Embedded Systems Design

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Lecture - 13
Sensors and Signals

In the last class we have covered up to FPGAs where we have seen how different logic functions can be implemented using FPGAs, you will have further lectures on hands on Xilinx platform and some lab activities as well, I mean some VHDL and other things as well. Now today, we will be talking a little bit more on embedded system hardware.

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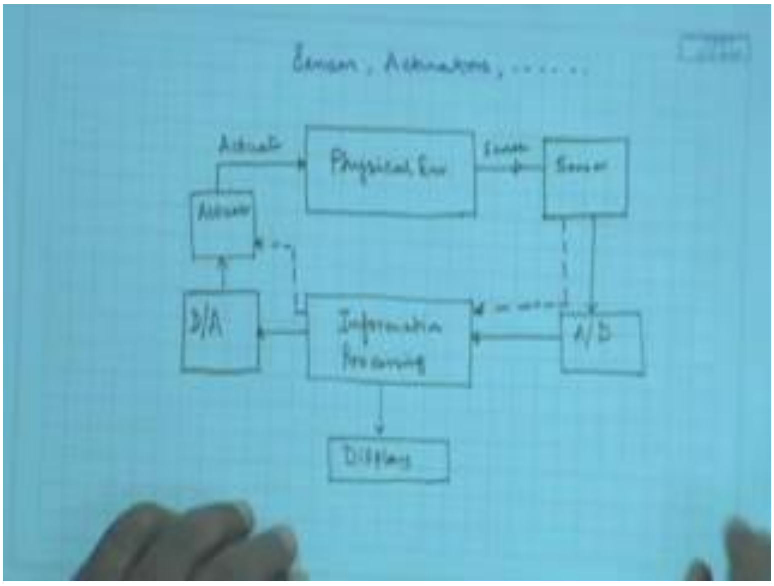

And will be essentially looking at sensors, actuators and other things. So, I know many of you are scared or have apathy when you hear about hardware, but in embedded system you cannot escape hardware because the simple reason as is shown here.

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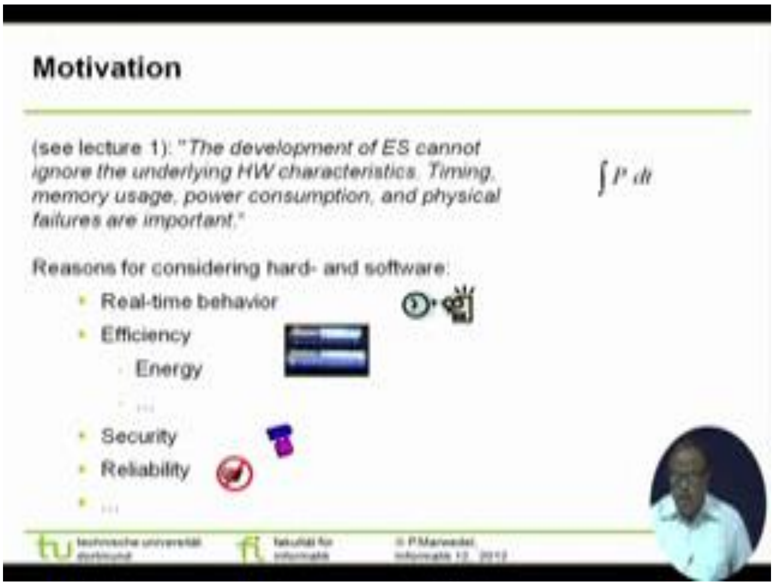

As before I will be relying on Professor Peter Marwedel slides, the book that I have referred to you in this lecture; so as I said here, the development of embedded system cannot ignore the underlying hardware characteristics, because of the reasons that we have to give real time behavior, efficiency, energy, security, reliability. So, energy battery and all those we have to think of how the hardware has to be designed.

And now in security earlier we are talking about encryptions and other techniques, now people are talking about different hardware means of security to resist against different types of attacks. It is even being tried that if the attacker wants to change the pattern of attack then there are hardwires which are sideline channels using got a special hardware to guess, what is the pattern in which the attacks are going on? So, all of these things are come will come under the purview of our immediate system design.

Now, coming back to the old scenario, we have seen that we have got a physical environment, we have got a physical environment which we want to control and this environment because of its own nature will have some physical parameters, for example, if the environment that I am dealing with this temperature then temperature has got some features like it is sluggish, alright, the range; there is some specific range, on the other hand if it be pressure then the range is something different.

So, we want to actuate the physical environment by some means. We want to actuate it by some means which is say let us call it the actuator. Now we want a particular performance from the physical environments as the temperature or something and for that we need to sense the environment using proper sensors, at this sensing, we have done it in an earlier lecture that once we sense, we can if my information processing is digital, I will be doing some sort of information processing here.

Later on, we will see that it is also controller in some for some applications, if we do some information processing here; often it is needed that this information processor gets the signal in the digital form. So, we will need A to D converter and we will get the information. So, we get that information and after processing the information, we will actuate it, we will take some decision and we can actuate it, we can either do display here, some sort of display here or we can actuate it.

Now depending on the actuator, there are some digital actuators which can be fed directly fed the digital signal, but otherwise if it is not so, then we will be needing a D to A convertor here and of course, there are parallel paths. So, if they be a digital sensor then I can directly have it without bypassing the A to D converter and if it be a digital actuator then I can also bypass this by filling it directly to the actuator. Now in order that the performance of this entire system is up to the level that is expected the desire not only your information processing algorithm should be correct.

Of course the information processing will algorithm will have to respect the real time constraints if any, the power constraints if any, but say for example, whenever we are talking of power constraints we will see later that the power consumption of the energy consumption of the battery life does not depend on the on the hardware alone, it also depends on the software we will show you that, but along with that software part the hardware that we are using for all these are also important.

The power consumption of different analog to digital converters will be different the speed of the different analog to digital or digital to analog converters will be different. So, we will have to select these also very carefully, very important is the selection of sensors and the actuators. The sensors come in different forms and I will put in a self study material for you today where you will have to learn more, dig out more about sensors I will give you the reference at the end of the class.

Now the sensors can come in for in different forms and for different reasons, for example, where we, what are the types of applications that we may need see the physical processes that we are talking about we may like to say here a couple of examples like say heating, heating a room.

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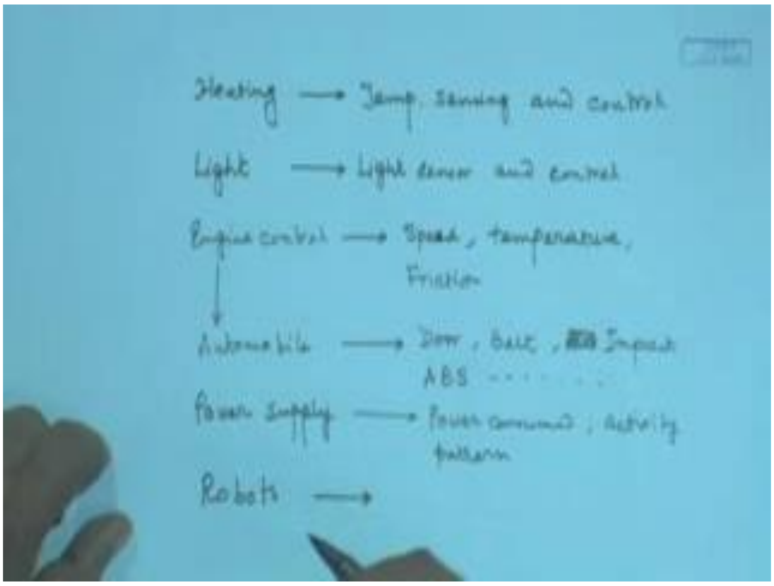

We will need to sense the temperature and control, similarly you may like to control the light, what type of sensor would you require in that case? You will have to have some sort of light sensor how you can sense light will see and accordingly you will have to actuate the light controller to control the light, similarly nowadays it is becoming practically omnipresent in every car that is engine control now here in engine control we can sense.

So, many parameters you can guess some one is of course, the speed I can sense this will also require the temperature of the engine what is the status of the coolant maybe stead speed and r p m are busy speed and r p m is a coming up it can be the gear it can be the now when we sense the speed we also often may need to sense the friction of the road because we want to maintain the speed and the as the friction of the road changes our applied force will have to vary. Nowadays not only in engine, if I just extend it to automobile control.

Then you will have to sense the door locks the door status the belts often in every car now nowadays we find that whether we have worn the belt or not that they are showing. So, all those are different sensors very important thing is the on impact the airbag comes out. So, I would rather say now it is airbag tomorrow it may be something different. So, impact we have to sense right breaking control Autom; ABS systems where we have got breaking control and so on and so forth. So, this is very important, I mean automobile is becoming a very interesting and lucrative also from the commercial angle for application of embedded systems here.

Now also another thing is that we are talking about power, but we will also have to control the power supply will see later we will see later that in order to minimize the power consumption in a system that will in order to maximize the battery life we will have to control the power supply. So, it will have to look at the power consumed at different parts it will also have to look at the activity pattern all those things have to be sensed and accordingly you change the power and a very popular among the students is the robots.

Nowadays, we have heard of robot software right where the robots are playing football. So, where we are giving them the ability to see the ball, see the opponent players and accordingly apply the information processing algorithm to find the maneuvering maneuver the movements. So, there are so many different parameters that we may like to sense even we may like to sense the or find out what is the chemical composition of a compound what are the things. For example, I want to that will be a very interesting project for all of you if you can make a small system which will take around and put it wherever you find water you just put it in and look at the measure the quality of the water, very simple and not very simple, not at all simple because you have to find out the proper sensors and then you have to end, you have to first of all take the water, analyze it through the sensors and find out through your information processing mechanism accordingly you can generate alerts and all those things.

So, we may need to besides the typical velocity, velocity is 1 we may like to sense acceleration w8s temperature electrical current all those things we also need to find out may be applied for chemical compounds and all those things as well next. So, say for that we have got different sensors some of them we can have a look at here.

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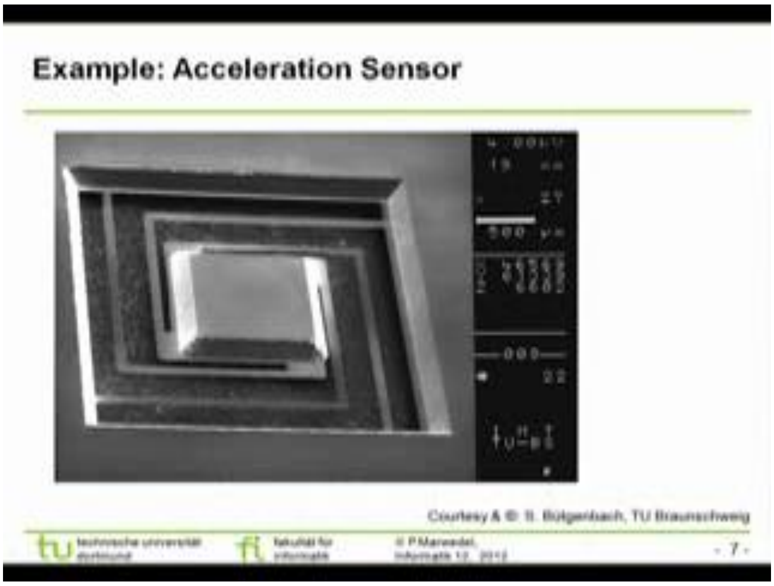

Here is an accelerometer, nowadays this accelerometer comes in different even in our phones where we have good gyroscopes and all those, but you never thought, what is the sensor that has gone inside? So, that will have to find out. So, actually there is a sorry there is a small thing that moves this thing and the rate at which it moves from there we find out what is the acceleration. So, there will be it can be a magnetic sensor.

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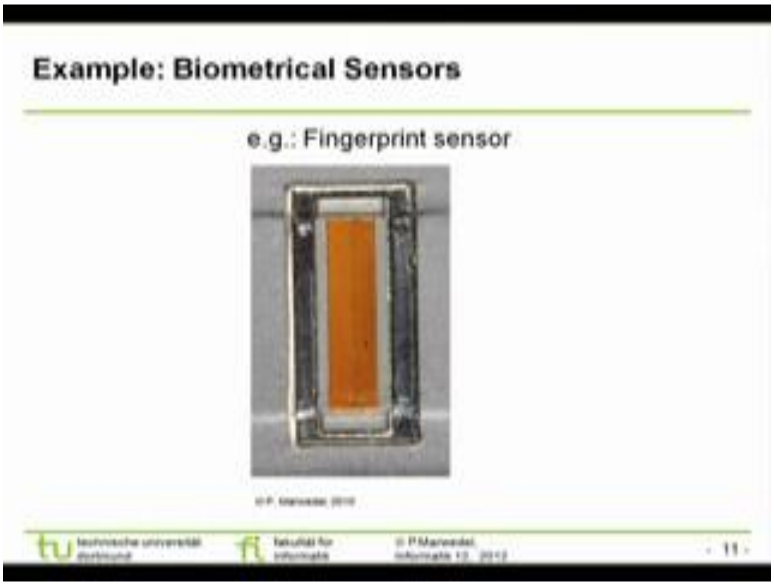

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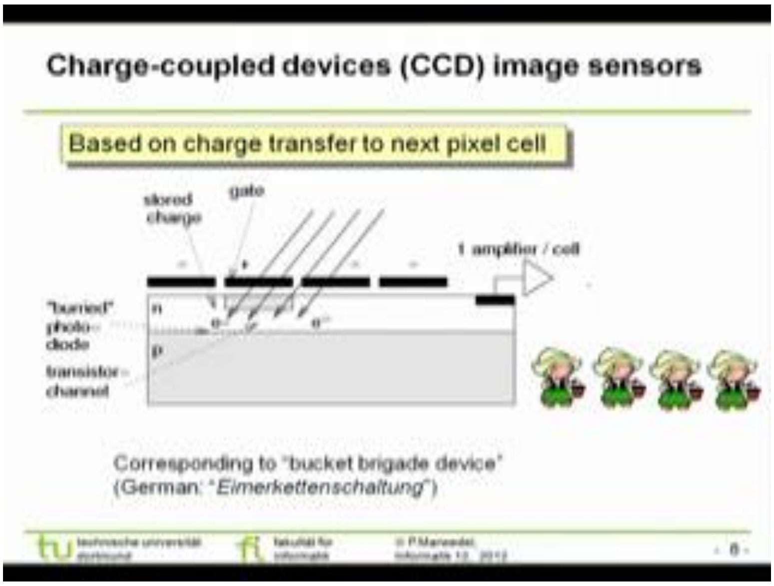

Now, there are different ways of image sensors which are there often in cameras, now they actually come in 2 forms, one is say CCD image sensors where we have got the charge coupled device here and depending on the light there is there is a physics that takes place in the semiconductor level and based on the charge transfer this works.

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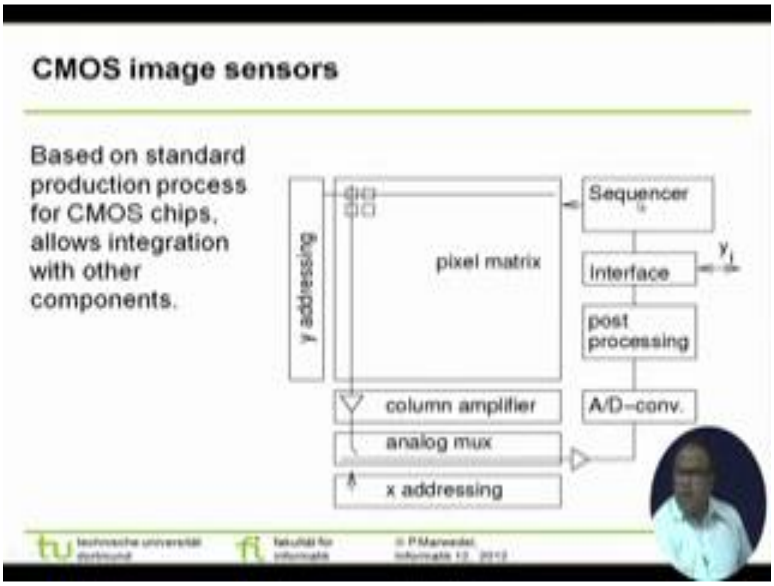

On the other hand there is another one which is a CMOs based image transfer image sensor, I am sorry, where we have got an area of image is being sensed in the rows and the columns and we are having an analog multiplexer and we are doing the analog to digital conversion and all those things.

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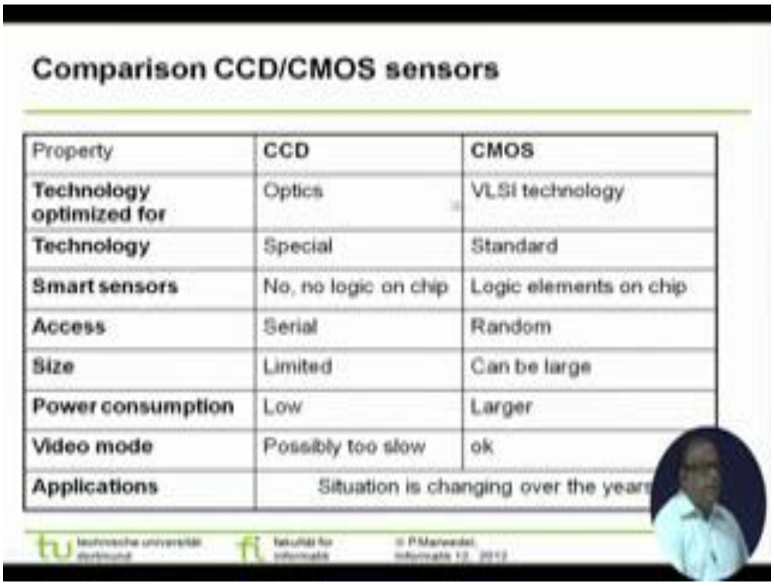

Now, both of them have got their pros and cons, some are VLSI technology and c series optical technology, alright in CCD, there is no logic. So, there you cannot put in smartness over there whereas, in the CMOs, one you have got logic on chip power consumption for CCD is low, but for CMOs, it is higher.

So, you will have to look at say for example, I am trying to sense image you have to decide on what sensor I will be using because you will have you will have to look at different contending parameters the parameters which are conflicting among themselves. So, you will have to wait out just like that has to be done by engineers at all stages right. So, here is a fingerprint sensor right that is often used.

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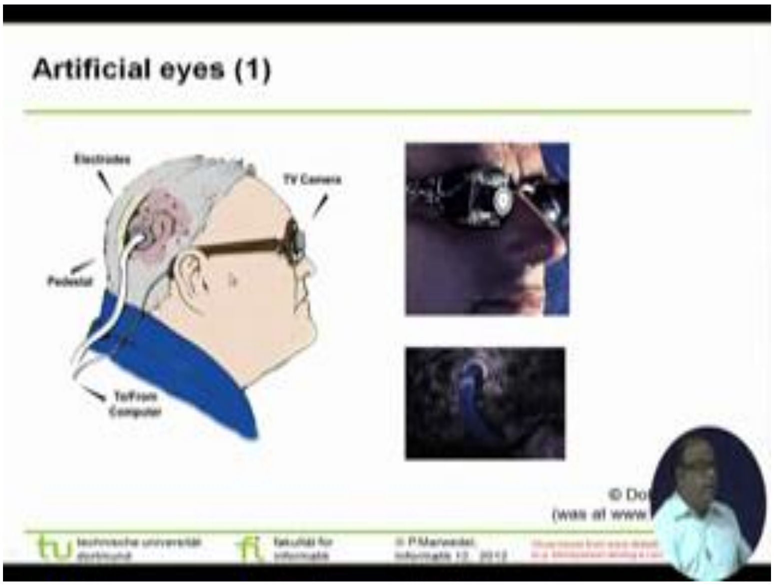

Now, this is very interesting, this sort of sensor which is experimentally, it has been done you can see that some person who is blind, they are having a camera and that image is being processed and with some sensors, it is being fed to the occipital lobe of the brain, now this is the electrodes, they are non invasive or it may be invasive, there are different experiments being done and thereby whatever the camera is capturing. So, that is also a sensor.

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Another nice application could be that there is a camera here and you just do not invade the brain, straightway you just do not invade the brain, but you convert it to sound.

Now, say in India in I mean say for example, the blind people are moving around and they have got a you have seen blind people moving at Cannes and that cane they move like this to sense whether there is any obstacles or not now systems have been designed here in India where people have tried and some of them are also commercially available one developed at IIT Delhi is commercially available that is the stick also has got a camera and the camera is sensing, it is at the gross level, it is identifying whether how far the object is, whether it is a moving object or not and accordingly it is giving some pre stored messages, a more sophisticated thing can be that it will.

Suppose I have got the image recognition capability coming up then that sensor; the camera is sensing the image and in real time it is saying what is there in front and accordingly, they can maneuver themselves. So, here is an attempt that is translation a sound you can look at this seeing with sound and you can see the typical features of this system there can be you can think of several such applications where you can help these people using embedded systems.

Next let us come to some now whatever we are sensing we are sensing the proximity maybe with the proximity with the stick how far the object is the cars can also have proximity sensors to find the distance and accordingly the speed can be controlled you can think of many such things now in all these things what we the sensor is sensing.

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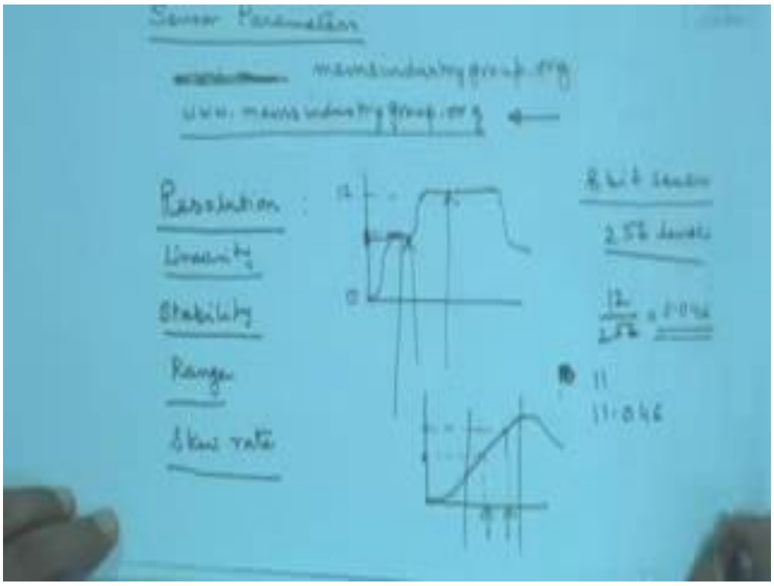

First of all, there are 2 things we have to know about the sensors, one is the what are the sensor parameters, I will take a seconds time to see if I can give you some reference here seems to be too slow, yes.

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You can let me write down, this not this one this one will also do I (Refer Time: 21:37) why is it so slow? So, I am just writing down MEMS industry group dot o r g, if you go over here, you will find the standardized product standardized sensor performance definitions alright, if you go down this page you will find this.

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And if you go here we will find speedy version the first version of this, it has a consortium has been formed and that consortium has decided on this is taking too much time where you will see that for the different parameters; different types of sensors what are the things that are required to be known.

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Here you see that this is the first drafts and etcetera, now you come say for example, you come to accelerometer here, you can see that accelerometer, now for accelerometer, what are the parameters? Full scale range, digital bit, depth sensitivity, noise, all those things you have to I mean, all these things are important.

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Similarly, for magnetometer what are the parameters that are important? So, you have to learn about this gyro meter what are the parameters how do you specify barometer. So, in that way you have got several of these things and I insist that all of you go to this site and read through this document and in this document you look at what are the what are the parameters that will give you an and you need not memorize you are all you can understand that why this is needed for example, let me just mention some very fundamental parameters what is meant by resolution when we talk about resolution, what does it mean?

Student: (Refer Time: 24:28).

Yes, resolution means the smallest identifiable element. For example, if I have got for example, a voltage I am measuring voltage through digit; some digital means or analog means and my voltage ranges from 0 to 12 volt, now it can be any voltage, it can be any voltage within 12 volt and I want to measure voltage at any particular point of time any particular point of time and the actual voltage is this and at this point if I want to measure it again, the actual voltage is very close here, can I differentiate between this voltage and this voltage? On what does it depend?

Suppose I am measuring it using a 8 bit sensor. So, what is the level of how many different levels can I distinguish? It will be 256 levels or 250; 0 to 255, so 256 levels. So, what will be the resolution? 0 to 12 volt, so 12 by 256, whatever that is, alright, anybody can compute and tell me 12 by 256 quickly. So, it will be around 1 by 20, so it will be around 0.5, coming to what?

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0.0046 0.05, right?

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So, 0.046, so this, so I can distinguish between these voltages. So, I can distinguish between 12 and or say or say a 11 and 11.046 words, in between if there is any, if these 2 are close by closer than 0.046, I cannot capture it. So, that is what is resolution, we must look at the resolution looking at how closely I want to monitor it, the other thing is of course, stability range, what is the range? Say I take a sensor or I take a temperature, what is the temperature range?

It can sense there are whenever I am trying to raise another thing this skew rate with our temperature sensitivity with temperatures how does it change? It is now if we always prefer a linear range, if there be something that is linear then I would rather prefer to operate in that linear range where this is my physical signal and the output that I will get from the sensor will be linear linearly related to the physical parameter. So, these are we also have to check for the linearity.

Up to which range is it linear after that it is linear it is lost. So, all these things, we have to look at and you can study these MEMS, for those of you cannot read this MEMS industry group: m e m s industry group dot o r g and you can look at into that. So, that is one aspect of the sensors.

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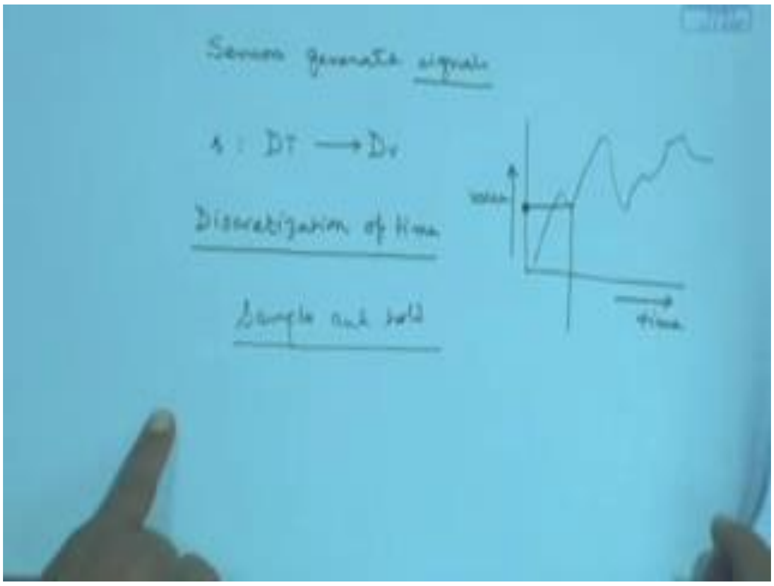

The other aspect of the sensor says that what do the sensors do the sensors generate signals right they always generate signals and what is the signal a signal s is can I write this a signal is a mapping from the con time domain to a value domain right some signal is going on like this some physical process is going on like right and I read the signal my sensor is reading the signal. So, it is taking at any particular time this is the time axis and this is the value axis.

So, at any point of time I sense it and I get a value right that is what the signal does now this is analog signal, this is a continuous signal now this time is also continuous now theoretically I can map from the continuous domain to the continuous domain or, but for all practical purposes what we do is we need to do discretization right. So, we want to do discretization of time we are not discretizing the signal we are trying to discretize the time alright now how do I discretize the time.

How do I discretize the time and yet get the value for that we need let me just come out of this come back to where I was now.

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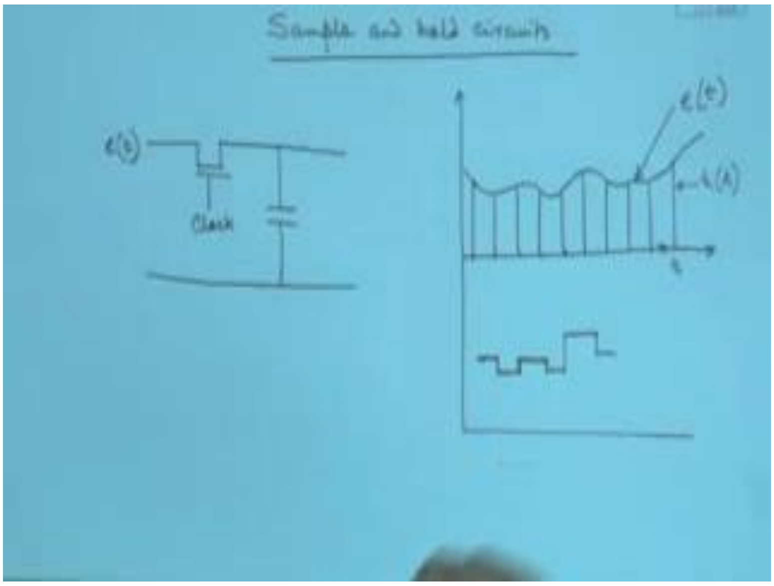

When I discretize I need to do something like sample and hold that is something that is very important, we will show that many of you from with electronics background may be aware of the sample and hold circuits, but just for the sake of completeness, let us discuss it in this context, now suppose I have got something like this here is time t and I have got a signal and on this side I have got the value and I have got a signal like this and let me call this signal some event e t, it is varying with time all right and I want to sample it at specific times at fixed intervals I am sampling them.

So, I am getting a series of discrete values because I do not know what is the value in between right I am getting some sort of discrete values now what does your as long as I do not know what is the next value the value that is there in my memory is this therefore, now. So, this is the sampled value these values. So, this we call h t or the value that has been sampled.

If I have a circuit like this, do not get scared with the circuit, it is a simple transistor 1 and I have got a clock here and the capacitor here, school level knowledge. So, I give the signal e t, this signal is coming over here and whenever I want to sample at those times, I feed the clock tuck, tuck, tuck, alright, as I feed the clock, this transistor is closed. So, it passes here, it passes so that means, every time I put the clock I am sampling it here, here, here, here, here, like that and as soon as that is closed, it is current is flowing and charging this capacitor and so, this capacitor will therefore, hold the values at each of these points and how will it look like? If I take it as long as the new sample is not there.

This value whatever this value I am just trying to guess this value is here then this value will be lower value will come when an intermediate value will come like that these things will be sampled and it will be held sample and hold the holding is being done in the capacitor. So, this is being held here because I have got no idea what happened in between. So, in that way we will get a sort of digitized version of the same signal. So, by this sample and hold signal what I am doing I am transforming a continuous signal. So, let me draw it a little bit more then it again came down to some value then I it get again went up to some value like that.

Now, so I had a continuous signal e t, I have converted into h t or that is the discrete signal. So, for discretization one very important thing is to get the sample and hold circuit now the million dollar question is when I am doing this am I losing some information yes and may not be. So, how do you do that how can we approximate a signal approximate a signal and yet can say that with whatever information I get I can reconstruct that signal exactly yes for that we will con discuss that in detail tomorrow, but in the next class, but it is the if the rate of sampling it was established by the famous nyquist theorem by Shannon that if the rate of sampling is greater than equal to twice the highest frequency of the signal then we can reconstruct the signal.

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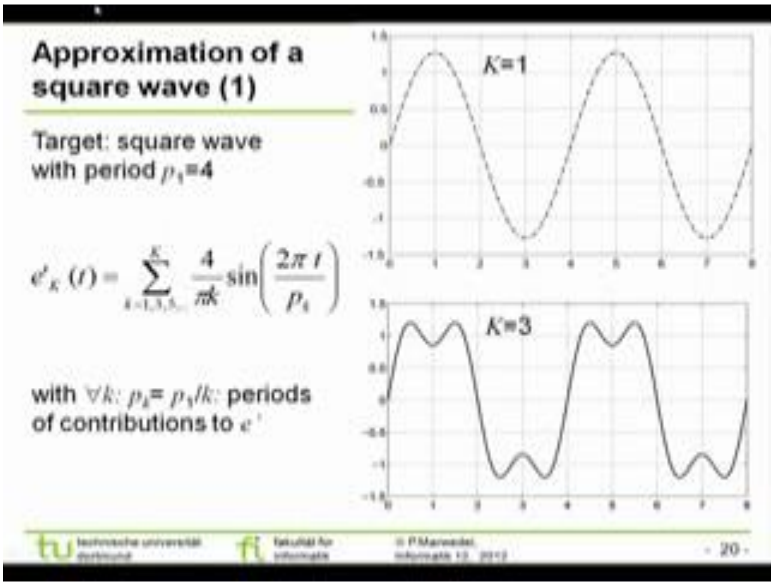

So, that thing where say for example, here is an approximation of a sin wave, I will just start it today and we will carry it on in the next lecture. So, here we have got my objective is say, I want to generate a square wave with a period 4, alright and I am starting with a sin wave. So, a square wave with I am starting with a sin wave, now if I hear k is equal to one if you just look at this equation.

The period is 4. So, 4 by pi sin omega t and the period is 2 pi by p k is my omega. So, here if I put p k to be 3 then this wave form becomes this alright I first now if I make it k equal to one and simply a sin wave right k is 1 and p k is 4 and you see the period, period of this is from here to here is 4, from here to here the same phase, the signal is in the same phase. So, it is 4, now if I increase the k value then you again see the period is still 4, but we have approximated it a little bit more.

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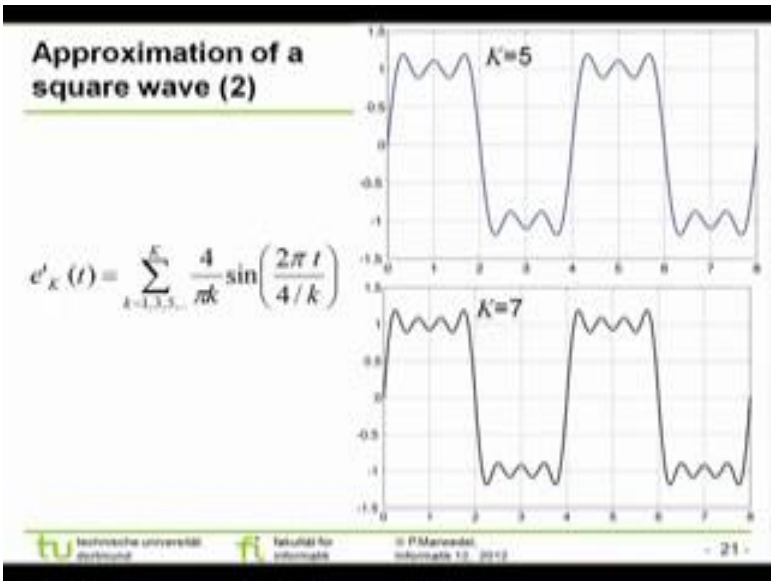

Now, if I increase it further, I make k equal to 5 then the same signal; I mean same equation will lead me this with a period 4 as I go on increasing k is 7 then again the period is 4 gradually I am approaching a square wave that was my intention. So, starting with a sin wave I can reconstruct the signal. So, I can create a. So, I was trying to approximate a square wave.

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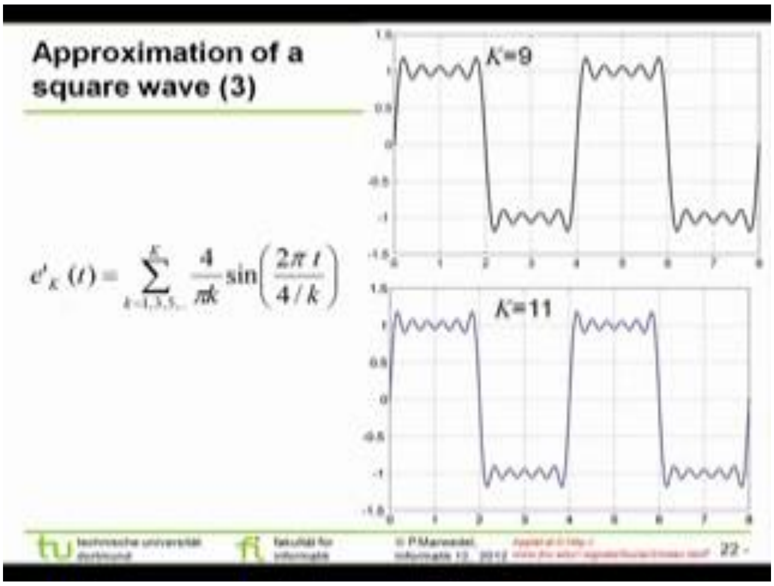

Now, my point is I want to approximate a square wave, as I go on you see k 9, k 11 is gradually becoming more and more of a square wave. So, thereby it is possible to approximate a desired signal with a set of other signals.

We will continue with this in the next class and we will see a little bit of how we can do ready constructions and proceed with a little bit of communication in the next class.