Introduction to Industry 4.0 and Industrial Internet of Things

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Lecture – 11
Industry 4.0 Cyber-Physical Systems and Next Generation Sensors

In this module, we are going to talk about Industry 4.0 and the different aspects of it. In Industry 4.0, first of all is a very popular wave, that is going on worldwide, among all different industries. Everybody wants to transform themselves into Industry 4.0 compliance. For Industry 4.0, there are different aspects that are important and should be understood in order for the industries to be able to comply themselves with the requirements. For instance, one of the very important aspects of Industry 4.0 is automation, full automation. Automation where there is no human intervention ideally or to a large extent, there is reduced human intervention.

So, the entire product line, the entire production process in a manufacturing plant, for example, would be made highly autonomous without any human intervention. And so, how can it be possible? It can be possible with the help of all these technologies that we have gone through so far like sensors, actuators different aspects of communication between them. So, these are going to be the enabling technologies for complying with the requirements of Industry 4.0.

So, we need sensors, actuators, communication, automation all of these things. But how these are going to be done? These are going to be done with the help of these IoT devices and something called CPS--Cyber Physical Systems and these Cyber Physical Systems is what we are going to go through in this particular lecture.

So, the idea is that there are different enabling components of cyber physical of Industry 4.0; Cyber Physical Systems is one of them. Likewise, there are different other ones, which we are going to go through in the next few lectures of this module on Industry 4.0 basics.

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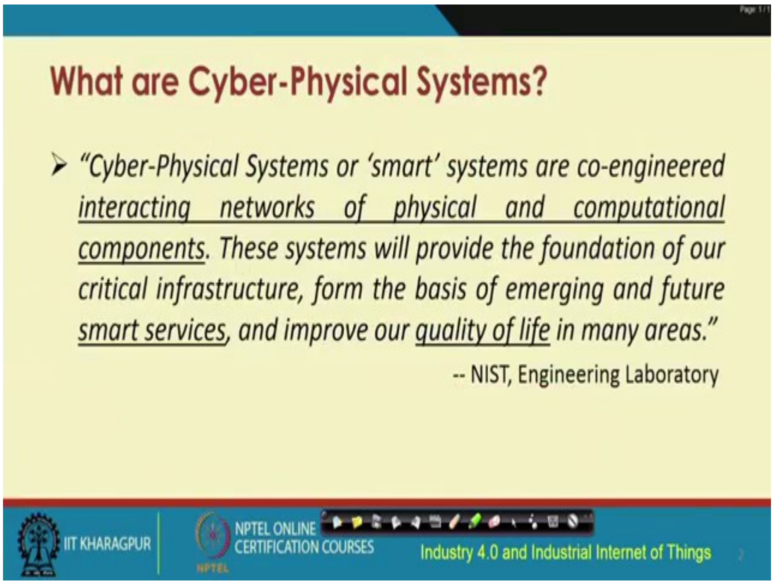

So, what is cyber physical system? There are different definitions that you will be able to find in the literature and people still confuse between what is IoT, what is CPS, what is the difference between them, what is M2M, like that there are different allied technologies, which have overlapping scope. But cyber physical systems is something that the scope is very clear. So, as this name suggests cyber physical. So, these are systems where there is a strong component of the cyber world and the physical world. There is a strong component of the physical world. So, there is interaction between the cyber world and the physical world together in these systems. So, how it is possible?

So, let us look at the NIST definition of what a cyber physical system is. So, cyber physical system also often known as smart systems are co-engineered interacting networks of physical and computational components. Interacting networks of physical components and computational. So, computational is the cyber one and physical is basically the physical world in which these systems are operating, physical world.

So, these systems will provide the foundation of our critical infrastructure; so, different infrastructure. All these public infrastructures that are there not only public, private industry infrastructure all this critical infrastructure that are there. These will be supported using these cyber physical systems in the next generation internet, the Industry 4.0. So, these are going to be all supported with the help of these critical structure will be supported with the help of these cyber physical systems. So, we need to understand really what these cyber physical systems are through the next few slides. But what is important is with the help of these critical, these cyber physical systems the quality of life will be improved because gradually we will be getting into smarter world, where there will be smarter systems offering smarter services.

So, for smartness autonomy in every respect is very important; autonomy and suggestions, based on the data that are collected are very important. So, that basically completes this definition of the cyber physical systems as per NIST.

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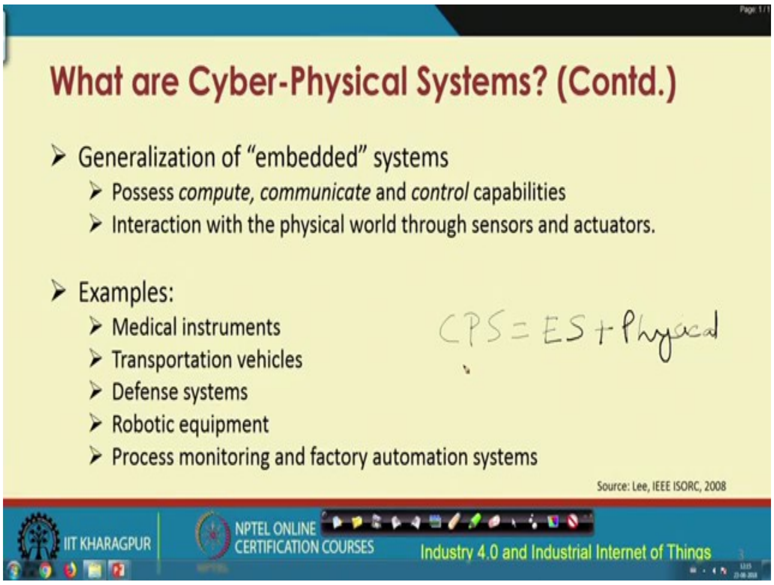

Now, the question is that what is a cyber physical system, but before that we need to really understand what is an embedded system. Cyber physical systems are embedded systems. So, these are basically cyber physical systems are you can think of conceptually as cyber physical system, conceptually as embedded system plus the physical system together you what you get is the cyber physical system.

So, what is an embedded system? So, you have some kind of software that is working on some kind of hardware. The software is embedded in the hardware. Embedded systems have found a lot in the cars; that means, vehicles, these are found in aircrafts embedded systems are found everywhere.

Nowadays, embedded systems are enabling technologies for making systems smarter and that is why these embedded systems are very popular. So, these embedded systems irrespective of where they are used, they possess certain capabilities of computation, communication and control, compute, communicate and control capabilities. So, where there is interaction with the physical world, through different sensors and actuators examples of it would be medical instruments, many medical instruments are embedded they have embedded systems in them, transportation vehicles, defense systems have embedded systems in them.

For example, the radar and different other systems, that are used even the aircrafts etcetera; they are all having different embedded systems in them. Robotic equipments likewise process monitoring and factory automation systems, all of these have embedded systems in them. So, this is the cyber physical system.

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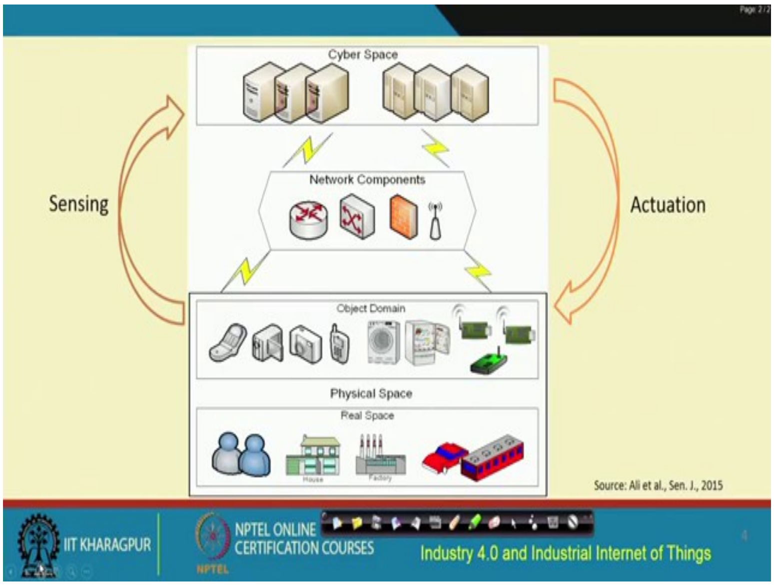

So, now let us move forward and see how an embedded system works. So, as I told you that an embedded system has the computational capabilities. They also have the processing capabilities, so, computation communication capabilities and so on. So these systems would help in building the cyber physical system. So, in the cyber physical system, you have the physical systems--the physical space. So, this is basically the cyber space. This is the physical space, and the interaction between them will make it the cyber physical system.

So, what does this physical space have? So, a physical space we are typically talking about different real objects like human beings, like houses, factories automobiles, buildings and so on. And different objects, these communication objects, for example different other household objects or even the objects that are in the industries like cell phone, cameras, washing machines, refrigerators. All of these are different objects these are different objects that work in the physical space.

So, these objects basically will sense certain data. They will sense different information in the place, where they are operating and then using certain communication devices like the ones shown over here. These data are going to be sent further. So, this sensing once it is done, this sensed data is sent for further processing. So, this processing will be done using different servers, server firms, cloud or, whatever. So, that becomes the cyberspace.

So, it will be done this processing will be done in the cyberspace and based on the results of this processing, those results will be sent back to the physical space for actuating different devices. So, these devices could be maybe, starting a washing machine, starting a refrigerator, if there is certain thing, that has happened; starting the air conditioning in air conditioner in the room.

So, let us say, that it has been sensed that the temperature has gone down in the room. So, based on their analysis that is performed in the servers over here maybe based on certain rules that are already pre-programmed in those cyber spaces. So, finally, based on that the actuation is going to happen and the physical space will be actuated with the intention of starting some device or operating some motor or anything like that.

So, these are some examples that I have given you. This could be generalized further and we can try to understand how, in general, a cyber physical system is going to work.

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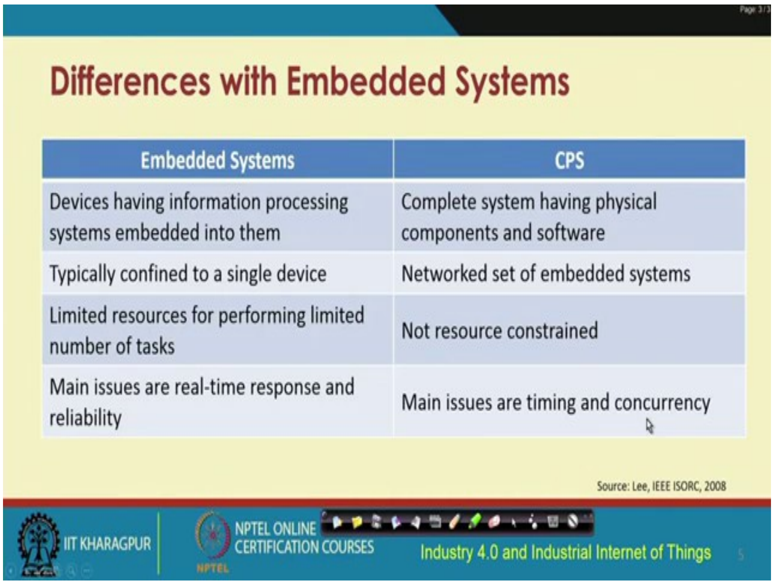

So, before I go any further, let us again try to understand in little bit of depth about how this cyber physical system, CPS is going to work; how the CPS is going to work.

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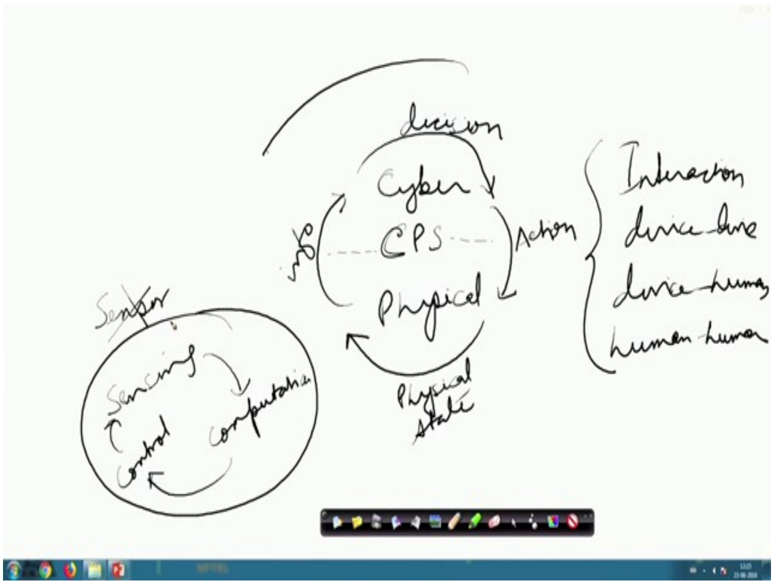

So, if you are talking about cyber physical systems, we have as I told you we have the cyber world, the cyber world, and the physical space. So, what is going to happen is this physical space is going to send some information. It is going to send certain information to the cyberspace and then some decision is going to be made over here some decision is going to be made. Based on this decision certain action is going to be performed and based on this action, the physical state of certain device, physical state of a device is going to be changed. Interaction primarily between devices device to device, but it could also be device to humans or it could be even human to human. So, all kinds of interactions are going to happen, but this is basically the kind of loop that we are talking about this loop is going to take into effect.

So, what we have essentially is some kind of a loop, some kind of a loop between the sensor. You have sensing, rather let me call it not sensor, but let me call it sensing. So, you have a loop between sensing, then computation, and then control. So, this kind of loop is going to exist in cyber physical systems. So, going back so, we need to understand that what is so, special about these cyber physical systems and how they differ from the embedded systems in general. So, we have in embedded systems we are talking about devices alone the devices that will process some information and this information are basically embedded in these devices, they are stored in these devices and so on.

On the other hand, the cyber physical systems, these are complete systems, where there is an interaction between the physical components and the software or, the cyber world. The next difference between cyber physical systems and embedded systems is in an embedded system, typically, you are talking about a single device and this tip the single device the embedded system is basically confined to this particular single device. On the other hand, in a cyber physical system, we are talking about a network set of such kind of embedded systems.

So, the networking of different embedded systems will typically exist in a cyber physical system. Embedded systems have limited resources for performing limited number of tasks. On the other hand, a cyber physical system may not be resource-constrained and there you can perform large number of different tasks at the same time. In an embedded system, the main issues are real-time response and reliability, on the other hand, in a cyber physical system in an addition to these the main issues are timing and concurrency. So, these are the differences, primary differences, between cyber physical systems and embedded systems.

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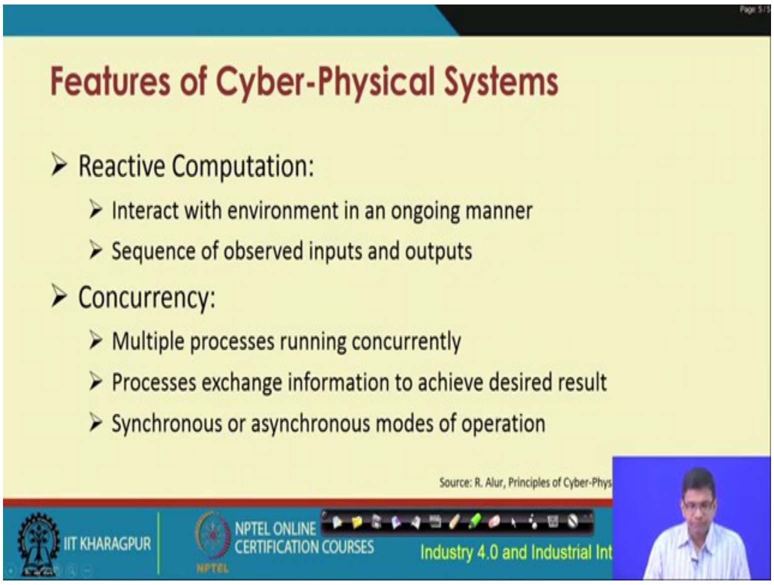

So, here are some features of cyber physical systems. Reactive computation is very important and that we have seen when I explained to you about this feedback loop, the control loop and so on. So, reactive computation means interaction of the system with the environment in a continuous fashion. So, basically there is a sequence of observed inputs and outputs in the process and that has to be dealt with by these systems suitably.

Concurrency is very important, concurrency as this name says we are talking about concurrency of execution of multiple processes at the same time. So, these processes, concurrent processes would exchange information to achieve certain expected result and these operations could be synchronous or, asynchronous in terms of their operation or, their modalities of their operation.

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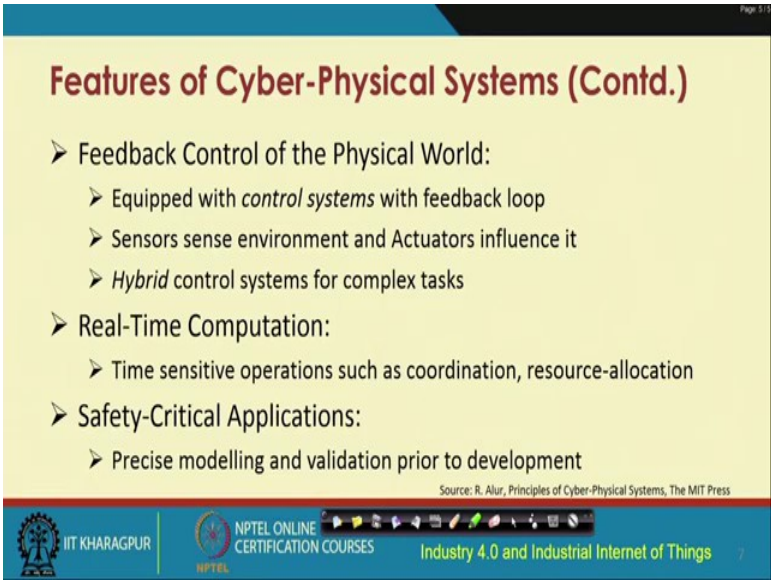

Some of the other features of cyber physical systems; there is a feedback control loop that I already talked about and these basically these systems will have some kind of a control system in them there is some kind of a control element in them with certain feedback loop. So, basically the sensors would sense the environment and these actuators will basically influence it and there is hybrid control system these are basically hybrid control systems for complex tasks. If there is a complex task, simple control systems will not work, it will be a network of different control systems it will be a hybrid control system, which will basically help in achieving the task. Real-time computation is quite well understood and supporting safety critical applications is what is very attractive of cyber physical systems.

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There are different applications of cyber physical systems. Healthcare is a very important domain where cyber physical systems are widely used. So, these basically in healthcare as that what is very important is to have medical devices and systems, which will measure things at a very high level of accuracy. Some physiological parameter of a patient, for example, has to be measured very accurately by different medical devices and systems. So, obviously, as you can understand if you think a little bit in deep you will be able to realize that cyber physical systems will be very attractive of use for healthcare.

For example, you must have heard about the use of robotic surgery or image-guided surgery. These are examples of cyber physical systems and they are used in surgery or healthcare, in general. Then we if we are talking about fluid flow. So, control of the fluid flow, control of blood flow into a patient, when required for medical purposes may be somebody having a bone marrow transplant or some kind of blood transfusion is taking place. So, cyber physical systems can find use to perform the tasks accurately. The system itself will be taking care of the accuracy to a great extent which if a human body. If a human was performing, then they would not be able to do it that much accurately; so cyber physical systems.

So, robotic surgery, already probably you must have heard that robotic surgery is very popular because of the precision, precision in surgery that can be obtained using robotic surgery or image-guided surgery, these are very precise and known. So, the doctors can perform this surgery very precisely accurately. So, that is where in healthcare this kind of cyber physical systems can be useful.

So, let us now talk about other kinds of engineered systems such as exoskeletons, orthotics, like entertainment robotics, therapeutic robotics, brain machine interfaces, prosthetics, and so on. So, these are like different other types of examples of cyber physical systems and their use in healthcare and these are based on cognition and neuroscience.

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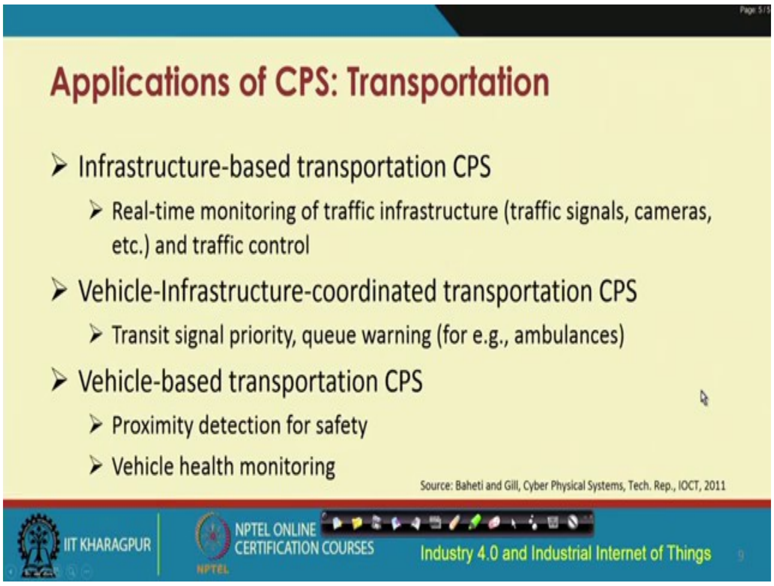

So, the next application domain of cyber physical systems and their use is transportation cars vehicles in general aircrafts they all use cyber physical systems. So, there could be infrastructure-based transportation cyber physical systems for real-time monitoring of traffic infrastructure such as traffic signals, cameras etcetera and traffic control vehicle infrastructure, coordinated transportation, CPS for transit signal priority, queue warning, example for ambulances etcetera. So, these are very important priority-based, priority-based queuing, priority-based system, integration and so, on. So, all these things in transportation could be addressed, with the help of cyber-physical systems.

Vehicle-based transportation cyber-physical systems, where proximity detection for safety. So, you must have boarded vehicles, where the vehicle will warn you if the vehicle is too close to the vehicle, another vehicle in front or if there is another vehicle coming from the back, which is close to that particular vehicle. So, all these things are examples of cyber physical systems operating on the road on the vehicles and so on.

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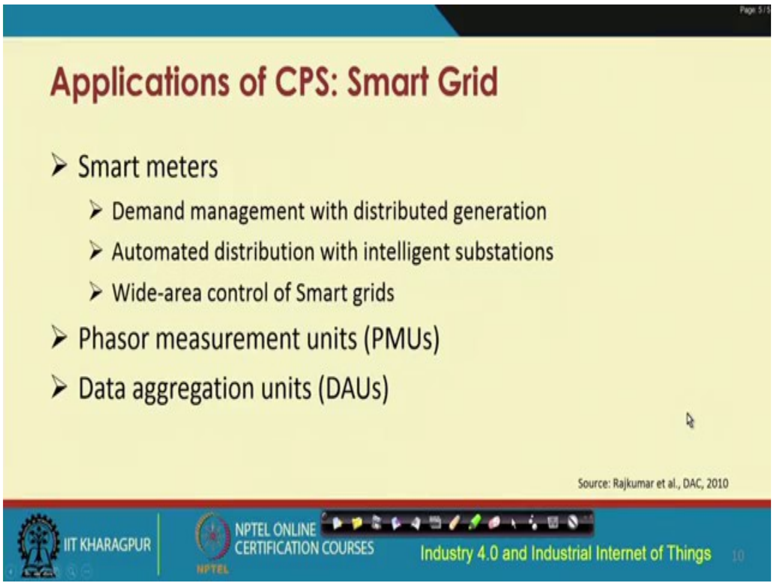

Likewise, other application domain would be in the energy sector, in the smart grid. Smart meters are examples of cyber physical systems smart meters can do demand side management with distributed generation, automated distribution with intelligent substations, wide area control of smart grid. So, all of these things can be performed with the help of smart meters and smart meters are good examples of cyber physical systems and their use in the energy sector. Cyber physical systems in smart grid smart meters is one, but then there are other examples also like PMUs Phasor Measurement Units, Data Acquisition Unit, and so on. So, all of these are basically examples of cyber physical systems in the energy sector for smart grid.

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In the industry, in general, manufacturing industries will use cyber physical systems. All these different machines that we talked about some of these may be robot assisted machines; some of these could be simple machines. So, machines, such as let us say the lathe machine in a workshop, milling machine in a workshop, the welding machine in a workshop. So, all of these could be equipped with different components to make them smarter for manufacturing, improved manufacturing, improving the efficiency of production using different sensors and actuators and different other processing. These could be made smarter and these would be also examples of cyber physical systems, in the industry, in the manufacturing industry.

So, these smarter cyber physical manufacturing systems can perform different things such as smart control, optimal resource utilization, smart diagnostics and maintenance, safety, safety of the industrial environment, safety of these machines, smart monitoring of the health of these machines. So, all of these things could be performed using cyber physical systems attached to or rather machines, which have been made cyber physical. So, these would be examples of cyber physical systems for use in the manufacturing industry.

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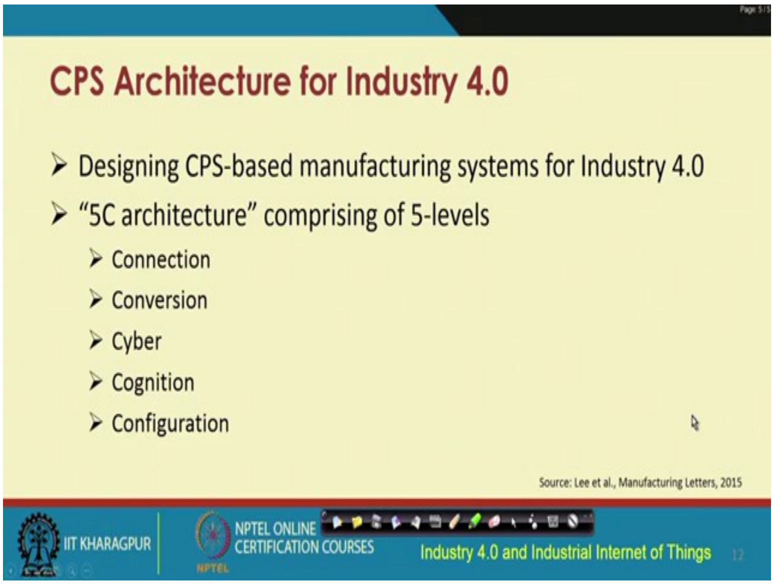

Basically we were talking about Industry 4.0 and we have seen that at the outset, I mentioned that cyber physical systems are very attractive for use in the manufacturing industry and other industries also for moving towards, for leaping forward, towards achieving Industry 4.0 goals, in general. So, in terms of Industry 4.0, there are 5C architecture goals, which can be achieved with the help of cyber physical system. Connectivity, conversion, cyber cognition, and configuration, these are the 5C architectural aspects.

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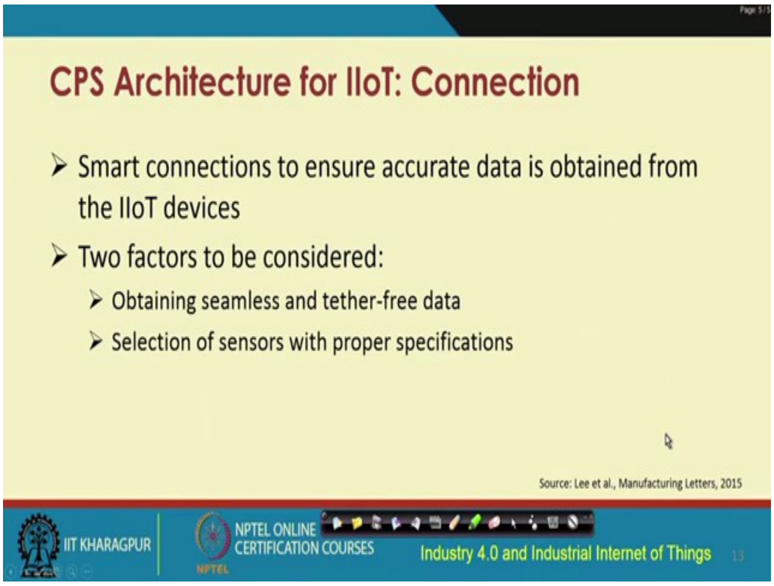

So, connection: so, we are talking about smart connections. To do what to ensure that the accurate data is obtained from these different IoT devices, IIoT devices, in the industry; these are obtained from these devices. So, here two factors should be considered obtaining seamless and tether-free data and selection of sensors with proper specifications.

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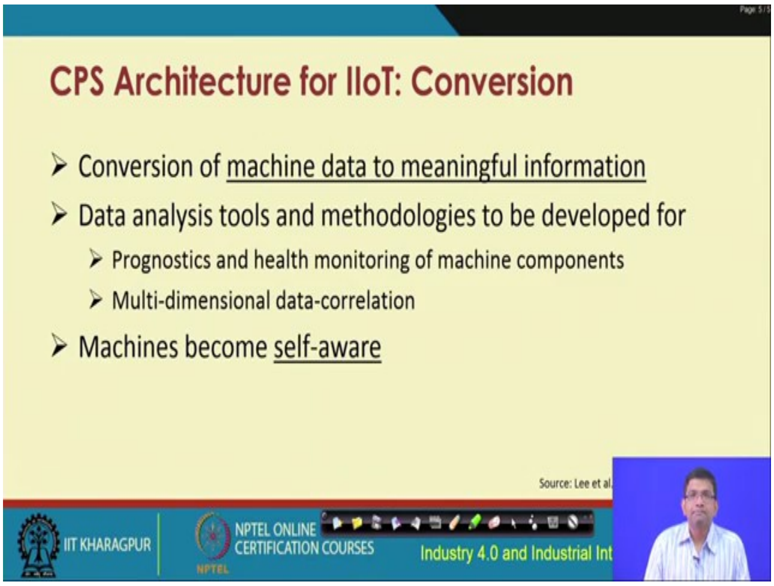

Conversion we are talking about by this term conversion. As the conversion of machine data to some information, that can be made meaningful and useful. So, data analysis tools and methodologies can be developed for the prognostics and health monitoring of different components, different parts of the machines, and for multi-dimensional data collection, and data correlation analysis. So, basically what will happen is these machines will be made smarter, they would be made self-aware.

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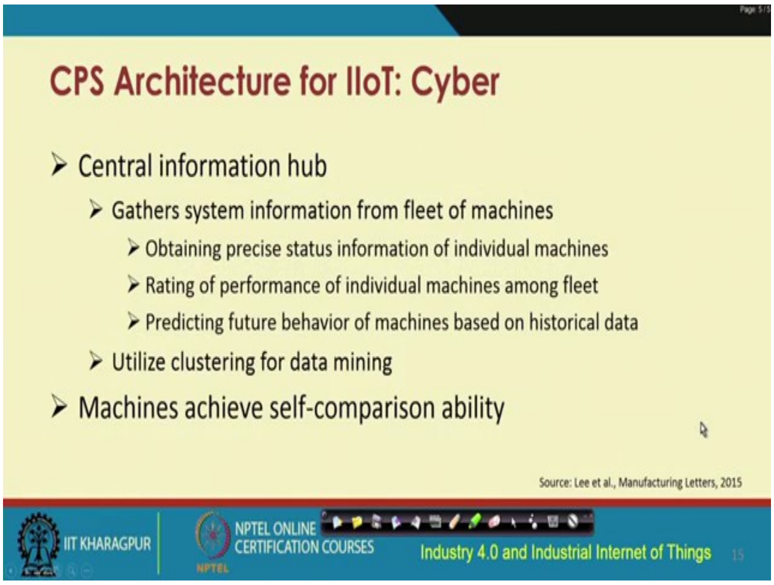

Then comes the cyber component and this is quite obvious. We are talking about analysis of the data that is informed that is received at some kind of a hub which will be comprised of different high end workstations, servers, cloud or whatever. So, that is the server component that we are talking about.

So, this data that is obtained can be used for analyzing the data, mining the data, storing the data and then based on certain algorithms that are run on it on the data or using the data. Then making others aware of what is going to happen next or deriving some useful information at the same time. So, this is basically done by the cyber component of it. So, this is the C of the 5Cs in the architecture of CPS for a IIoT for or Industry 4.0.

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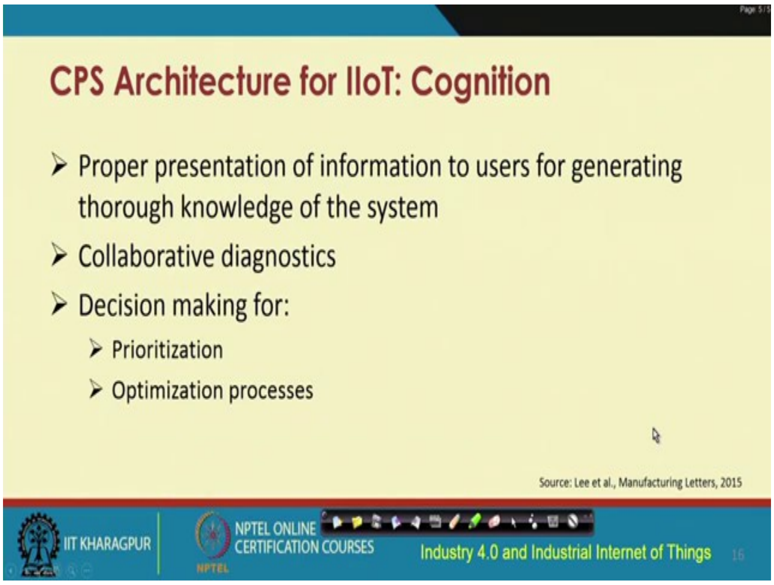

Cognition is another one. So, here by cognition what is meant is basically the proper presentation of information to users for generating thorough knowledge of the system. So, we are talking about collaborative diagnostics, decision making for prioritization, optimization of processes and so on. So, all of these are different aspects of cognition that come into picture in the CPS systems.

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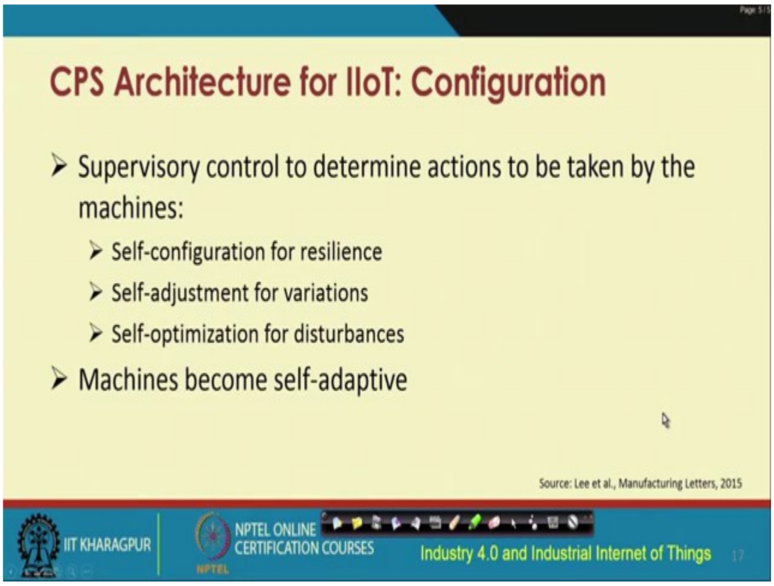

Configuration is the other one where we are talking about supervisory control to determine actions to be taken by the machines themselves. Examples would include self-configuration for resilience, self-adjustment for variations, and self-optimization for different disturbances. All of these self properties would help in the supervisory control for performing certain actions by the machines themselves. These machines are going to be self-adaptive consequently.

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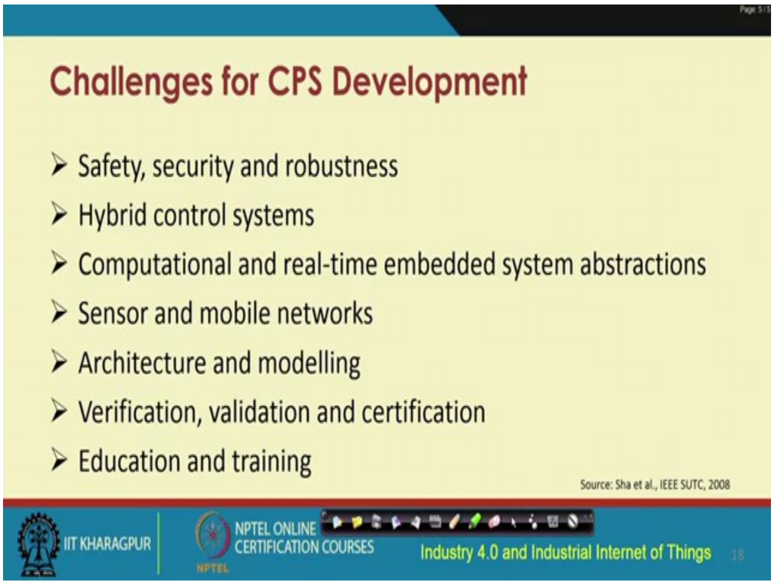

So, there are different challenges of cyber physical system development; challenges with respect to safety, security, robustness, computational challenges real-time embedded system abstractions sensing and mobility challenges are there architecture and modeling verification validation and certification and including education and training of these systems. These are all challenges for of the deployment of CPS for in the industries towards the compliance of complaints for Industry 4.0, the next little while we are going to discuss about the next generation sensors, that are going to be used.

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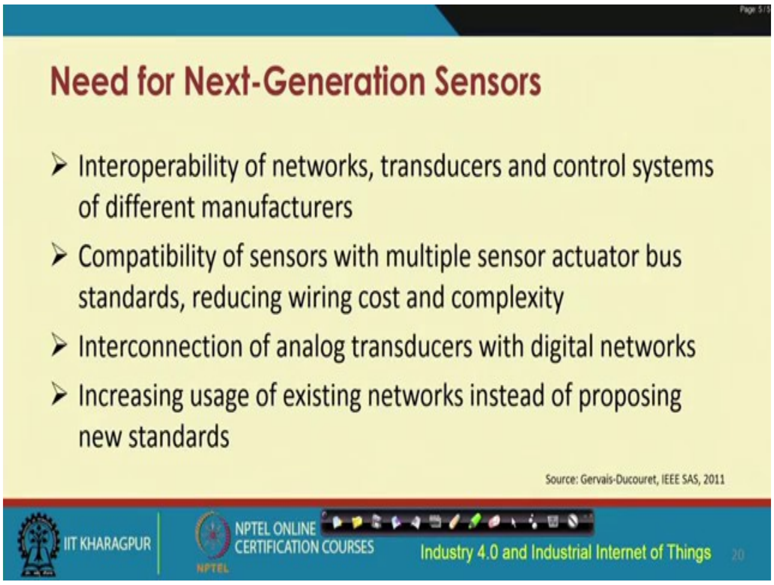

So, all these sensors that we talked about in the introductory module before these are simple sensors. These sensors can only sense and then send the sensed data forward. So, these can be thought of like smart sensors, but then for next generation sensors throughout the world industries academic labs and so, on.

They are working on making sensors intelligent. So, not only that these sensors the smart sensors would sense and send, but these would be made intelligent because certain small algorithms lightweight algorithms will be executed in these sensors to do certain tasks at the sensors themselves. So, these are, this is very important in the context of Industry 4.0.

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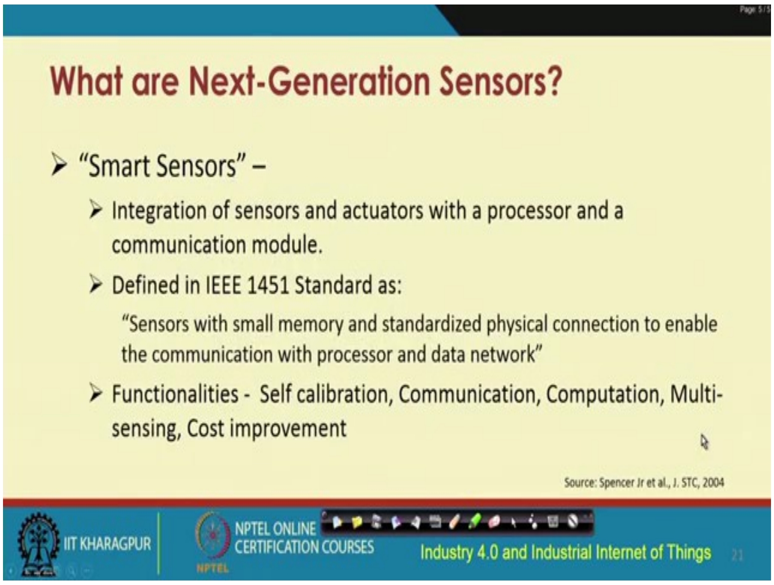

So, here basically you are talking about integration of sensors and actuators, with a processor and a communication module. This is basically these traditional sensors, how they look like. So, there will be a sensor component an actuated component optionally and a processor for processing certain, whether the data that is sensed and certain communication module for connecting these different sensors with a central hub for processing or the sensors themselves. So, these are the simple smart sensors these sensors will also have to do certain functionalities like self calibration, communication, computation, multi-sensing cost improvement of their own.

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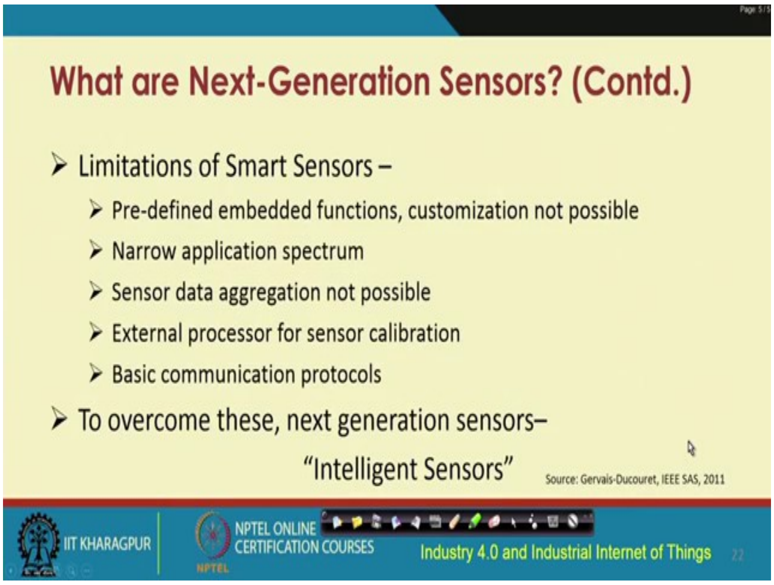

So, these are some of these different features of the smart sensors, but these smart sensors have severe limitations. They have predefined embedded functions that cannot be used for certain customized scenarios. So, you have to customize them based on certain requirements and that makes it difficult for use in real life industry scenarios. Narrow application spectrum is the second limitation sensor data aggregation using the sensors is not possible or limitedly possible and external processor for sensor calibration is required for these smart sensors and also they would support very basic lightweight communication protocols.

So, for overcoming all of these different limitations of smart sensors, next generation intelligent sensors have been proposed. They are in the works and these are the different features of these intelligent sensors.

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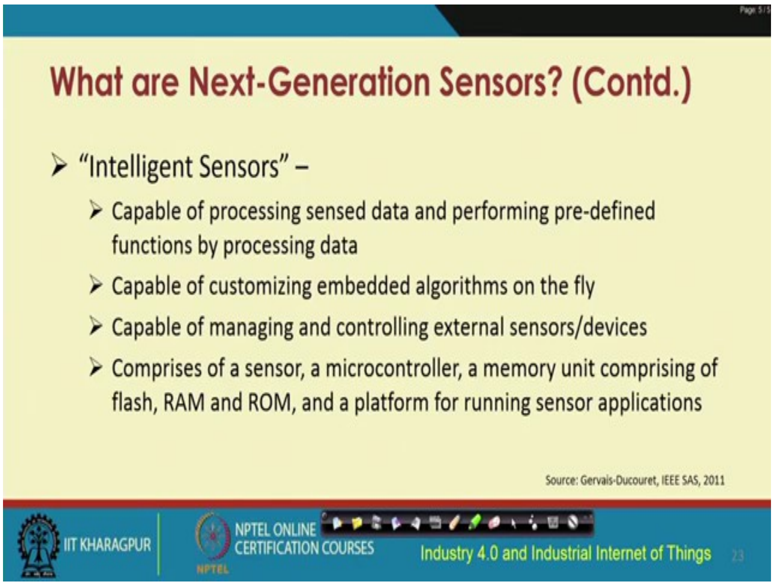

So, these intelligent sensors are capable of processing sensed data and performing predefined functions by processing the data. So, they are capable of customizing embedded algorithms on the fly unlike the smart sensors which were not able to do so. They are capable of managing and controlling external sensors and devices and they would comprise of a sensor, a microcontroller unit, a memory unit comprising of flash RAM, ROM, and a platform for running different sensor applications.

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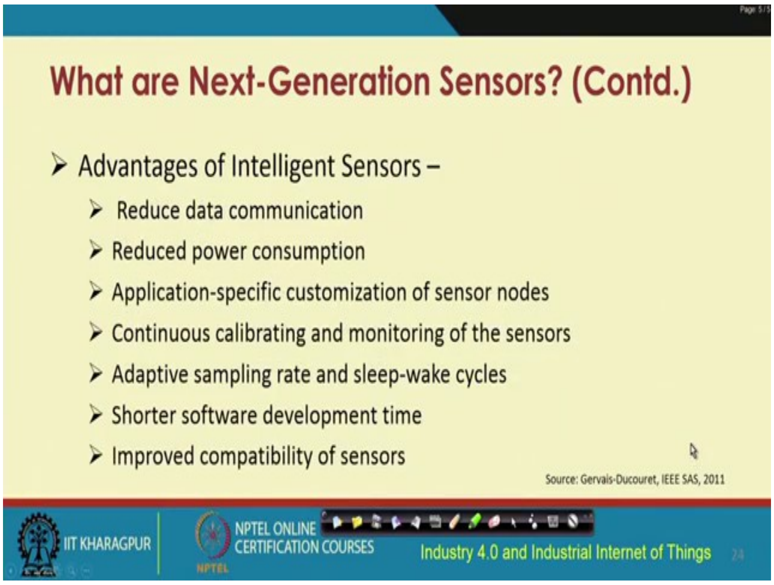

So, there are; obviously, different advantages of these intelligent sensors, in terms of reduced data communication, reduced power consumption, shorter software development time, improved compatibility of sensors, possibility of continuous calibration and monitoring of the sensors. These are the different advantages of these intelligent sensors and that is why these are very attractive.

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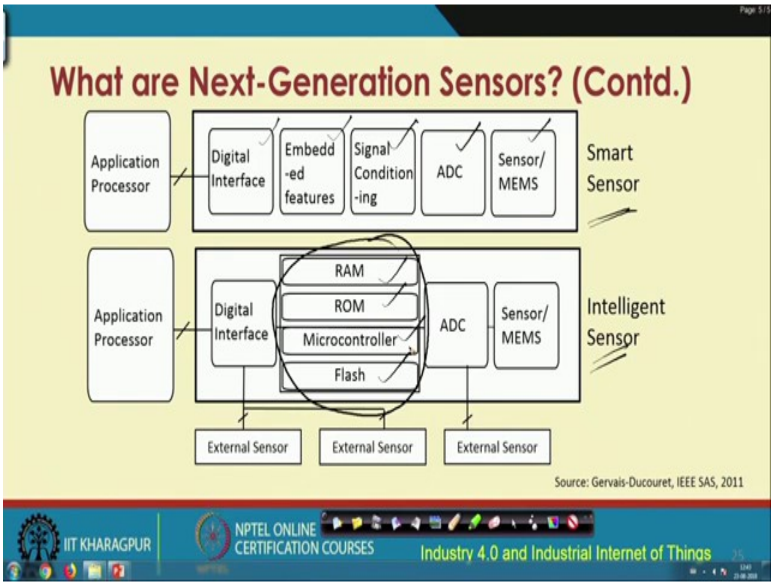

So, this is how is this is how a smart sensor would look like a smart sensor this is an example of it. So, as you can see over here, there is a digital interface and embedded there are different embedded features signal conditioning circuit, then you have ADC Analog to Digital Converter and the sensors or MEMs which actually sense the material, environment or, sense whatever it is supposed to sense.

So, in addition to all of these things in the intelligent sensor on the other hand, you have mostly whatever is present in the smart sensors, but also a component for processing and computation. So, you have this RAM, ROM microcontroller flash and so on. All of these basically make these smart sensors intelligent, by virtue of having these components in them.

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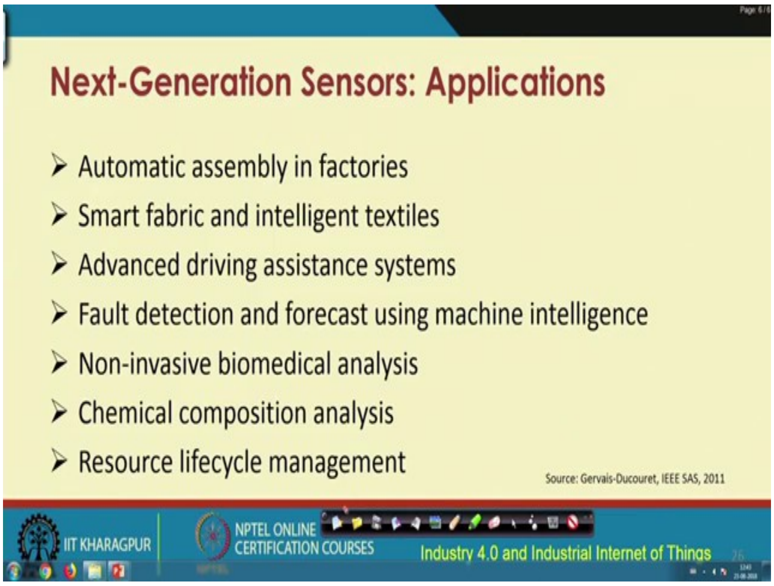

So, there are different applications of next generation sensors these intelligent sensors. Automatic assembly in factories, smart fabric and intelligent textiles, advanced driving assistance systems, fault detection and forecast using machine intelligence, non-invasive biomechanical analysis, chemical component analysis resource lifecycle management. These are some of these different applications of these next generation, intelligent sensors.

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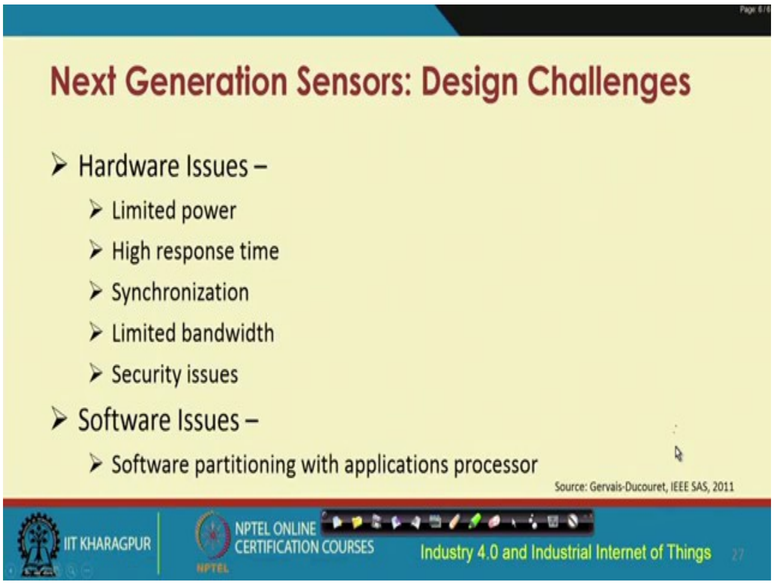

So, there are different design challenges in the manufacturing of these intelligent next generation sensors. There are different hardware issues. These sensor nodes, they themselves are already limited in terms of power, they have very high response time and there are synchronization issues, issues of limited bandwidth of operation, security issues are also there and there are different other software issues such as the issue of software partitioning for complying with different applications and their different processors in them. So, all of these are different design challenges with respect to hardware and software.

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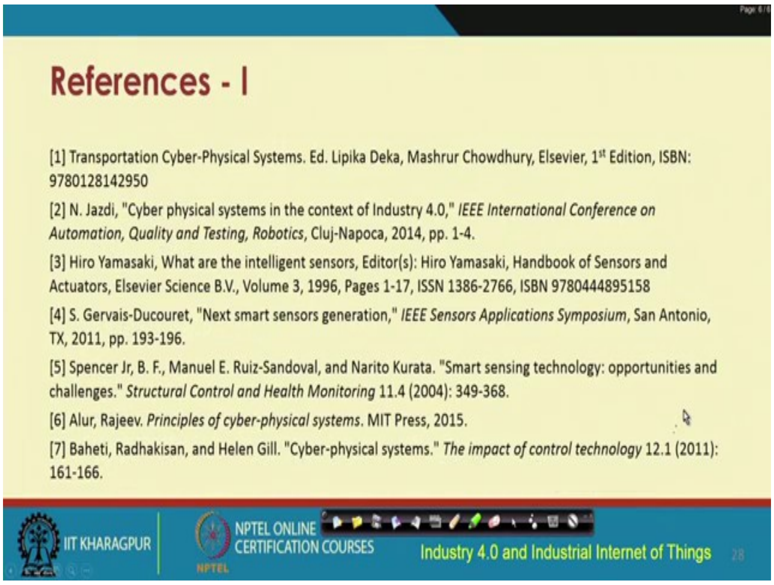

So, with this we come to an end of cyber physical systems and next generation intelligent sensors, discussions on them. So, this brief of brief idea about cyber physical systems and the use of intelligent sensors basically equips you with an understanding of how you can go forward in the years to come, if you have to make your industry compliant with Industry 4.0 expectations, the objectives of Industry 4.0 and so on.

So, cyber physical systems and IIoT are strongly interlinked. So, essentially what we are trying to do is we want to use these cyber physical systems. The abstractions of these cyber physical systems in the form of different objects; objects means we are talking about virtual objects not the physical objects. So, these different physical or virtual instances of the corresponding physical objects in the physical world, these could be networked together and the data would be received at the other end for further processing analysis and so on for making the industry smarter. So, we are gradually leaping forward towards building industrial internet of things and in the industrial internet of things IIoT using CPS, we are going to talk about in further detail later on.

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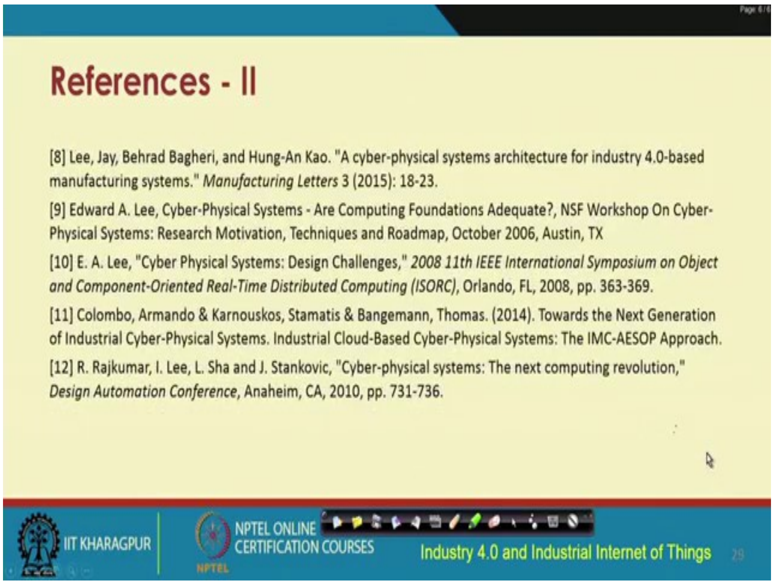

So, these are some of these references and if you are interested you can go through these references in further detail, to know what are the different other issues of the cyber physical systems and how next generation sensors could be developed; if you have to develop these next generation sensors.

So, these are different concepts knowing these concepts is required, but then if you have to develop a cyber physical system yourself or if you have to develop a next generation sensor, an intelligent sensor, that is a complete completely different ballgame. So, you need to be specialized, there are researchers who spend years together to build a sensor and intelligent sensors it will take even more effort to build these intelligent sensors.

So, obviously, that is a completely different ballgame, but here we are just getting an exposure to these different concepts of cps, next generation sensors, and so on which will be required for building Industry 4.0.

Thank you.