Transducers For Instrumentation

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Lecture - 30

Smart Sensors: Introduction and Architecture

Hello, welcome to the course Transducers for Instrumentation. Today we are going to discuss about the smart sensors. The smart sensor is not a very different sensor. In fact, the main sensing element in the smart sensors is one of the sensors what we have already discussed. For example, optical sensor, magnetic sensor or thermal sensor. All these sensors are there as a sensing element in the smart sensors. The only difference between those sensors and the smart sensor is we put some amount of intelligence in the system itself so that when we are sensing the environment using these traditional sensors and we get the data from this sensor output, that data itself is processed within that sensor itself. So the sensor has a one part which is the traditional sensing and the data generated by this traditional sensing is processed using some extra electronics attached to it. So the whole system now it is called the smart sensor. It has certain intelligence, it can have memory, it can have some algorithms which can process this data and the refined data or the processed data is sent for further processing or for further visualization. So this is called smart sensor. So we have smart sensor here. So this smart sensor is a device that takes input from the physical environment. And uses built-in computer resources. To perform redefined functions. So smart sensor is a device which takes the input from environment using some traditional sensor. Let us say we are talking about a thermal sensor now which is a smart thermal sensor. So the basic element of sensing is still that thermal sensor what we have discussed earlier. This traditional sensor is going to measure how much is the thermal energy and based on that it is going to convert this information into an electrical signal. Now this electrical signal is further processed by external circuitry which is inbuilt in this smart sensor.

This extra circuit is going to compute on this data which is electrical data coming in. This electrical data will be processed using this electronic circuitry to perform predefined function. For example, it can have multiple stages. For example, the data comes with some noise that need to be cancelled out. The amount of signal is very weak so it need to be amplified and then this data will be converted into a digital domain because the processing of data in digital domain is very easy. So we perform something called analog to digital conversion and these A to D are there in this smart sensor itself. They convert this data from analog to digital and then this data, this digital data is further processed using algorithms. This algorithm is also part of extra electronics which we put alongside the sensor. So this whole system which can process the data also and transfer it to some other location, this whole system is called the smart sensor. So this sensor, the smart

sensor is also crucial and integrated element, an integral element of something called Internet of Things. Or sometime it is called IoT in short. These IoT technologies makes it possible to do this or about those things over the internet. Or a similar sensor network. So these smart sensors, these are very crucial and integral part of IoT or something called Internet of Things which is a very new, very recent concept of putting sensor nodes. So the explanation of IoT is for example we have a very large field and we want to measure the moisture of the soil using some sensors.

So one way is we put multiple traditional sensors like humidity sensor or soil moisture sensor each and every point in that large field, every 10 meter or so. So the number of sensor we need to put will be like 100 or even more sensors we need at every interval. These sensors will generate their own data. Each sensor will have this moisture to electrical conversion and this electrical data need to be processed. So now it has multiple requirements. For example the very first is the soil moisture does not change very rapidly. It takes time in changing. So we are not worried very much about the real time or the instantaneous data. So what is the moisture now? It's going to remain almost in the similar range for quite some time, let's say one hour or two hours. So we do not need this data to be transmitted every time. So the sensors which are hundreds of sensors which we need to put in that field, they need not to be sending data all the time for processing. Sometimes we know the data that remains in the same range for over a certain amount of time. So this is one crucial aspect of these sensors and smart sensors. So we put the electronic circuitry in such a way that the data which it is not measured continuously, it is measured in after certain interval of time. And the IoT technology makes it possible to transmit data from or about these things over the internet. So this hundreds of sensors which we have put together it's called sensor network and the sensors, individual sensor is called sensor node. This sensor node can transmit this data, this moisture or humidity data directly to the internet which we can see in our remote location or it can send its data to neighboring sensor node so that this data hops on from one node to another one and it reaches its destination. So there are two ways of sending this data by these smart sensors over the internet directly or to similar sensor nodes or sensor networks. So this is another way of transmitting this data. So next we have low power and low cost mobile processors.

Typically provide computation resource, IoT environment and a sensor that just sends its data. For remote processing is not considered a smart sensor. So as we have seen this example where we have a large field and we put hundreds of sensors or sensor nodes in that field to measure the moisture of soil. Now because we need to put large number of sensor nodes in a given field, so there are two constraints which comes up. The very first is the low cost. These sensor nodes in the individual sensors need to be very low in cost so that we can deploy in hundreds of numbers. The next is the low power. So when we are putting these sensors which are smart sensors now and extra electronics is also put

along with them for doing all these processing. This extra electronics as well as the sensor now they require power supply to perform the processing in that function. This power supply is generally in the form of built in battery. We need to provide a certain amount of battery in the sensor node itself because if we put hundreds of sensors in a field there is no way we can power them individually from a power socket. So they need to be self sufficient in power. So the power supply should be adequate for this sensor to run for a long time. It is not even possible to replace the battery or charge the battery because we have hundreds of sensor in the field. So low power and low cost sensors need to be there and generally we put a microprocessor or a very small processor which is good enough to process the signal generated by these sensors and this is the processor which provide computational resource in the IoT environment.

And a sensor which just receives the environment which sends the environment and convert it into electrical domain and just send it to the remote location processing. It does not process any data within inside. It is not called smart sensor. Smart sensor is the one which accumulates the data and process the data using built in algorithms and then transfer it to the remote location. That is a smart sensor. If it does not process any data within itself then this is not considered as a smart sensor. So let us look at the block diagram of a smart sensor. So in the all the sensor smart sensors we have a traditional sensor which is the sensing unit. This is the traditional sensor which is sensing the environment and generating the electrical signal. This signal actually received by signal conditioning unit. Then the bus is sent to another unit which is analog to digital conversion. After this the data is sent for application of algorithm. This application of algorithm phase can have simultaneous input from the memory which is the inbuilt memory in the smart sensor and the user interface. So once this algorithm application is over then the data is sent to communication or transceiver. So this is a typical block diagram of a smart sensor. Of course the number of blocks can change depending upon the application but a general smart sensor contains these kind of blocks. The very first is the sensing unit which is our traditional sensor. For example the moisture sensor in this case what the example we have taken. So the moisture sensor is nothing but which is converting the moisture or the humidity or the water content into a electrical signal. Now this electrical signal goes from sensing unit to signal conditioning.

Signal conditioning is the unit which process this signal so that it is appropriate to apply or to transfer to electronics because the signal generally we receive from any sensor is not in the desired format or is not kind of suitable to directly transfer it to electronics. For example the noise, the generated signal generally has noise and we need to filter it out before sending it for processing. Another important point is the amplification. If the signal generated by the sensor is very small in magnitude it will not be easily processed. So signal conditioning unit does all these functions. It amplifies, it filters out noise and do other things as well and make the signal appropriate to apply for other process, other

blocks which is further electronics. When the signal conditioning sends the data to A to D converters or analog to digital converter, this unit converts this analog signal into digital signal because most of the time when the signal is generated from traditional sensors the signal is always analog. Most of the time it is analog in nature and processing analog signal is difficult compared to digital signal. We have all these digital processors with us. So we can process a digital data very easily compared to analog.

So it is required to convert this analog signal into a digital signal using this analog to digital converter. Once the data is converted into digital this is sent to this application algorithm block where this data, this digital data now we process it using built-in algorithms. This algorithm and all other previous data is stored generally in memory. So we have the second block attached to this block which is memory which is in direct communication to this block. It can receive and send the data to memory and using these algorithms the processing of data is happening. At the same time some smart sensors can have a display as well which is a user interface. If I want to intervene with these smart sensor processing I also have an option to change the things by myself or by manual intervention. So for that there is a user interface. It may or may not be present depending upon the case what we want to make. But there can be a user interface to control this algorithm which is applied on this data. So once algorithm is applied and the data is processed it can be in the multiple stages, may not be a single block, may be multiple blocks. Once the data is ready then we need to send it to remote location. It may be within the sensor network or it may be over the internet. That is done using this communication transceiver. Transceiver is nothing but transfer transmitter and receiver.

So this block can send the signal as well as receive the signal from outside world and this is the communication block which is used to transfer the data from sensor node to sensor network or to internet. So this is the complete block diagram of a smart sensor. However depending upon the application few of the blocks cannot be there or few extra blocks can be there in this block diagram. So we have here. The first is the sensor and actuator hardware. The second is the conditioning circuitry. Then we have microcontroller and we do multiple processing in this. Let us say signal filtering in this stage can also be done. So these are the few building blocks of a smart sensor. Now let us see the some advantage and disadvantage of a smart sensor. So the very first advantage of smart sensors is energy efficiency and sustainability. Second is access to data in different environments. In some difficult environment. High performance. Next advantage is the built-in analytics and processing. This also offers self calibration and self assessments and it can also detect erroneous data.

So these are some advantages of smart sensors where the energy efficiency and sustainability. How the smart sensors are energy efficient because as we discussed in the example the soil moisture it does not change very much with time. Only in the longer interval it changes. It does not change very frequently. Maybe in one minute or two

minute it does not change. Whatever is the soil moisture is there it remains in that range only for quite long time. So if we put a normal sensor without any intelligence this sensor will keep measuring the environment the moisture and keep sending the data to outside world which is very energy hungry. If we put a smart sensor however the smart sensor knows that this sensing need to be done in every one hour or every ten hour. So for one hour or ten hour this sensor node will go into an ideal mode which will not be burning the power from the battery. So in that way the smart sensors are energy efficient. Next is the access to data in difficult environment. Some environments are there has some harsh environments where it is not possible to measure this data using traditional sensors. So we use these advanced smart sensors to measure those environments. High performance these sensors can send this data very much efficiently and compute on the data. Built in analytics and processing. So we have extra hardware and extra electronics microprocessors in place. These processors will keep on applying some analytics on the data and processing on this data and after the processed data will be sent to the remote location for visualization. So this is the advantage of smart sensor. Self calibration and self assessment.

This is also very good advantage of smart sensor. The self calibration is something all the sensors all sensor what we put in the environment they deviate from normal behavior with time. So if it is a normal sensor if there is a drag in the sensor output that we will not be able to detect at the far end when we receive the data. However these smart sensors they have built in algorithm and they can keep checking the data when the data is continuously drifting towards one direction then they can detect it as a problem of calibration and they can calibrate the sensor itself so that the sensor detects the accurate reading without any drift or drag. So this is another advantage of smart sensors and it can also detect erroneous data. So for any reason if the conventional sensor is failing it is not giving accurate readings and the readings are way off than its normal value. This can be easily detected within the node itself when the data is coming from sensor and processor is detecting whether this data is not within that range. So instead of sending this data this erroneous data to remote location this data will be corrected within itself or the sensor will be recalibrated so that it will start receiving the meaningful data. So this is the advantage that sensor nodes can detect these erroneous data. So let's see some of the disadvantage now of these smart sensors. These sensor nodes are susceptible to tampering and hacking. The higher cost because of extra electronics we need to put here. Silence, battery lifetime, expertise. And meeting requirement for IoT development. So these are some disadvantages of smart sensors. The very first disadvantage of smart sensor is they are susceptible to tampering and hacking because we have extra electronics in place which is continuously monitoring the data and this processing is happening because of this microprocessors we put which has certain memory and we put algorithms in that which is processing this data.

Now with intelligent systems these sensor nodes are susceptible to hacking. One can place or it is possible to change the algorithm itself so that this sensor node will start sending different data than what it should be sending. So this is susceptible to tampering and hacking. Another disadvantage is the higher cost because these microprocessors what we put there along with the built-in battery and some other electronic circuitry this increase the cost of overall system which is a very crucial factor for large scale application because in a field let us say we want to put 100 sensor nodes even a small increase in the cost of one sensor node that get multiplied by 100 number of sensors so the overall cost increases very much. This is the disadvantage. Maintenance sometime is difficult for these smart sensors though it is case to case basis whether the sensor needs maintenance or not but this is also one of the disadvantage. Battery lifetime is also one disadvantage because we are putting extra amount of electronics which is also driven by the battery itself. So here in this case battery lifetime reduces depending upon the extra electronics and transfer of the data and other factors. So battery lifetime is shorter which is a disadvantage for smart sensors.

Expertise is also a problem. So these sensors need human expertise of putting algorithms and connecting it interfacing it to the traditional sensor sending data. So all these expertise is needed which is a kind of a maybe a bottleneck for deployment and meeting requirement for IoT developments. So IoT is nothing but arrangement of the sensor node in a particular fashion and sending this data over the internet. So to do this all these sensor nodes need to be following certain rules or regulations imposed by IoT system. So meeting those specification is also sometimes challenging for these smart sensors. So these are some advantage and disadvantages of these sensor nodes or the smart sensors. Now all these smart sensors as we discussed have traditional sensing which is then just like our thermal sensor or optical sensor in a normal way which converts let us say temperature to electrical signal. Now this electrical signal is processed using some extra electronics or some processors. So there are two kinds of processors which are very widely used in the world. The very first one is the Arduino which is a very low cost microcontroller and the other one is the Raspberry Pi which is a more powerful version of microprocessor which can do multiple computation. So these are two types of microcontroller and microprocessor used for tensor node development. So these are shown here. These are the images of Arduino and Raspberry. So Arduino on the left which is this blue color PCB. This has certain ICs placed inside and this Arduino is built up by this Arduino team and Raspberry Pi is on the left on the right side where we have a strong microprocessor built in and it can do multiple kind of applications together.

So let us discuss what is the difference between these Arduino and Raspberry. So one side we write Arduino and the other is Raspberry or Raspberry Pi it is called. So Arduino is a development circuit board. It is based on microcontrollers. It does not have operating system. It only does only one task at a time. If we want to add some extra features then

we need to use some extra Arduino shields. It can be programmed in CE or CPP. CE language or C++ language. The logic level, the voltage is 5 volt for this case. It needs additional Arduino shields to connect to internet. And there is no wireless connectivity on the board. This has open source hardware and software. And this is not very costly. So these are some points about the Arduino. Arduino circuit board is nothing but a development circuit board. This comes as a development circuit board and this is based on the microcontroller. It is not the microprocessor. It is a microcontroller. It means the data comes in and it will be processed using this microcontroller and the output will be generated in real time.

So this is a microcontroller based board and there is no operating system inside the Arduino. Whatever the algorithm or the data we put that we put in a memory and there is no further updation of this algorithm by itself or using the external data. It is just the algorithm with what we developed and put in the Arduino that is going to process now all the data from sensor. So there is no operating system in Arduino and it usually does only one task at a time. So the signal comes in and it will be processed using Arduino and the output signal will be generated. There is no multiple algorithms which will be running at a time to process the data. It is only one algorithm which will be running in sequence. Usually Arduino needs extra hardware to add certain other features. For example, we want another feature of like display or something or to kind of transfer the data using Bluetooth. For that we need extra hardware to put on Arduino. Standalone it is not there. Arduino can be programmed in C language or C++ language. The logic level is 5 volt means the voltage needed to turn on the Arduino and all the input output signal they all 5 volt in the electrical voltage. So this is very much compatible to very legacy kind of sensors which still work in 5 volt domain. And it needs additional hardware to connect to internet.

So there is no Wi-Fi or internet transceiver or chip already in place in Arduino. So it cannot send the data to us to the internet. We need extra hardware for Arduino to do this function. No wireless connectivity also on the board. So there is no Wi-Fi chip or Bluetooth chip on the board which can send the data. Anything we need we need to put a separate hardware on top of Arduino which is generally available in the market. This is a open source hardware and software structure. It means anyone can update this hardware or upgrade this software based on the requirement and there is no restriction by the manufacturer. So this is a open source hardware and generally Arduino is not very costly which is very suitable for these sensor node application. So these are some facts about the Arduino. Let us discuss the second very popular microprocessor now which is Raspberry Pi. So here we have Raspberry Pi which is a single board computer. This is based on a microprocessor and it has a operating system which is Raspberry Pi OS which is a Linux based operating system. It can perform multiple tasks simultaneously. Hardware can be attached or extra features can be programmed in multiple language in Python, C++ etc.

The logic level is 3.3 volt. Can connect to internet using Wi-Fi or Ethernet. Wi-Fi and Bluetooth on the board. It is a not open source system and it has a operating system which is Raspberry Pi OS and which is Linux based OS. The hardware can be attached for extra features though Raspberry Pi has lot of features on the board itself but for any extra feature we can always put a separate hardware and connect it to Raspberry Pi. This can be programmed in multiple language for example Python, C, C++ or even Scratch. There are multiple programming language which can support Raspberry Pi. The logic voltage level is 3.3 volt which is different than Arduino. So Raspberry Pi work on a lower voltage it means the power consumption of Raspberry Pi can be limited lesser than Arduino but Raspberry Pi has so many functionality on the board and the speed of operation is higher hence the Raspberry Pi overall consumes more power generally than Arduino. Raspberry can connect to internet using Wi-Fi or Ethernet. It already has this Wi-Fi and Bluetooth chip on board. Raspberry Pi is not an open source platform means we do not have functionality of we do not have flexibility of changing the Raspberry Pi board whatever it comes from the manufacturer we have to use in the same way. And the Raspberry Pi is generally expensive compared to Arduino it is like 3 or even depending upon the version of the board it can be 5 to 10 times expensive than Arduino. So these are the basic points about Arduino and Raspberry Pi. These are the microcontrollers and microprocessor generally used for making smart sensor nodes.

So, this is all for today.

Thank you.