Transducers For Instrumentation

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Lecture - 33

Data Acquisition: Signal Conditioning

Hello, welcome to the course Transducers for Instrumentation. We discussed some conventional sensors and we discussed that there are certain smart sensors which are nothing but the conventional sensor which is interfaced with extra electronics for example microcontroller or a microprocessor which locally process the signal generated by these conventional sensors and this meaningful data which is already processed by these controllers. This is now sent to the base station or over the internet so that we do not send kind of erroneous data or the garbage data generated by sensor because the sensor is sometime may overshoot or may provide a data which is not meaningful so we need to process that data as soon as possible so that we can find out only the relevant data out of it. So we have a for example in smart sensors we have a conventional sensor which is generating this data and on the other hand we have these microcontrollers or microprocessors which are processing this data. Now the data which is generated by these sensors this is not most often adequate to apply directly to these microcontrollers because for example the generated data by a sensor is typically in a very small range for example few millivolt of signal only is generated by these conventional sensors. However, the microcontrollers they work in 3.3 volt or 5 volt range as we saw in smart sensors so they expect a data which varies from 0 volt to 3.3 volt or 5 volt depending upon the microcontroller. So the expected range is 0 to let us say 3.3 volt but that signal generated by a conventional sensor is in few millivolts only.

So the very first step to do to make this data adequate to a microcontroller is to amplify it. So the very first thing which we can think of is to amplify this data from few millivolt to few volt kind of a range. So this is one step. There are certain other steps as well which we have to do to make this data appropriate or kind of suitable to apply to other electronics. So this stage where we are modifying this data generated by sensor making it suitable to apply to microcontroller. These stages are called signal conditioning and signal acquisition. So signal conditioning is the process where we process the data generated by these smart sensors make it suitable to interface or to give it to further electronics. So we have a signal conditioning. So signal conditioning is the operation formed on the signal to convert it to a form suitable for interfacing. With other elements in the system. There are many factors actually which may prevent a signal used by one device or circuit from being usable by another device or circuit requiring an intermediate rate to bridge the gap. So we have signal conditioning which is the operation which we perform on the data and this data is generated by some conventional sensor and this operation involves certain steps so that this data becomes usable to another electronics or another circuitry. And there are multiple factors in fact that what we saw is one thing that the data is of very small range few millivolt and the electronics which is processing it, it expects the data in 3.3 volt range. So this is one aspect where we need to amplify the data to make it suitable.

There are other things as well for example noise is there in the data that we need to filter out and some other aspects. So all these factors are there which prevent this signal which is produced by this sensor from being usable by another circuit or devices which actually processing this data. So this unusability is there because of certain aspects and there are multiple factors involved in this and to process these factors we need extra hardware or extra circuitry to perform these functions on the data and this is called the signal conditioning of the sensor. Now this kind of bridging operation is called signal conditioning. And there are certain examples of this process. For example, the range and offset correction. Convergence. Convergence, for example current to voltage conversion. And filtering. So, here we have signal conditioning hardware which process this data generated by conventional sensor and make it suitable so that it can be processed efficiently with the microcontrollers or microprocessors.

So this signal conditioning hardware is separate from conventional sensors as well as from the microcontrollers or microprocessors. This hardware is called signal conditioning hardware. This hardware acts some sort of a bridge between a conventional sensor and the controller. This bridging what the function is providing this is called signal conditioning and there are certain example. For example one is the range and offset correction range we just discussed. If the sensor is producing a data which is varying only in few millivolt let us say 0 to 10 millivolt of range which is very small range and the data generated is confined only in this range. Now this range is not suitable to process by these microcontrollers. So we need to amplify this range from 0 to 10 millivolt we convert it to 0 to 3.3 volt. So this is a range conversion. Similarly, if we have certain offset in the sensor data that offset also can be corrected using this signal conditioning hardware. This is one function which need to be performed before processing the data. The second is the convergence. For example, our sensor is a current sensor and our microcontrollers which are nothing but voltage devices that measure the voltage at the pin. So, we need to convert this current data into the appropriate voltage data.

So, this kind of conversion is also happening in signal conditioning block. The third is the filtering. Filtering is removing the unwanted signals or which we refer noise. All the sensors when they generate data that data is most of the time analog in nature along with certain other frequencies which are unwanted by us. So, this unwanted frequencies or unwanted data is like a noise to us and this need to be removed from the data before processing the data using our microcontrollers. So, this kind of filtering stage is also a part of signal conditioning block. So, these are the some of the functions which we do using signal conditioning hardware. Let us see how a signal conditioning block look like in the full block diagram. So, this is a typical block diagram of a sensor where we have first a transducer or simply a sensor. Now this transducer exchange the data it has both input and output communication with unit something called signal conditioning unit. So, we have a signal conditioning unit. This is signal conditioning unit. This has multiple parts for example one function of this signal conditioning unit is to provide excitation to the transducer. Excitation means it provides necessary bias conditions and the signals. The other block is a bridge completion.

Then we have next stage amplification. This is generally followed by a filtering unit. So, this is signal conditioning unit. This process the data and send it to the next unit which is data acquisition unit. So, here we have a transducer which is providing the data this can be a normal conventional sensor for example a thermal sensor which is detecting the temperature and providing its input to the signal conditioner. This signal is very small in magnitude 0 to 10 milli volt or so and this is having certain amount of noise as well as unwanted frequencies. Now this data this controller or this smarts this conventional sensor is attached to the signal conditioning unit. The purpose of signal conditioning unit is to provide necessary excitation to the sensor for example the sensor is active sensor which requires external DC supply and certain signals as well when we want to activate the sensor or when we want to deactivate the sensor. These kind of signals can be generated using the signal conditioning unit. So, it has a separate portion of excitation which is necessary to excite the sensor and the data which is generated by the sensor this comes to the bridge completion. So, we can have some sort of bridge completion for example the Wheatstone bridge we use for the digestive measurement. So, this kind of bridge completion is provided by signal conditioning unit. Now this signal which is still a very small signal 0 to 10 milli volt this is applied to amplifier which can be our Op-Amp based amplifier or BJT based amplifier this must be a linear amplifier. This amplifier is now going to amplify the data from few milli volt to volt range 0 to 3 volt or 5 volt as per our requirement. So, this amplification is a linear function which is applied to the signal whatever is the signal coming in if it has noise or it does not have noise it does not matter everything whatever is received by amplifier is going to be amplified.

So, at the amplifier output we get the amplified signal as well as the amplified noise as well because amplifier cannot distinguish between a signal and a noise it amplifies whatever comes as a input. So, after amplification stage generally we have a amplified data with amplified noise. Now this amplified noise which is unwanted, and we need to filter it out before further processing. So, this filtering is done by filter stage these filters are generally the next stage of amplification because as soon as we amplify the signal noise also get amplified and we need to suppress the noise immediately after that. So almost everywhere amplification stage is generally followed by a filtering stage here in case most of the time low pass filters. So, this stage filter out the noise and the amplified signal now amplified by this amplifier is now sent to the next unit which is data acquisition unit. Now this data acquisition unit has its own certain role before sending its data to the microcontroller. Let us discuss this data acquisition. So, this data acquisition primarily has a sample and hold circuit. This stage is then followed by the analog to digital converter. And this stage is further followed by the multiplexing and data transmission. This is multiplexer and after this stage the data is sent for further stages for processing, filtering or display. So, here once this data which is already filtered out the noise this data is sent to data acquisition unit. This data acquisition unit again has basically three parts. The first one is sample and hold circuitry.

This is used to sample the data at certain instances and hold the data during that period so that this data can be applied to analog to digital converter. The next stage analog to digital converter is this has multiple levels and based on the level of analog signal a code is generated by this analog to digital converter. This code is a digital code, for example 011101 this kind of code. This code is now easy to process using microcontrollers because microcontrollers are digital, and they process the digital data efficiently. So, this analog to digital converter gives out that code to the next unit which may or may not be multiplexer. For example, we have multiple sensors connected to a single controller then in that case we need multiplexer so that one sensor is connected to controller at a time and the data is processed only for that particular sensor. So, we may or may not need multiplexer in all the smart sensors depending upon our number of sensors attached to microcontrollers. So, this is the data acquisition unit which after this unit we get a data which is digital in nature 0 and 1 0 for example low voltage or high voltage and this digital data is now suitable for further processing or we can record it directly to some hardware or we can display it in the some LCD or this kind of display. So, the data goes to the next stage. So, this is a complete bridging happening in the smart sensors when we have transducer on one end which is conventional sensor and on the extreme right we have a processing or recording or display which is nothing but our microcontrollers and in between we need these two types of hardware which is one is signal conditioner and one is data acquisition unit.

These units we need separately to make the data suitable for processing. So, we are going to discuss signal conditioning now in little detail now. So, the signal conditioning unit it provides external excitation and grounding. It completes the circuit for some time we called bridging. It linearizes the data. It filters out the noise amplification. It also provides isolation. It isolates one part of system electrically from other and typically the input is in milli volt and the output is in volts. So, these are the some of the functions performed by this signal conditioning unit. It provides external excitation and grounding. If sensor need a 5 volt supply then this signal conditioning unit provides a 5 volt supplied with limited current so that the sensor can act efficiently. It completes the circuit whatever is the bridging or whatever external hardware circuit is needed for sensor to work that is provided by signal conditioning unit. It linearizes the data. It filters out the unwanted noise. Amplification is generally done in signal conditioning unit so that the input is in milli volts, but the output is in volts. And this also isolates one part of the system to another part of the system electrically so that they do not interfere with each other. For example, the sensor which is producing data in milli volt that stage might be working at very low voltages. If we connect directly this stage to microcontroller which is running at 5 volt this 5 volt can interfere or can damage this sensor directly. So, signal conditioning unit provides an isolation so that the sensor can act efficiently at low voltages and microcontroller sees a signal which is 0 to 5 volt. So, these are some of the functions of signal conditioning unit. As we discussed the first stage is the bridging stage where we put necessary hardware for example Wheatstone bridge or a linear resistive divider or any kind of electrical network which is particular to that sensor. So bridging is that function. Now after bridging is the amplification stage which is generally there because the signal generated as we see in milli volt and we need in kind of volt range. So, amplification is the stage where we need to put in the signal conditioning unit.

So, we see the amplification stage. So, the ADC generally requires high levels of voltage. Typically, 0 volt to 5 volt range. So low voltage sensor output may need amplification prior to conversion. Now for this step we can use an op amp circuit with gain. May be inverting or non-inverting. If signal need to be DC shifted, we can use an op amp level shift circuit. So, one configuration of op amp based amplifier is something like this. We have amplifier which is made up of op amp. Op amp has two inputs one is plus one is minus and one is the output. Now this op amp on one side this is connected to the sensor using a resistor. So this is V sensor. This is R. This generally has a feedback resistor. This is feedback resistor RF and on the positive side we attach a voltage which is V ref and this is V amp. So this is the basic configuration of a amplifier using an op amp. In this we have a sensor which is connected to the negative terminal of op amp using a resistor R and in feedback we have a resistor RF. So, this unit act as a amplifier. Now on the positive side we can directly connect it to ground so that we do not shift the level of the signal. If we put a voltage source V ref in between so this means then we can shift the entire voltage by this V ref voltage if it is 0.1 volt so we can provide a offset of 0.1 volt using this V ref in the output signal and output is collected at the output node which is V0 here with respect to ground. So, this is a simple stage simple op amp based amplifier. We can have op amp based amplifier or we can have VJT or MOSFET based amplifiers so that can be used as per the requirements. This is amplifier stage. So now this amplifier does not know whether the signal is with noise or without noise. Whatever comes in at the V sensor node that will be amplified using this circuit and the V out will have a amplified output along with the noise if noise is there that noise also gets amplified. This amplified noise is the problem because we cannot send this noise also to the controllers otherwise, they also cannot detect this whether it is a signal, or it is a noise.

So, this stage is immediately followed by a filtering stage where we filter out this noise. So, the next stage is the filtering stage. So, these filters may be classified as digital filter or analog filter. So, the digital filter is. These filters are implemented using a digital computer or special purpose digital hardware. And the next is the analog filters. They may be classified as either passive or active. And usually implemented with R, L and C components and operational amplifiers. So, in this stage where we have this filter these filters can be classified first as digital or analog filters where the digital filters are implemented using our special purpose hardware or a digital computer. In this stage we convert the data into digital form, and we have certain algorithms which can filter out the noise out of the data out of this digital data using some algorithms and these algorithm run on our digital computers or our normal computers or we can use special purpose hardware which are specified in filtering out this digital data. So, there are digital filters available which we can use but for that we need to convert the data first into the digital form. This is first classification the second is the analog filters where we have these analog filters which are made up of electrical components like resistor, capacitor and inductors and these components along with we can use an Op-Amp or operational amplifier. So, these analog filters are again classified into two types one is the passive filters, one is the active filter. Passive filter means we do not need external power supply to act as a filter. For example, a resistor, inductor and capacitor, the combination of all these component only does not need an external power supply and they can act as a filter without any power supply so these are passive filters. However, if we put a Op-Amp as well along with these filters these Op-Amp these are semiconductor devices they need external power supply external DC power supply to act as a Op-Amp so in that case the filter is called a active filter. So analog filters are of two types passive filter and active filter. Now let us see how a filter actually look like and how it works. Typically, a signal after amplification must be low pass filtered to remove high frequencies generated by amplifiers. So, for example we have a signal which is amplified by amplifier and when we filter these plot this graph which is on the x axis is frequency and on the y axis we have gain. So now our signal is which is getting amplified now we apply a filter, and the filter has certain characteristics for example it has a pass band and a stop band.

Similarly for a filter we have a pass band and a stop band this portion where the gain is high of a filter this is called pass band and where the gain of a filter is very low is called the stop band and this portion where the gain is transitioning from high to low this is called transition zone and there is a very low value of gain which is called the noise floor. This red is our frequency response of our filter. So, this is a typical amplification or the frequency response of a low pass filter. We are discussing here the low pass filter which the name itself says low pass means the low frequencies which are applied to this filter they will pass through, and the high frequencies will be cut down. So, we are applying a low pass function to our data because the noise we are assuming is high frequency which are generated by amplifier. So, this high frequency noise we want to filter out using this filter. Now this filter has certain filter response which we can see for the low frequencies which are close to origin. These low frequencies filter has a high gain it means these low frequencies will come and they will smoothly pass through this filter because of this high gain. However, this filter response is very less or the gain is very small. It means if the high frequency comes in at the filter those frequencies will be suppressed because of very low gain of this filter and these high frequencies will not pass through this filter. So, this act as a low pass filter high cut filter high frequencies will be cut down. So, this we can see by this red filter response high gain on low frequencies and very low gain on the high frequencies. This very low gain is not actually 0 is a certain value which is not actually 0 it means the high frequencies which will come they will not be eliminated because the gain is not 0 gain is very low value but still a certain value. So these low frequencies these high frequencies will be suppressed to a very low value which is generally called the noise floor of a system that very low values generally we consider as a noise floor and we do not operate our systems very close to this noise floor. These are very small signals which are generally considered as noise floor.

So, the response of a filter should be very close to noise floor in the stop band and where we have a high gain of filter this is called pass band. This pass band and stop band the transition does not happen very sharply. So, because these are realistic components RLMC they do not have a very sharp transition from high frequency to low frequency. There is a transition smooth transition from pass band to stop band that is called the transition zone and we generally do not want to operate our sensors in this transition zone because there is no certainty of the gain in this transition zone. So, we want to have our signals very much close to the pass band and the noise is all in the stop band region. So, this is a typical filtering stage of a signal conditioning unit. So let us see some realistic filters. So, there are four types of filters generally used. The first one we just saw is a low pass filter where we have frequency axis and the gain. Ideally we expect a flat transition zone and the transition is very sharp and in the stop band we want a absolute zero gain. So, this is the desired characteristic of a low pass filter. But with actual circuitry we get this kind of characteristic. This is the practical or real filter which has certain transition zone and transition does not happen abruptly. This is an ideal case for a low pass filter. Similarly, we have something called a high pass filter where the low frequencies will be cut down only the high frequencies will be passing through.

The desired response is like this. This is ideal and the actual response is like this. This is high pass filter. The third we have a band pass filter where only a band of frequencies will be passing through. All low frequency or high frequencies will be rejected. So for a band pass filter we have a desired response like this which is the ideal case. However practical case this filter response is like this. There will be some of the transition region where the frequencies will be still passing through. So, this is real response of a band pass filter. And the fourth one is the band reject filter. This is the opposite of band pass filter. In band reject filter certain frequencies only will be rejected everything else below that frequency or above that frequency will be passing through. So, in band reject filter we have a desired response like this. For a band of frequency, the response is zero everywhere this is high. So, this is the ideal case. In the practical application the filters have this kind of response. This is the real response of band reject filter or band pass filter or band stop filter. So, these are four types of filters generally used for filtering. Low pass filter is passing low frequencies rejecting higher. High pass filter is removing low frequencies passing high frequencies. Band pass filter means we have a certain band only where we are interested in. Below this frequency or higher than this frequencies all will be rejected that is band pass filter and band reject filter is we want to reject certain band where these confined frequencies we do not want these frequencies to come over. So, in that band the gain is zero except or the below these frequencies or higher these frequencies those frequencies will be passing through. So that is band stop filter. These are the four types of filter generally used in signal conditioning unit. So, this is the third block of signal conditioning unit.

That is all for today.

Thank you.