Introduction to Uncertainty Analysis and Experimentation
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Module - 04
Methodology for Uncertainty Analysis
Lecture - 11
Instruments and DAS

Welcome, to this lecture in the course Introduction to Uncertainty Analysis and Experimentation. Today we will be continuing to look at the Methodology of Uncertainty Analysis. And in this lecture, we will look at Instruments and Data Acquisition Systems. So, the first question is, why do we need to look at these aspects?

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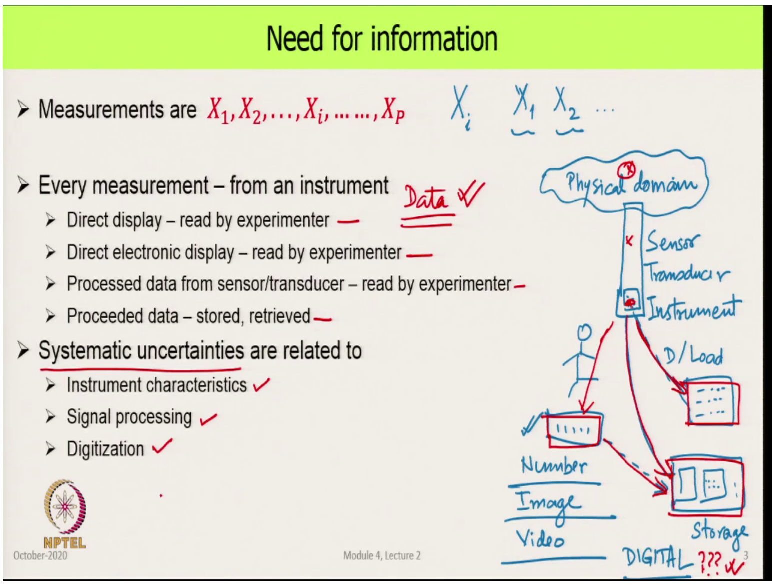

Typically, education about instrumentation is given in instrumentation courses, where you look at different types of instruments used for making different types of measurements. So, let us see how that becomes relevant to uncertainty analysis. In our notation, we have said that, the measurements that we make in an experiment are denoted by X subscript i and depending on the number of measurements that are there, this could be X 1, X 2 and like that.

Each one of these is one physical parameter that is being measured. A little later in the lecture, we will see how many different types of parameters are there that are typically measured. So, when we say that we make a measurement of a particular parameter, there are a few things interacting with each other; first there is the physical domain or this could be something about which we want to make a measurement.

Into that, we have a sensor or an instrument or a transducer. From there two things happen, it displays the value and then there is a manual reading by which we actually get our measurement and this is a number. It could also happen these days that, instead of umber; we could also get a picture, which is an image or we could also be studying it with a video, a visual range video normal one or maybe an infrared video. So, that is one way the data comes to us and this is the data we need for uncertainty analysis, this is the one.

The other thing that could happen is that, the instrument could itself store all the data there and then we can download it to whatever device we are looking at a PC or a laptop or to the cloud. And then we have our data with us on which we can do analysis. Or the third thing that the instrument could do is that, it could transmit this data into a device, which does some signal processing and finally, it stores here.

And it is from here that we can start reading the numbers. So, besides of course visual reading, in this case the data is already in digital form and we can straight away start using that in various algorithms to do calculations. Where the data was recorded manually, we have an extra step to work is to get this data into the software system; it becomes digital data and then we proceed with the analysis. So, this is how this data comes into being.

So, we have either this route, followed by this route or here followed by here or directly from there, going over there. In the end, we have what we want which is our data which is in hard form here and in digital form over here. Now, what happens is lot of things are going on which start with the physical domain, which had some properties or values and in the end, we are reading something in our final digital format.

And the question is, how do these type of operations influence the uncertainty in the value that we are looking at here? These become part of our uncertainty calculation and so, we need to have a good idea of what this system is doing in order to be able to go ahead and make the uncertainty analysis. So, what we have seen here is that, every measurement from an instrument; it could give a direct display, which is read by the experimenter.

Now, this could be something like a using a scale; that we put the scale to measure this is the width of a sheet of paper and directly we read it out from there. So, that is the direct display. Then you could have a direct electronic display, which is read by the experimenter.

So, that is again the manual route; but instead of being the instrument itself in analog form, we are getting the digital form and the example of this is a vernier callipers with a digital readout. Or we could have process data from the sensor or transducer, which is read by the experimenter.

So, here some operations took place and then you saw the data and this is an example of this is a thermocouple sensor, which data has been produced has been processed and finally, a display gives us the temperature in degree Celsius. And the last thing that we saw here was that, the data was directly sent to a storage and from there we retrieved it and we looked at it as numbers.

So, that is how we got our data. And that was the starting point of all our uncertainty analysis. But there is additional to seeing these data, inherent to each one of these processes and the hardware and software that is there; they give rise to a series of systematic uncertainties.

These are related to the instrument characteristics, we will see that in a minute, they are related to the signal processing that takes place; that means we got the signal something produced by the sensor, we did some operations on it before we digitized it what uncertainties did we put into it and third the digitization process. So, we spend a little time on each one of these in this lecture.

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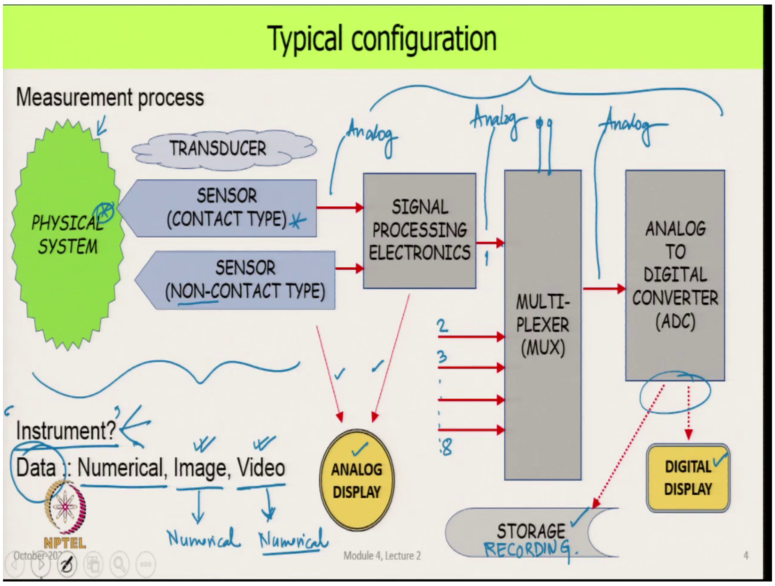

So, the typical configuration that I had showed earlier as a sketch is again reproduced here in a little more detail. And what we have here in the first point, this is the physical system; from which either you have a contact type of a sensor, which means it is in physical contact with the domain and the two are interacting with each other or it is a non contact type of a device, which does not disturb the system at all, sits outside of it and collects all the information that is required.

So, this first part, the contact type one, this can influence the domain which is the object of measurement. An example of this is that, if we want to measure the temperature of a surface and if we attach a thermocouple to it; we are actually changing the temperature of the thermo of the object at locally in the vicinity of that instrument.

So, what the instrument will show is something different than the original temperature of that surface. So, that is the major difference between contact and non contact instruments. But in either case they both produce an analog signal and the solid line here tells you that this is an analog signal. This analog signal goes into the electronics the hardware part, where we do some signal processing; this produces still a different type of an analog signal which we feed to a device called a multiplexer.

If it is only one measurement that we are making, then the multiplexer is not required; but when there are more than one instruments which are being read, then we have to have a multiplexer. And what it does is, it takes inputs from this instrument here we can call this number 1; then it takes input from another instrument number 2, number 3 and so on, as many as its capabilities, the physical capability.

And then we control this through a separate device, which sequentially connects each, one by one it connects this to the output; the output is only one. So, by switching it, we can first connect this to this, so that the signal coming out is the signal from instrument number 1. Then we can switch it off, so this one goes. So, this one is now gone and we then switch and connect the second one to it.

So, now this signal is going out. So, now, you are getting the reading of the second instrument. After that has been read, this is disconnected, switched off and then we connect the third one. So, now, the output signal coming here is the signal from the third instrument. So, in this way we can go one by one and connect every instrument to the output in this cycle.

And if there are say 8 such instruments connected here, then after the 8 has been done it could; then go back and start with the first one again, again it will go to 1, 2, 3, 4, 5, 6, 7, 8 like that. So, a lot of parallel inputs are being converted into a series of serial outputs. The data here though is still analog. And then we get to the device which is the analog to digital converter; so, this takes this analog signal and mix it into a digital signal, which can either be then sent here to the storage or it can be displayed.

Similarly, the signal coming out of the instrument here which is an analog signal can also be displayed but recording is only digital. In some devices, these two could be swapped; that we could first have the multiplexer and then do the signal processing, and then send it to the A to D converter that could also work.

So, this is the general configuration of both the instrument which would be say this part and the electronics which is this part. But these days you have many instruments, where most of this is done in the instrument itself. So, all it has at that point is a communication device which sends the data either for display or for recording.

So, things have changed, fifty years back you had these things very very separate distinct entities; today you could just get an instrument in which it is all being done and you are limited by what it does and if that is good enough, we use that. And then you have a variety of instruments. So, that is what we said; what it was fifty years back, what it was 20 years back, and what it is now, the word instrument has evolved quite a bit.

Data as I said, it could be numerical; that is normally what we understand is data. We could also have images and we could do image processing and get numerical values from there. This is quite frequently done these days. And we could also have videos, sequence of videos which also we could analyze; again now frame by frame, which is basically image by image in a time sequence and again get numerical data.

So, how what we have, what we understand as data the time. Sometime back it was only numbers; now we have to also add to it image, also video and there are many techniques coming and more coming in the future, that convert data from a picture into numerical numbers. This has changed the world of instrumentation, control, research quite a lot. And we will continue to evolve. So, we have to be up to date with it.

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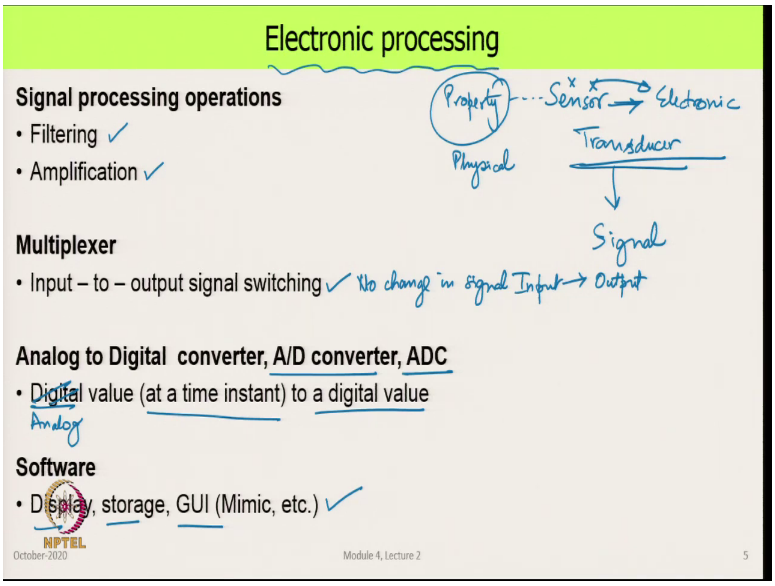

So, now let us see what all was has been happening to the signal that the sensor produced. The device that senses the physical world and produces an electric signal, this we could call it a sensor or generally referred to as a transducer. Sensors have different types and it is selected, so that it can measure some particular property; that means some physical property.

This change in physical property causes a change in some other intermediate property inside the sensor, which is then converted into an electronic signal. So, we have a transformation of the physical property to some electrical signal that is the transducer. Now, let us see what happens to that electric signal that comes out of this.

One of the operations that we saw there was signal processing, where we do two things; we do filtering, and amplification. After that there was a multiplexer, which was basically nothing but input to output signal switching; it does not change the signal itself. So, there is no change in the signal from input to output. And then we have analog to digital converter, which is also referred to as A slash D converter or ADC.

It samples the analog signal at a time instant say, this should be an analog and convert its to a digital value. And then thirdly, at the end we have our software, which can be a display, storage or graphic interface, which could be like a mimic of the system and in real time we see all the data on it. So, this is all that goes on in what broadly we have called signal processing.

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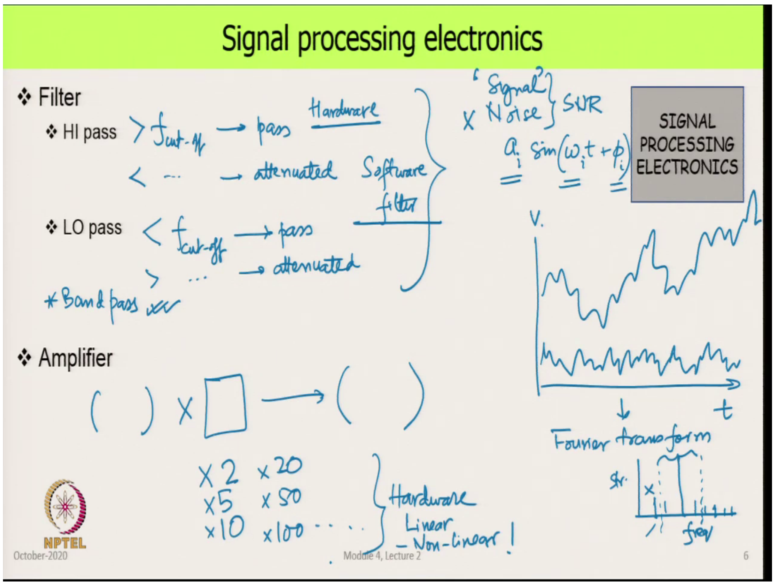

Now, we will look at some of these in a little more detail. Each one of these is a full course by itself and in this course, I am just giving a very very brief overview of what it does. First is high pass filter, a filter which can be HI pass or LO pass or even we can call it a third one Band pass.

So, what we are saying is that, we take the signal which is time versus its voltage or the magnitude of the signal. And typically a sensor will produce something that goes like this; if it is changing with time, it will show a trend; if it is steady, it may just show something like this. And this is all completely random.

So, this sort of a signal, each one of this vaguely things, it can be broken up using a Fourier transform and this will tell us, how much strength is there in the signal at different frequencies. So, here we put frequency and here we put the strength and you get that at this frequency its strength is this much; at this frequency the strength is this much, here it is this much, here it is this much.

So, depending on the nature of the signal, we will get that many number of these lines. A pure single line would mean that, it is a sinusoidal pure sine signal that is all. So, what this telling us is that, this signal is composed of some amplitude related to the frequency multiplied by sin, this is the a i omega i t plus phi i; amplitude, the frequency, at that frequency and its phase.

So, we have a mixture of lots of frequencies that are there in the signal; some of those are the genuine signal produced by the sensor, others are what we call noise. And the word signal we refer to the information that is of use to us. And the ratio of these two this is what something we have to be worried about and this is called SNR or signal to noise ratio.

A high value of signal to noise ratio is good; that means a signal is strong, noise is less. If SNR is of the order of 1, then we have a real problem that noise and signal are of comparable magnitude. And then there could be other instances, where the noise is much larger, signal is very small and embedded in that noise and that becomes a challenge to figure that out. Such issues come up in many applications; an example of the last case where you are looking for a signal in a noisy environment is a remote sensing.

We are trying to pick up very small changes in place where there is a lot of noise taking place. In the context of measurements what we want is that, we somehow want to get rid of the noise. We only want to look at the signal, because that is the strength which is related to the physical parameter we are measuring; and that is the one which we will ultimately get into our data acquisition system.

So, what one does is that, in many of these frequencies that are there here; we need to have a priori some idea of the frequencies which are quote unquote good for us, which are of use and then we want to remove the other frequencies. In the hardware this is done by two types of filters HI pass, which means that there is the cut-off frequency and all frequencies greater than cut-off they pass.

Those which are less than this frequency are attenuated, may be completely eliminated, may be eliminated to some extent like that. That means on this case, if we knew that there were this was a noise; then we could do a cut off here and remove this frequency. The LO pass filter does the opposite of that; it allows all frequencies below the cut-off frequency to pass.

And all frequencies greater than this, they are attenuated. So, in this picture if we wanted to remove all of this; we just say we make a cut-off frequency there, all these things get attenuated, we are left with this. And so, if a filter has both LO pass and HI pass and it only allows these frequency to be there, this is what we get as a Band pass filter.

So, this removes the noise and what I have explained, this is done in hardware, classically this has always been the case. These days many of the things that we do and we see in the camera for instance is that, we take the image and instead of doing hardware based filtering; we first digitize the signal and then we do software based processing.

This is again a very big subject by itself; I am just introducing what this means and in many cases we may even use this. The point here is for uncertainty analysis, we need to know what this process all did to the signal that we are seeing and how much uncertainty has this produced. The amplifier as the name suggests, it just takes an input signal of some value, multiplies it by some value and outputs the signal.

So, at any instant whatever was the value of the signal, it got multiplied by this. Classical hardware amplifiers these were like 5, 2 times multiplication or 5, 10 and then they would go in the same order. You could multiply it by 20, 50, 100 or even 1000 like that and you got fixed amplification. These days you can get amplifiers where you can select even other values instead of just these ones. So, this was what was earlier as hardware amplification.

And while this formula tells you that, every signal will be multiplied by the same number; so that means wherever whatever value we had, the same value in the output will be say double of that, then at any other instant also, it will be double of that. So, this is what is happening here, but that is the ideal case; amplifiers are not ideal, there is a range over which they are linear, which means that the amplification is constant.

But then there are other ends of the frequency spectrum, where nonlinearities start coming in and this starts introducing uncertainty for our application. So, we need to have some idea of what we are doing here. So, these are the two main things that happened in signal processing as far as our instrumentation is concerned.

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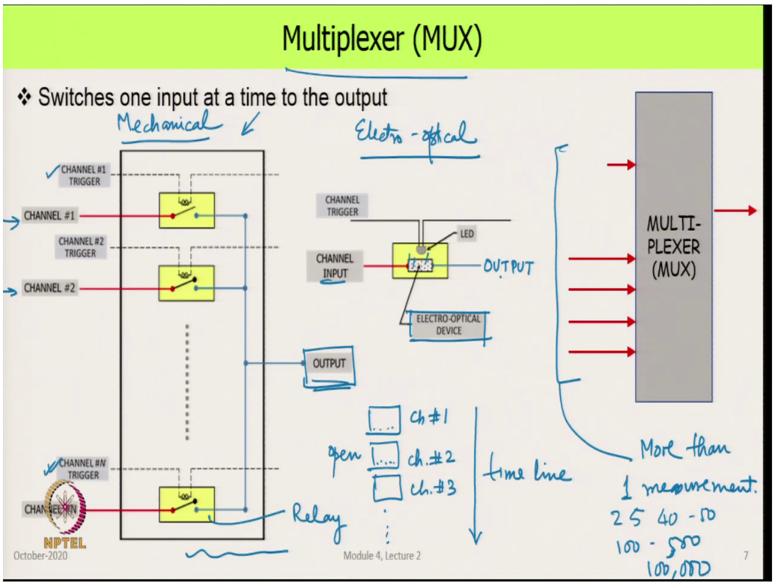

Now, we come to the multiplexer. I have shown one picture here and it is a small little device in which there are, these are the mechanical type of a multiplexer. In which there are these little devices, these boxes that I have shown, which is a relay. Inside this there is the physical contact a switch, which is activated by a small electromagnet; this electromagnet gets signal which is called the trigger signal. So, each such device takes one signal in and connects it to the output and the switch is activated by the trigger for that signal.

So, we call this channel number 1 and this is the trigger for channel number 1. This is channel number 2, the line on which the signal is coming in and this is the trigger for channel number 2. And on the output they are all connected to a single line and there is one output which we get. So, what one does is to an external program or in some cases you can even do it manually, initially you keep all the switches open; that means none of the signal that is coming in nothing is going out.

If there is a display here, the display will show nothing; it will show 0 and go blank. Then if you trigger channel number 1; then what happens is that, this switch will close, the circuit will get completed and this signal will come out. And in the output, you will see the value of channel 1 or you can take this value into the hardware storage. Having done channel 1, you then de energize this. So, this is taken off and this circuit again becomes open and then you trigger channel number 2 and this circuit gets closed.

Now, the signal of channel 2 is coming here and what you see is channel number 2, the value. After channel 2 has been read, we again switch off this signal, switch opens, then you go to channel 3. And so, here is what happens then? One by one we got all these channels and then after a while they keep repeating themselves. And so, we got the signals on a timeline.

Because there was a finite time between which this channel was read and then this channel was read and that is what is going on here. The other way of doing this is electronically these days. What you have is an electro optical device, which is a device which is normally an insulator; but when a particular wavelength of light is put on it, it becomes the conductor and then it is connected. So, two ends of this; one is the input end, the other is the output.

When there is no signal in the trigger circuit, this is an open circuit, nothing comes out; when this is triggered, LED is energized, this gets a light, this gets conducting and the signal comes out. So, these days when we go to buy a multiplexer or we want to make our own multiplexer, both options are available; the mechanical one here, and the electro optical. This one of course reduces, has very little chances of error in it; it does not activate the signal much, there are no mechanical parts, no wear and tear, so in some way this is superior.

So, this is what the multiplexer does and this becomes useful; because like this we have seen, these are the inputs of the multiplexer. In most experiments, we have more than 1 measurement that we are making. And our objective then is to record the signal from every one of those instruments; you could have maybe 2, 3, 5 like that or even 40, 50 going all the way to 100, 500 like that. In a modern aircraft, this number goes up to well over 100,000. So, many signals are coming in. So, that is what the multiplexer does.

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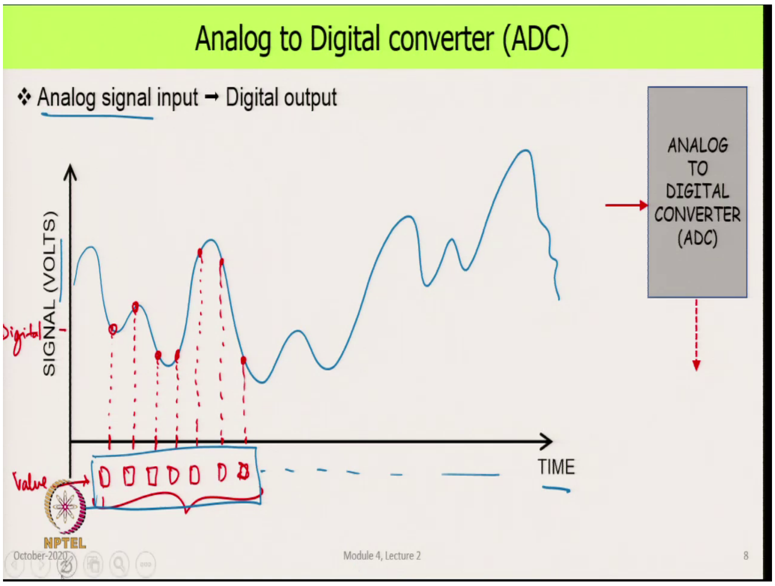

Now, let us see, what is analog to digital converter? So, what this does is that, your input signal is analog. So, if I have a time on this axis and I show the strength of the signal on this side; then the analog signal could be something like this. And this becomes a digital signal; which means that instead of what the signal had is that at every point, the value of the signal is known.

In the digital world what one does, we say look I look at this time instant; at this time instant I will capture the signal value, which is there and then convert this value from an analog value to a digital value. So, they becomes a number, binary number and we get that value stored.

Then after a little while, we do the same thing. So, we allow some time to elapse and then at this point, we again pick it up.

Now, we have this signal strength, we digitize it and store it. Then again after that much time, we take another time instant; see what are the signal there, digitize it, store it. So, like that this thing continues; at a regular time interval, the signal will continuously keep getting converted, that what the digital system does. So, here again it is the same thing happening, it will pick up this signal.

Then at this point, it will pick up this signal; at this point, it will pick up this signal. So, in the end, we will have as a function of time a lot of numbers; so these are the signal values at these time instance. And so, when you look at just this data, all the way you will see a series of numbers and you know at what time instant that signal value was there.

But beyond that, we know nothing about the original signal; the original signal has been lost. So, what we will see in the digital world then is that, everything in between that was there is gone, we are just left with these points. And this is the real challenge that, if how good are these numbers representative of the original analog symbol, the signal.

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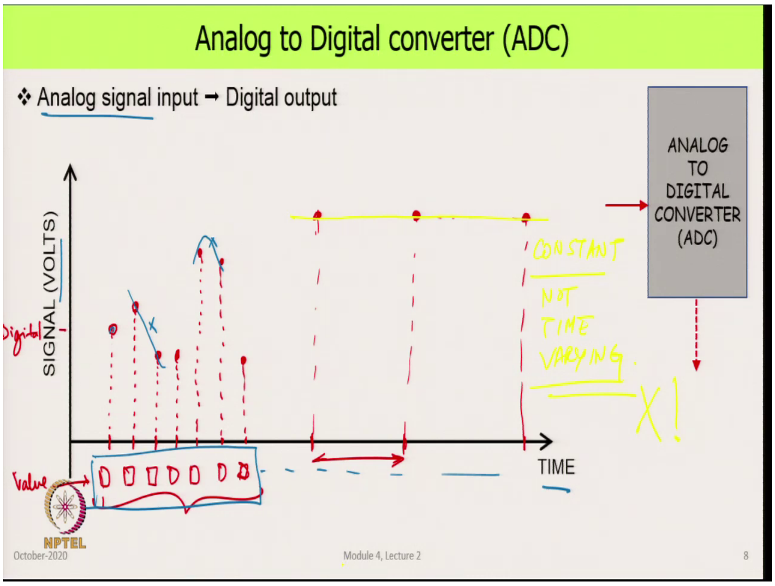

If you recall, there was a peak over here something like this, here there was something like that; we have missed this information, we have missed this information, there has been some loss. So, this is one of the issues that comes up with analog to digital conversion that, if you have a very high frequency of the conversion; that means these numbers the time at which you take this is much more finely spaced than the frequencies in the signal, then we get a very faithful reproduction of the signal itself.

And then we can store it and do all types of operations with it. This can also cause serious problems. Let me give you an example here. Suppose a signal is a pure sine wave and we do sampling or this time that we pick up is say here, at this point and the next signal that we pick up is at this point, and the next signal we pick up is that this time. So, what we are saying is that, this time at which we are sampling is one over the value of the frequency of the signal or it is equal to the period of this sine wave.

So, what will happen? We will get this value, then we get this value, then we get this value and so on. And then when you look at the digital numbers, where this analog signal has disappeared; what do we see? We see this. And what do we interpret this that, this is constant signal; it is not time varying.

And this if you compare it what we had; we had a pure sine wave, this interpretation is gone completely wrong. So, this is a gross exaggerated view of what how our A to D converter can lead us into highly unrealistic conclusions; but this is something we have to be careful about. So, this is the third device that did electronic processing.

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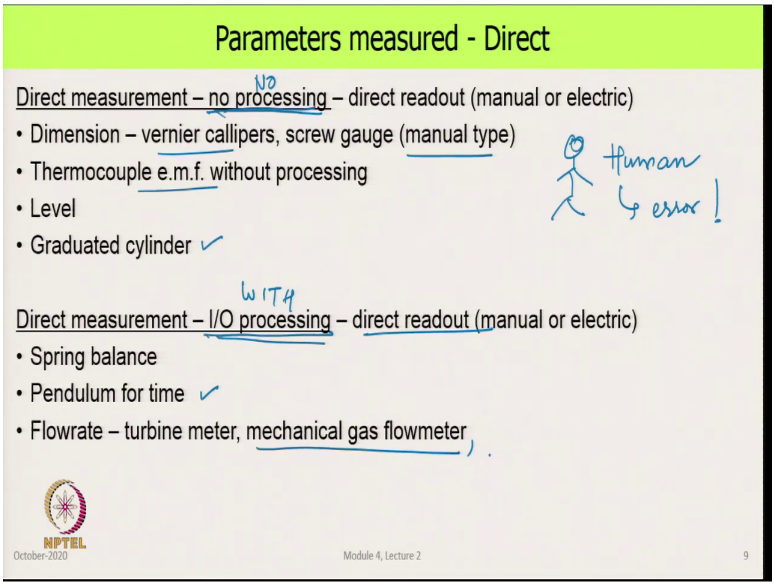

And now we come and ask, what types of parameters are measured and what are the ways in which they are measured? So, what we have is a direct measurement, where there is no processing and the examples of that is that; that means there is a instrument which shows something and we note the reading simple as that.

A vernier callipers which are manual type, which we have to read the markings on it; the voltage of a thermocouple on analog voltmeter or the level indicator. So, just put a scale in a tub of water and say what is the level or a graduated cylinder. So, I have given some very simple examples which you would have already seen somewhere earlier and this is the case of direct measurement without any processing.

But remember here, there is human intervention and we will see later on, what this does in causing an error. The next I have listed here is direct measurement with some input-output processing; earlier one there was no processing at all.

And then you get a readout, so the display and we get the value; it is like the wing balance, the spring balance. So, we just have a spring balance we have put it and it shows the reading; what has happened is that, the signal that we put, the weight got converted into a displacement by a conversion which is what I have called I O processing, which is the spring.

Similarly, if you want to measure time with a pendulum that would be the case and that says a flow meter, water flow meter at your house or the mechanical type of a gas flow meter; these are devices which operate complete in the mechanical way and depending on something that rotates it gives a number that is how much we have consumed. So, there was a processing happening, because there was a mechanism in it; but no major electronic thing, again there is a direct readout which could be manual or electric.

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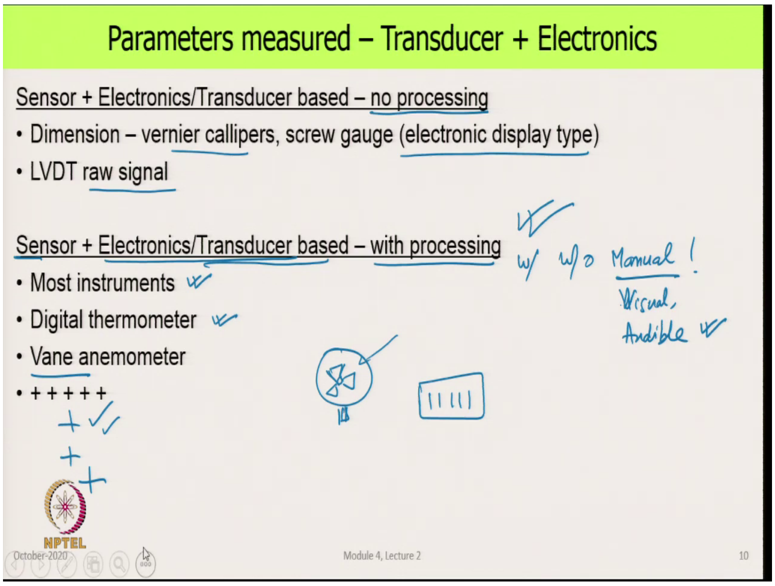

So, here also the human being is an actor. Then we have some devices, where there is electronics and transducer; but not a much by way of processing. So, there is no signal processing happening here and an example of that is the dimension indicated by an electronic type of a vernier callipers or the raw signal coming out of a LVDT. And then the fourth category which is the most prevalent category, everything is pretty much like this these days is that, you have a sensor; there is electronics and transducer and there is processing with or without manual intervention.

So, in this category I have said, almost all instruments come in here; an example you say that digital thermometer that is the clinical thermometer that is there, there was a sensor in it which measured the temperature, there was a electronics inside it which converted it to a temperature and then we had a display which was read manually. Manually means also audible also is there; visual we can see it or audible, so that it produces a sound and you can hear and see what it is. These days a lot of things have to be this way for a variety of reasons.

Another example is the vane anemometer, where there is a you hold it; it is a sort of a circular thing with a bunch of blades in it as the air flows normal to this, it spins, there is a sensor which picks up the rate at which it spins, does a processing and gives a readout which tells you what is the velocity of the air.

So, in ventilation studies, air conditioning studies this is a very common instrument. And if you want to look at air circulation in a room, which in this COVID days is become a major issue; this would be one of the instruments you would like to have. Like this there are very large number of instruments, there is no way I can list all of them; I encourage you to go to the web and read some of these.

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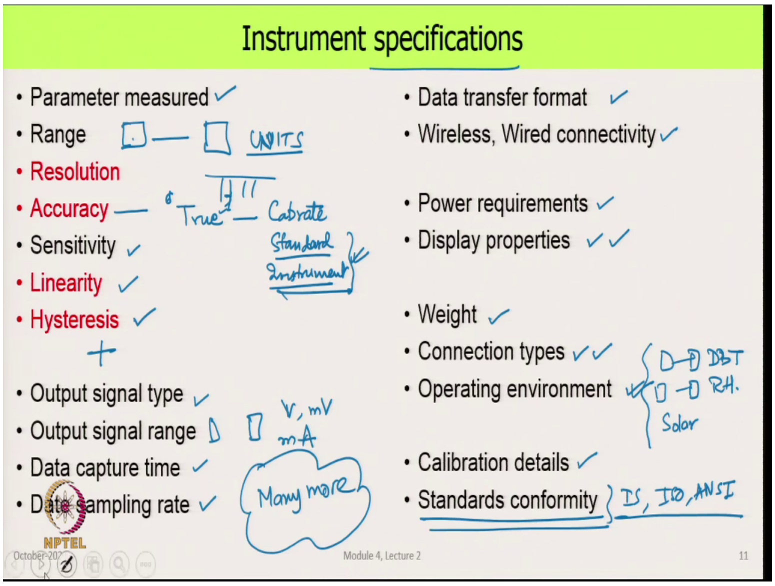

Now, we look at instrument specifications and we will see as we listed; why this is important for uncertainty analysis? In the assignments I have asked you to go and look up instrument specifications, look at what manufacturers tell us about their instrument and we have to be able to intelligently interpret it; not just for using the instrument correctly or buying the instrument.

But also once you have got data from it, using that information to get uncertainty data. So, here we go. It will always tell you what is the parameter being measured; pressure, temperature, flow, pH, concentration of CO 2 all of that. Range that is the smallest value that it can measure and the largest value; smallest value need not be 0, very close to 0 many instruments become non-linear and manufacturers do not recommend using it below a certain value.

So, this is the range and it will also always tell you what are the units. And in all our work and all other engineering work as well, you must always kept keep track of units at every step. Then it tells us what is the resolution, that is a in a very crude way on this scale; what is the markings and what the spacing in the markings in relation to the physical parameter.

Then there is accuracy; that means how good this instrument that the data that you get from this instrument, how good is it compared to the true value. And as we have said earlier, true value is never known. So, we have the next best thing to the true value, which is that you have calibrated with respect to a standard instrument.

Simply that the standard instrument is far more accurate and close to the true value than anything else we have. So, the primary standard, this is the best thing in the world; every country has its own standards laboratory or standards institution. For example, in India the national physical laboratory maintains many of us primary standards, so that is at par with the best in the world. So, we are there.

And we take as our instrument, give it an input, see what an instrument tells; then you give the same input to the standard instrument and see what signal value it gives, that value will tell us the accuracy of our instrument. Then there is sensitivity, linearity. Linearity means that, the rate of change of the output to the input is it constant. Many sensors have hysteresis; that means when you are loading it up or increasing the physical parameter, it value take it shows up one value; when you are decreasing and coming back to the same value, in between it shows different values. That we have learnt in school, the same thing coming up here.

So, these now these are red items, these are very important for uncertainty analysis; resolution, accuracy, linearity, hysteresis and there will be many some more others which we will look at later on. The instrument will also tell us what is the output signal type analog or digital; what is it is range and in what units it could either be Volts or milli Volts or milli Amperes.

It will tell you how much time it takes to capture the signal and make it display; what is the rate at which it can refresh that. And then what is the data transfer format, that is the wireless or wired connectivity in what format does it send out the data that it has got. What are its power requirements?

The battery or mains power source and what is the display properties? So, it could either be a, this is the 8 digit display or maybe there is a screen or there is a touch screen, all of that comes in at this point. Then there are some gross information about the instrument like weight, what type of connections does it require?

If you are going to connect it to a electronic thing, it could be a USB port or maybe a power supply could be different type of a port, or if it has got a water supply connection coming in, what is the type of connection that you get there that will be detailed over here. And every instrument will tell you, what is the environment in which that instrument should be used.

So, they will give you a range of the temperatures, which is the dry bulb temperature and a range of relative humidity. And in some case they may also say, whether it can be used in direct solar radiation or not. So, what the manufacturer is telling us is that, as long as you are in this range, my instrument will do what I am claiming it does. If you are going out of this, then I have no idea what the instrument will do, it may even get damaged.

Then he would also give you details of the calibration on the standard and finally, one of the most important things they everybody will tell you is the various IS, ISO, ANSI standards to which it conforms. This is become very important now; that is becomes a common language that, people anywhere in the world can identify with.

So, these are some of is a sampling of some of the types of specification that manufacturers put on their instrument specific sheets; depending on the instrument this could change, and there could be many more.

So, this is just a small representative list. I encourage you to go see more and more instruments on the web these days and see what is it that the manufacturers are telling us. Maybe there is something missing, which we need for a analysis, both for using and for uncertainty analysis; in which case we have to contact the manufacturer and ask them, please tell me this information. So, that is about instrument specifications. Now, let us see what is it that we should look for, when you are looking at the electronics and the analog to digital converter specifications

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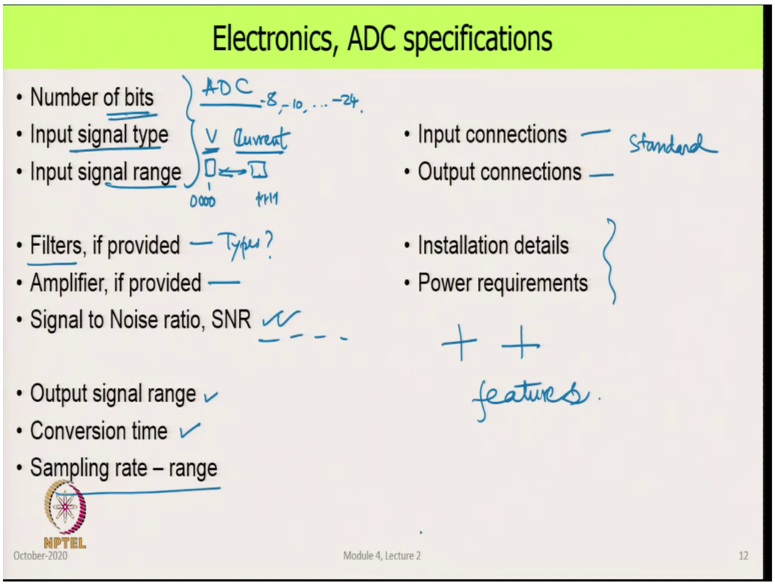

When it comes to the A to D converters, the most important thing we are looking at is the number of bits and input signal type and range. So, this could be either a potential or a current and this will tell you how many bits does the output number contain; this could be 8, 10, 12 all the way to 24. The range tells you that at the input to this analog to digital converter; this signal whether it is a voltage or a current, must be within this range.

At the lowest value, the digital value will have all 0s at the upper range it will have all 1s the digital value of the signal. We will see later on how this is very important in our uncertainty analysis and also when you are designing the experiment; why we have to understand this and select the correct type of the A to D converter. Then are filters provided and if so, what types and at what frequencies; we could even buy filters and put them together in our circuit.

Same thing with amplifiers, we can either use the inbuilt amplifiers in the instrument or the A to D converter or the data acquisition card and or configure it ourselves by buying individual items. And in both cases they will always tell you, what the signal to noise ratio under various circumstances; for amplifiers it will tell you, what is the output signal range.

So, input signal range was already there and for A to D converters it will tell you what is the conversion time; in how much time does it converts the analog value into a digital value. It is not instantaneous, there is a small time involved in it; because that is what the electronics does its own job and after that it produces a digital signal. That means, as long as the A to D converter is converting it, we cannot input the next signal into it.

Then the sampling rate, the rate at which we can take in samples and then the input and output electrical connections; what type of connections are there and what standard they follow and also then installation details and power requirements.

The addition to this there will be many more things depending on the various features that manufacturers provide and we have these days a wide variety to select from; the best thing is to go to the web, look up the specifications and try to understand what is it that these things do.

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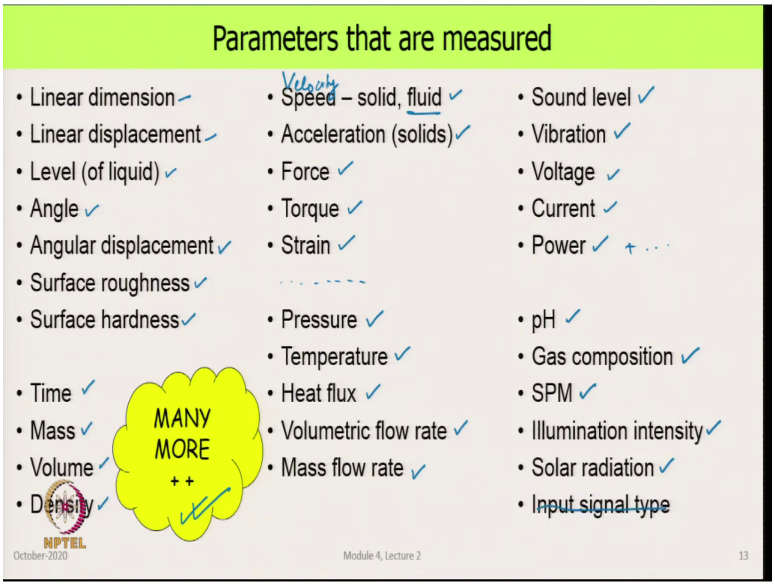

Here is a small list of parameters that are measured. In typical experiment, you will have many instruments measuring many things; by no means is this list exhaustive. There are many many more parameters that can be measured. You can quickly go through this and here it is you could measure linear dimension, linear displacement; that means movement level of a liquid, angular measurement angle, angular displacement.

For example, how much degree a shaft rotates, surface roughness, surface hardness, so that is one category; then you have time, then mass, volume, and density. Many of these you may be familiar with, I am just listing to show that every one of these; if they are measured in our uncertainty analysis, we will get their uncertainty coming into it.

Then there is speed and velocity or in a solid or in a fluid, liquid or a gas; then acceleration, usually solids and bodies, physical solid bodies, force, we measure force, we can measure torque, and strain. Then we have another family of measurements that comes in a lot of thermo fluids, the most fundamental being pressure measurement, temperature measurement; then there is a device which measures the heat flux.

What is the rate at which heat goes into a surface, volumetric flow rate, mass flow rate, and of course here it was fluid velocity on a point wise measurement. Then we have other parameters like sound level and of course, the frequencies that are there, vibration and then electrical measurements like voltage, current, and power and of course many more things in the electrical side.

And then various things which are relatively specialized; we measure the pH, the composition of gases, suspended particulate matter; how much dust is there say in the air, this is the major issue in our cities these days. Illumination intensity, then solar radiation; the instrument by which we say right now how much is the solar energy incident on at the earth's surface and of course, this is not there. So, there are so many other things that we can then add to this.

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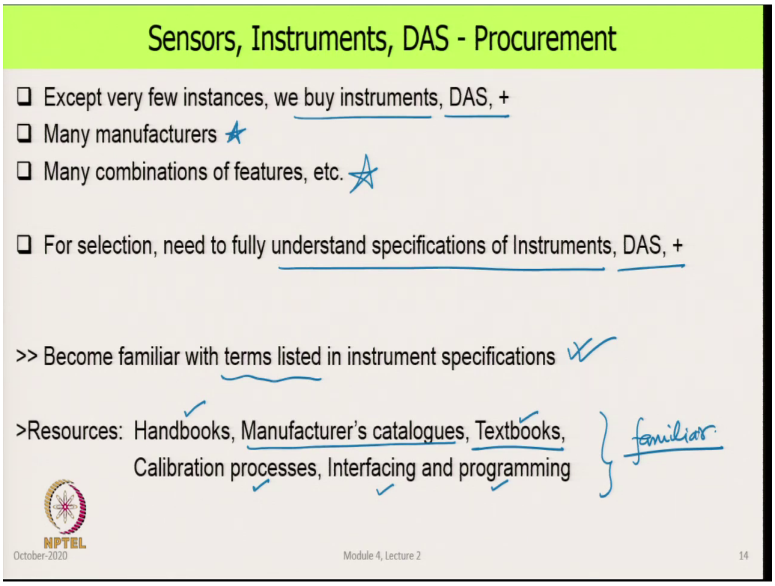

So, what is central to all of this what we have seen in this lecture is that, except for very few instances, we buy instruments and we buy DAS or we buy the whole thing as a package. There are many manufacturers to choose from and they have many different combinations of features.

So, for selecting it, when you are putting together an instrument, experiment and also later on when we are analyzing the data; we need to fully understand the specifications of all of these. So, we need to become familiar with the terms listed in the instrument specifications.

And beside catalogues from manufacturers, we can get such information from various handbooks, textbooks very limited amount though and then there are various processes, standards which related to calibration, interfacing and programming. We need to become familiar with these. And so, the world of experimentation, very interdisciplinary to begin with.

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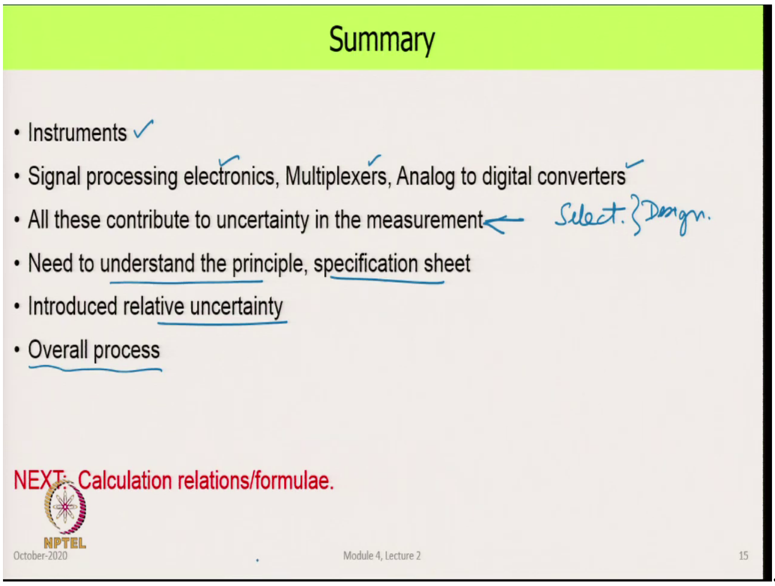

So, on that note we will conclude this lecture. And what we have done today is had a flavour for instruments, signal processing, electronics, and devices like multiplexers and analog to digital converters. We learnt about this, because they contribute to uncertainty in the measurement and also of course, we need to understand this in order to select the instrument.

So, when we are looking at different phases of experimentation in the earlier module; in the design stage, this is what comes in. And as an experimenter, we should understand the principle on which that instrument works and be able to interpret the specification sheet. All of these have been introduced in this part, because they have uncertainty. So, this is what we have looked at in this and we have seen the overall process of sensing to storage, everything that goes on in between.

On that note, we will conclude this lecture. And we will now move on to use this information in our next module. So, we come to the conclusion of this lecture. And.

Thank you.