two signals. So, if you see this is the transmitted signal and this is the received signal you will see that there is a phase shift between these two. And, therefore, we can measure this θ we can look at this θ if you can measure this θ then we can actually find out because we know L we know λ and we know other parameters.

So, we will be able to get this D can be calculated. So, what we are interested is to know the distance D travelled by the beam and therefore, we will be able to get the distance D. So, just measure this θ the phase difference between the transmitted signal and the received signal and use that one for correcting the distance D. So, that is the basic principle of laser range sensor.

So, we are not measuring the time of flight directly, but we are looking at the phase difference because it is easy to measure the phase difference than the time because time is too small to measure. So, we will use this indirect measurement of the phase difference to get this. So, that is the way how we use the laser range sensor to get the distance measured.

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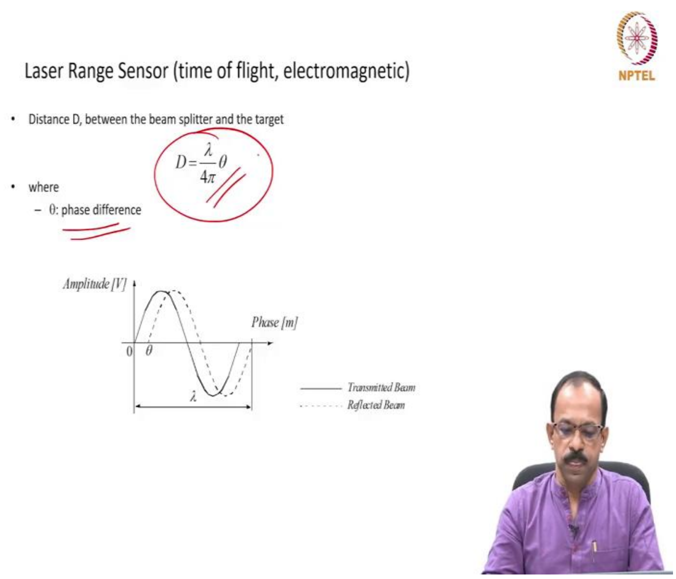

So, $D = \frac{\lambda}{4\pi}\theta$. So, if distance D between the beam splitter and the target is given as $\frac{\lambda}{4\pi}\theta$. So, θ is the phase difference between the two signals. So, the laser range sensor will be having a transmitter a receiver and then a processing system where the two signals the phase difference of these two signals will be measured and then you convert that into that is a distance based on this relationship. So, that is the principle.

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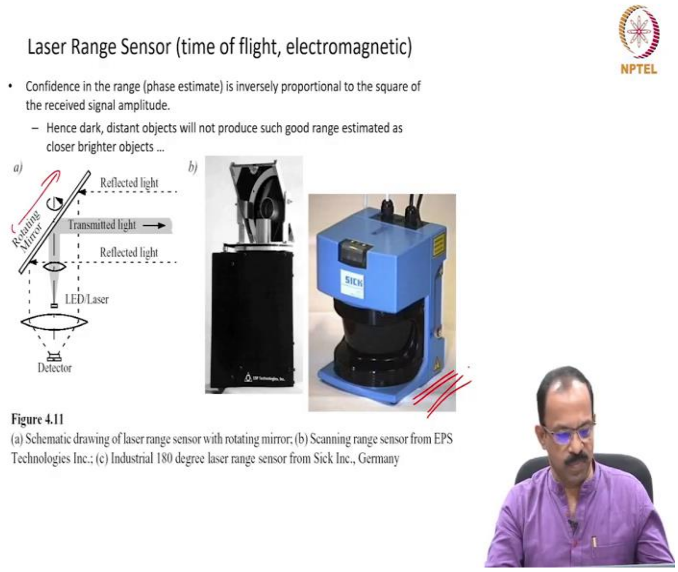

And, you can see there are so, this is the basically the detector and this is the rotating mirror. So, you can actually rotate this mirror to get a 3D sensing also. So, most of the 3D laser range sensors will be having a rotating mirror which will move the beam in a 3D space and then get the measurements done.

So, these are some of the this is a commercially available laser range sensor which is a 3D laser range sensor which can measure the distance to objects on its in its environment and use that one and we can use that one for either for localizing the robot or for creating a map of the environment.

And, you will see most of the autonomous robots will be having a laser based system we call it as Lidar and that will be used for localization as well as for map building.

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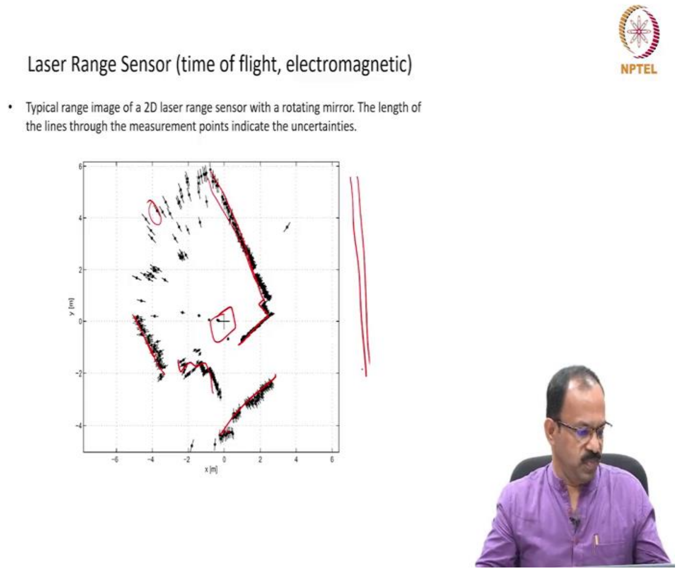

So, this is an example how we can actually get the distances and then use the distance measurement to create the map. So, you can see if the sensor is here and if you move the laser beam in a 2D space or in 3D you will be able to get all the distances to the measurement.

So, it actually shows the distances and some uncertainty. So, you can see there is a line which actually shows some uncertainty because of the measured measurement error, but still you will be able to see that there may be a wall here in this in here may be a wall and then there is a wall here.

So, these are the things that you can create and then that can be used to generate the map of the environment. And, this is widely used in indoor navigation as well as for outdoor navigation also for measuring the distance to the objective objects and then to create the map and can be used for one for obstacle avoidance in many cases ok.

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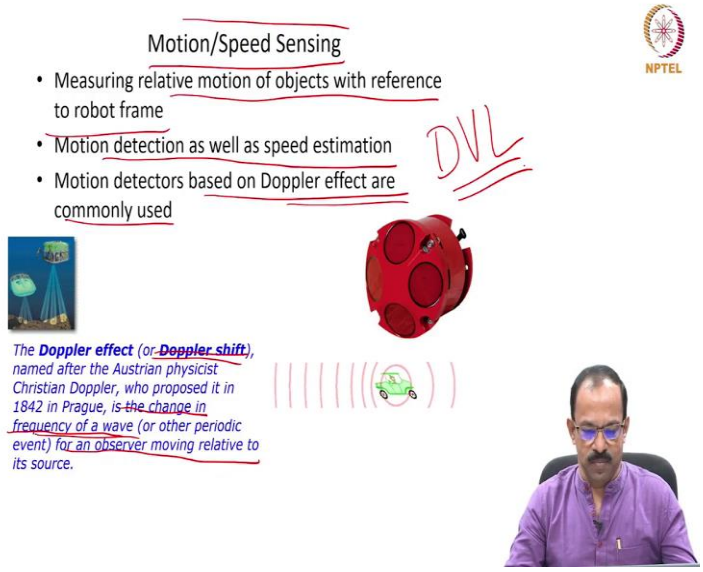

So, that is about the range sensing apart from the position and range sensing we want to have direct velocity sensing also not by using the accelerometers, but using some other sensors which is not more of an exteroceptive sensor. So, we can use the motion over a speed using sensors by measuring the relative motion of object with a reference to with reference to the robot frame. So, we want to know the relative motion between the robot and the environmental object.

So, if we can actually identify the relative motion, then we know that how much what is the speed at which the robot is moving. So, here you can have the motion detection as well as speed estimation.

And, many a times we use the sensors based on the Doppler effect. So, you must have heard about the Doppler effect. So, Doppler effect or Doppler shift named after a the Austrian physicist. Basically, the change in frequency; the change in frequency of a wave for an observer moving relative to it is source. So, that is basically the Doppler shift.

So, you will see a change in the frequency of the signal that is received when there is a relative motion between the receiver and the transmitter. So, somebody is transmitting something and you are moving relative to that, then you will see that there is a change in the frequency at which you are getting the signal.

So, this is very typically seen when you are standing on the road on a at a bus stand or some other place you are standing at a location and there is a an ambulance passing by. So, when the ambulance is quite far away you will hear the sound with a particular frequency, but as it comes closer to you will have it in a different frequency. The frequency actually shifts or there is a change in frequency of the signal as it comes close to you or and there is a and it is passing.

So, this is known as the Doppler shift so that is basically the change in frequency of a wave moving relative to it is source. So, as you can see here as it is moving there will be a change in the frequency at which you are actually receiving the signal and the same principle can be used for measuring the speed of the robot also and that is basically known as the Doppler effect based motion sensors.

And, there is a something called DVL Doppler velocity log which uses the principle of Doppler shift for measuring the relative speed of the robot with respect to a reference. So, if the robot if the robot is moving with respect to a constant reference you can actually transmit a signal and then see how much is the frequency change with respect to the reflected signal and that actually tells you at what speed you are moving with the reference to that fixed object. So, that is the Doppler velocity log or Doppler based velocity sensor.

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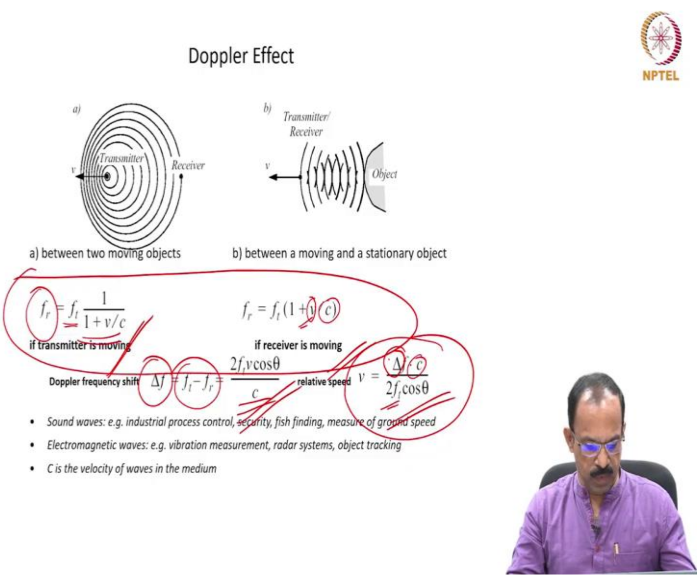

So, this is the as I mentioned. So, you have a transmitter and a receiver either the transmitter can be moving or the receiver can be moving. So, both can actually or it can be having a relative velocity also. So, depending on which one is moving you will be able to calculate the speed at which the or the relative speed can be calculated between transmitter and receiver.

So, you can have between two moving objects or between a moving and a stationary objects. So, the received frequency will be given as the transmitted frequency $f_r = f_t \frac{1}{1+{}^{v}/_{c}}$ ok. So, that is the frequency that is received when the two moving objects are there or the if the transmitter is moving in this case the transmitter is moving you will be getting this as the frequency or if the receiver is moving you will be getting $f_r = f_t(1 + {}^{v}/_{c})$.

So, this is the received frequency or the frequency at the receiver whether the transmitter is moving or the receiver is moving. So, in both cases you will be seeing that f_r is different from f_t and then v is the relative speed the speed at which the receiver or the transmitter is moving that is the v and c is the speed of the signal in that medium. So, that is the way how we can actually calculate the thing.

So, the Doppler shift $\Delta f = f_t - f_r$. So, you have an $f_t - f_r$ which can be given as $\frac{2 f_t v cos\theta}{c}$, where f_t is the transmitted frequency and then v is the speed and θ is the angle at which you are actually measuring it if it is normal then θ = 0, otherwise you will have an angle at which it is being the between the transmitter and received signal.

And, then c is the speed at which the signal is are moving in that particular medium or the velocity of the signal in the medium. So, $v = \frac{\Delta f.c}{2 f_t cos\theta}$. So, that is the way how we can get the relative speed $v = \frac{\Delta f.c}{2 f_t cos\theta}$ ok.

So, what we need to measure is? Δf. So, the Δf is known and then if f_t = n.θ, θ are known c will be c will be a constant ok, the speed of wave that will be constant in that medium. So, you will be able to get the velocity measured using the using this principle ok.

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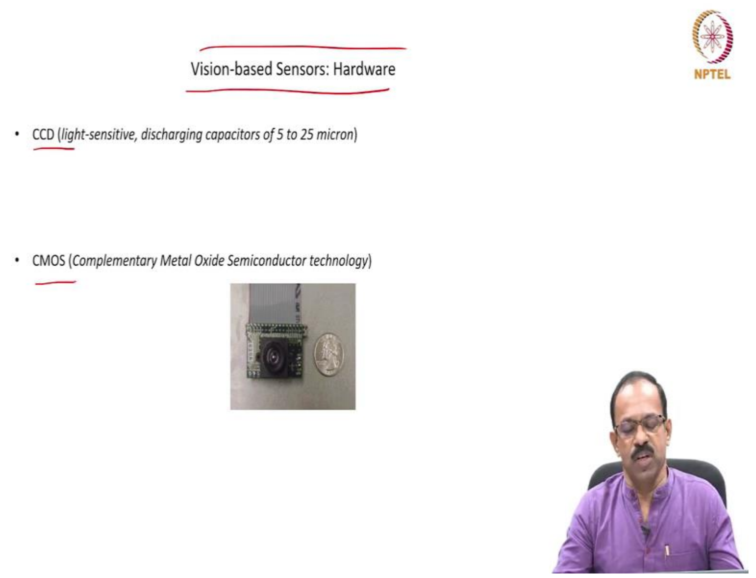

So, that is about the velocity measurement and there are many other sensors which are used in a mobile robot for getting information from the surroundings. So, one of the commonly used one is the vision based sensors. So, vision based sensors are mostly the cameras. So, you can have a CCD camera or a CMOS camera a charge coupled device or the CMOS Complementary Metal Oxide Semiconductor technology. So, these are commonly used to collect the information from the surroundings.

So, whatever may be the camera the what you are getting is an image from the camera and then you need to process the image and then collect the information and then see what actually you are seeing on the getting what information you are getting from the images.

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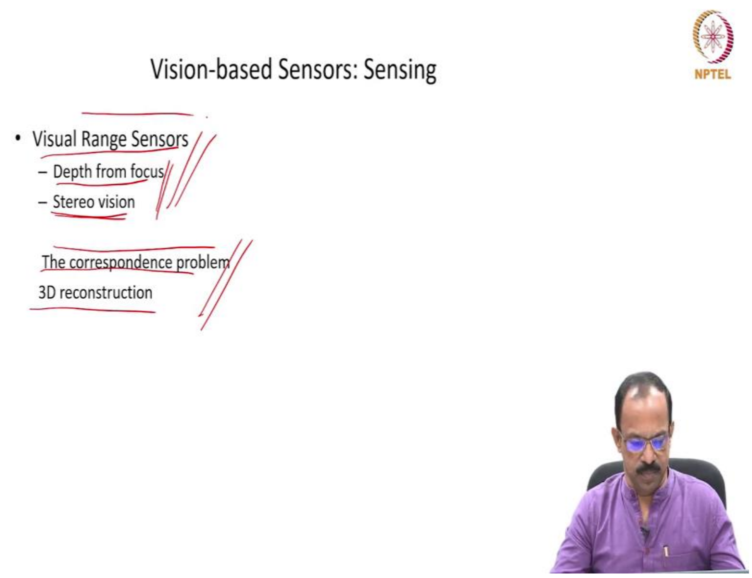

So, that is the vision based sensors we do not go into the details of these sensors, but you can actually use this visual range sensors that is you can get the depth from focus. So, you are getting a you have a 2D camera, but then using 2D cameras you can actually get the depth also that is the 3D image information also collected that is based on the principle of depth from focus or using a stereo vision cameras also.

So, you can create 3D 3D information can be collected either using the 2D cameras based on the depth from focus principle or you can use stereo vision cameras can be used or you can create stereo images using 2D cameras. So, any one of these can be used for creating getting the information and then using that information for navigating the robots.

So, there are a few issues with this basically constructing 3D from 2D cameras over the correspondence problem because there may be many objects which will be appearing to appearing similar in 2D images. So, that correspondence problem will be there that needs to be overcome of course, that is a separate discussion on its own image based navigation and all. So, we do not go into the detail, but just want to tell you that we can use sensors based on the vision based sensors also can be used to get the distances measured.

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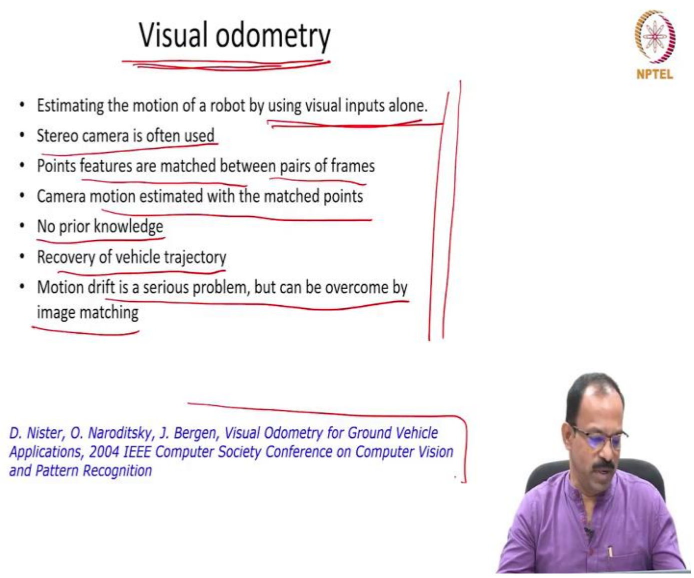

And, something similar to that is basically known as a visual odometry. Visual odometry is basically estimating the motion of a robot by using visual inputs alone. So, we want to use the camera images and then recreate the path or identify the path travelled by the robot. So, that is basically known as visual odometry. We do not use any other sensors to know the position of the robot. So, we use the visual sensors and then create the trajectory of the robots.

Many times stereo camera will be used and what we do is that we will match the features between pairs of frames. So, different pairs of frames should be adjacent frames will be compared. And, then see how much changes are happening and based on the changes we will try to see what is the change in the robot position. So, that is basically the principle here. And, then camera motion is estimated with the matched points and that camera motion is considered to be the motion of the robots though no prior knowledge is needed.

So, we do not need to know the prior information about the environment, but only what you are getting is the trajectory of the robots. So, recovery of the vehicle trajectory is possible and of course, motion drift will be a serious problem can overcome by image match. So, we are just the comparing the frames you will be always getting a lot of drift, but then you need to match the known images then you will be able to correct it to some extent.

Of course, it does everything has got its own challenges, but this is another method of getting the position of the robot using the cameras alone that is known as the visual odometry.

So, if you are interested you can actually see lot of iterations is available on visual odometry. Now, we would not be able to cover all those in this course, but you can actually look at some of the papers and then see how visual odometry is used for getting the trajectory of a robot in an unknown environment.

And, now with a lot of this learning and artificial intelligence people are trying to use this technique also to get the trajectory or improve trajectory from the camera images ok.

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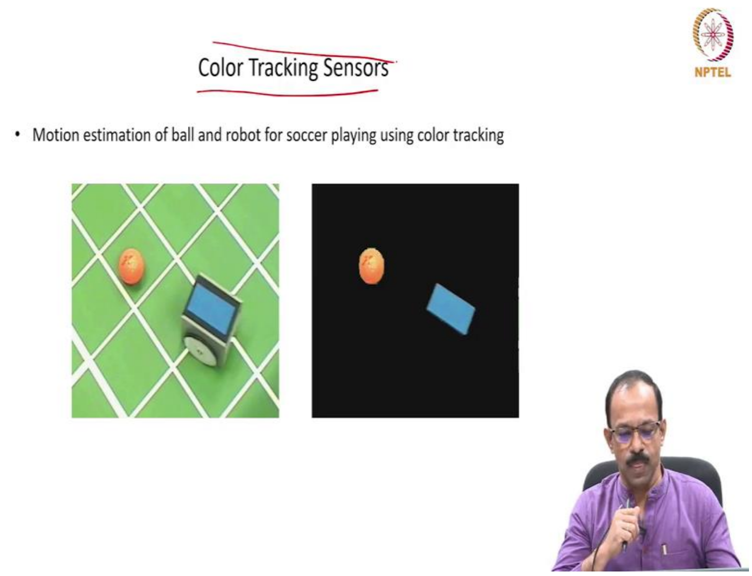

Some other motion estimation sensors are basically again based on the cameras you can actually look at the colour tracking sensors. So, you can identify the colour of something and then you can program the robot to follow that colour as long as the camera is seeing the same colour the robot will be able to follow the that particular object.

Or it can be used in many other applications like this robo soccer and all they use different coloured robots and then the camera will be identifying the ball and then the. So, the robot can be programmed to follow the ball or to take some action based on its position. So, that is basically the again using vision based sensors we will be able to do that ok.

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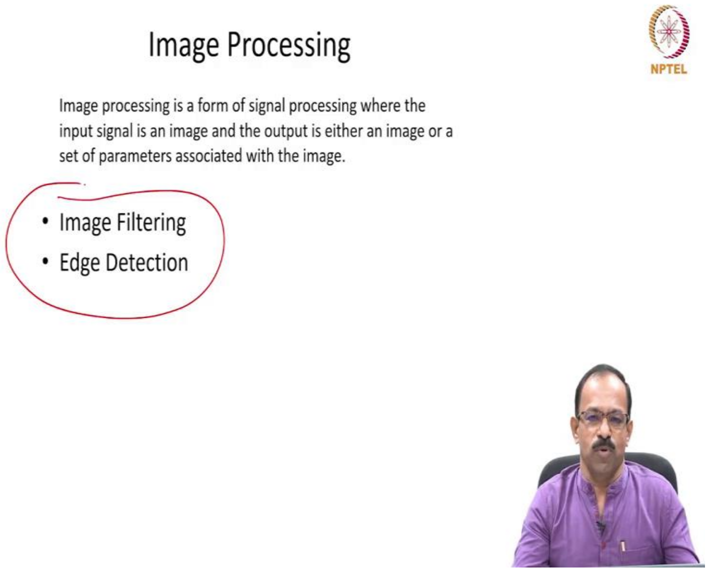

So, whatever maybe the image that you are getting in the camera we need to do some kind of processing to convert that into a good source of information, a raw image may not be really useful. So, we do a lot of image processing within the robot itself to get collect necessary information needed.

So, many times we will be doing a image filtering or edge detection to identify the edges in a given photo. So, that in a given image so that you will be able to identify the walls or the objects or in the case of a mobile robot to identify the track. So, all those things can actually be done by some processing of the information. So, image filtering edge detection these are basically some post processing of the image.

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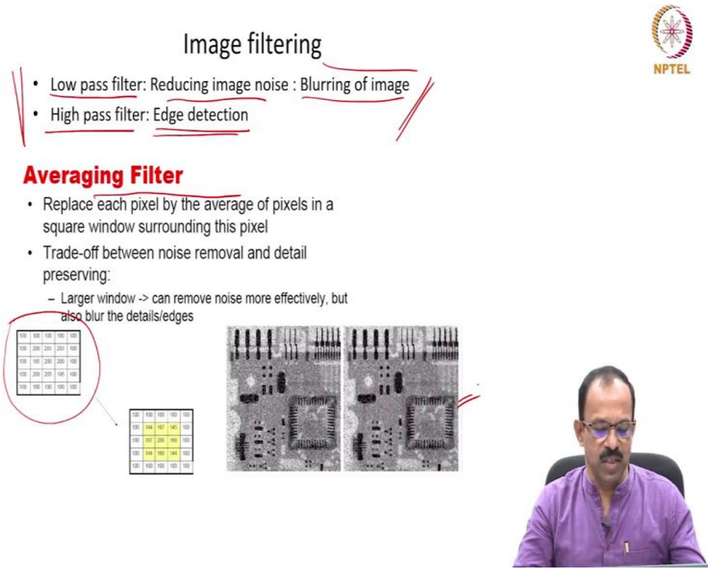

So, what we do is to we can actually have a low pass filter or a high pass filter in a low pass filter we will try to reduce the image noise, but it will actually the image will get blurred. So, there will be a lot of signals or lot of data in the image. So, we try to have a filter to reduce the noise or to remove a lot of unwanted data. Or you can have a high pass filter to get the edges detected.

So, that is the low pass filter will pass all low frequency signal high pass filter will pass only high frequency data. So, that is where you get either a blurred image or a sharpened image with edges. So, those these are the two primary processing we do of course, we can do many other things, but you can have a low pass filter or a high pass filter to collect the information.

So, what we will do? We will in the low pass filter we do an averaging filter. So, replace each pixel by the average of pixels in a square window as you can see here. So, you have this suppose the every pixel has got some value. So, we will try to do an averaging here. So, take the average of the nearby pixels and then put everything as a common value for the pixel.

So, that way you will be get able to get an image with a less noise because it will be more uniform distribution will be there, but what will happen is the image will get blurred to some extent. But, you will be able to remove all the unwanted details and get a better image compared to the raw image that is the a low pass filter for or averaging filter.

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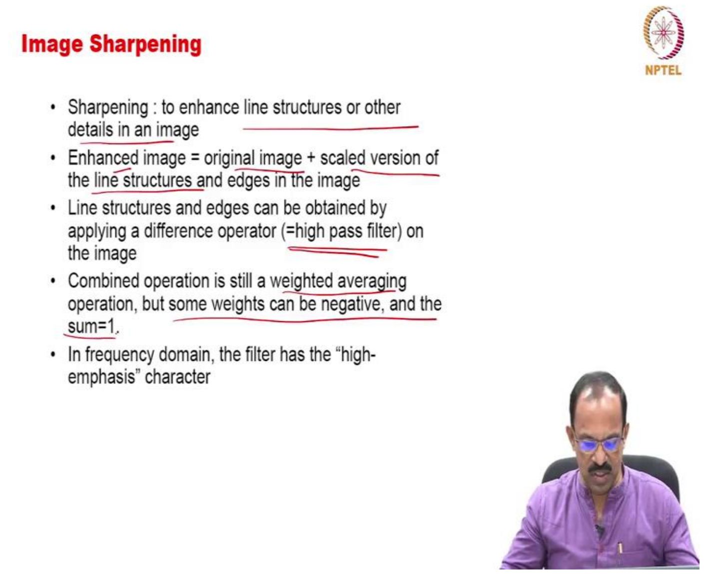

So, image sharpening is basically to enhance the line structures or other details in an image. So, what we do is that we will have the enhanced image with an original image plus a scaled version of line structures that is what actually we do. So, we will add something to the given image and then improve that image by getting a sharpened features.

So, we will do a high pass filter operation and this is actually done as a weighted averaging operation, but some weights can be negative and the sum is equal to 1. So, that is the way how it is done ok.

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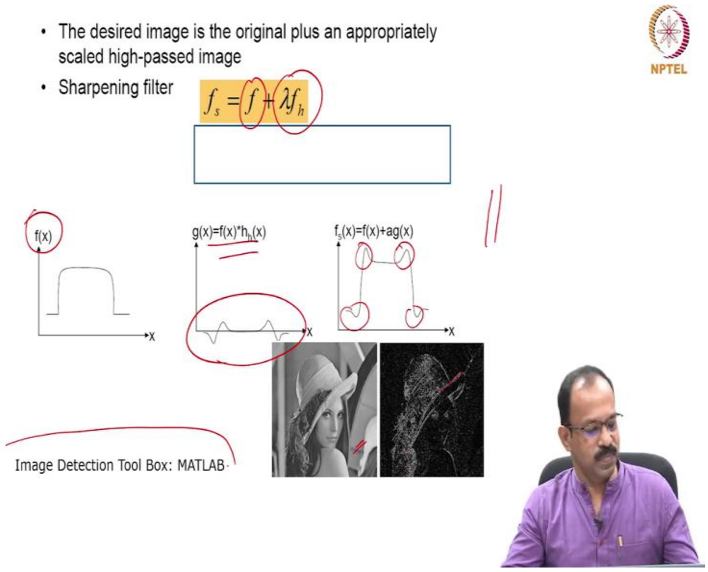

So, what we do? We will actually this is the original one. So, we will have a $f_s = f + \lambda f_h$. Suppose, this is the f_x if this is your original image, we will add something to this one is the added signal. And, when you add that this will actually get added up to here at this points will be much more sharper. So, you will be getting more sharp images at the edges.

So, this is basically the image sharpening principle and as you can see here in this picture. So, if you do the sharpening. So, you will get the edges more sharpened more with more clarity and all other things will be disappearing. So, depending on the requirement you can go for a low pass filter where the noises will be removed or you can have a high pass filter where the edges can be edges and sharp features can be much more prominent. So, that is these are the two ways in which you can process the image and use it for your application.

Of course, there are many other things you need to know if you want to apply this, but nowadays these are coming as a tool boxes in many of the software. So, MATLAB has got a image processing software. So, you can actually use this software to sharpen your image or you want to have a blurred image you will be able to do and there are many other things that you can do nowadays even your cameras come with many of these processing tools. So, you will be able to use them to identify desired features in a image ok.

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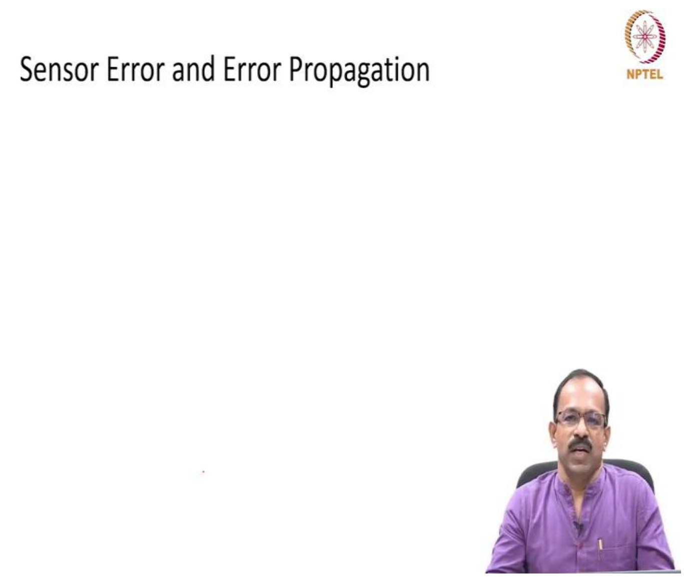

So, we will stop here now. We have covered a few of the sensors which are commonly used in mobile robots. So, we will look at a few issues when we use the sensors and then how can we overcome these issues by having some kind of sensor fusion or error propagation models. So, we will discuss that in the next class.

Thank you.