**INDIAN INSTITUTE OF TECHNOLOGY
KHARAGPUR**

**NPTEL
ONLINE CERTIFICATION COURSE**

**On Industrial Automation and
Control**

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**Topic Lecture – 04
Architecture of Industrial
Automation Systems
(Contd.)**

So we have some desirable behavioral patterns and we want to achieve those behavioral patterns that we want the, we want the temperature to let us say ramp up in a certain over time then beheld constant. Then after some time ramp down things like that. So obviously we achieve it how do we achieve it, we achieve it by comparing the output with whatever we want and then so to be able to compare.

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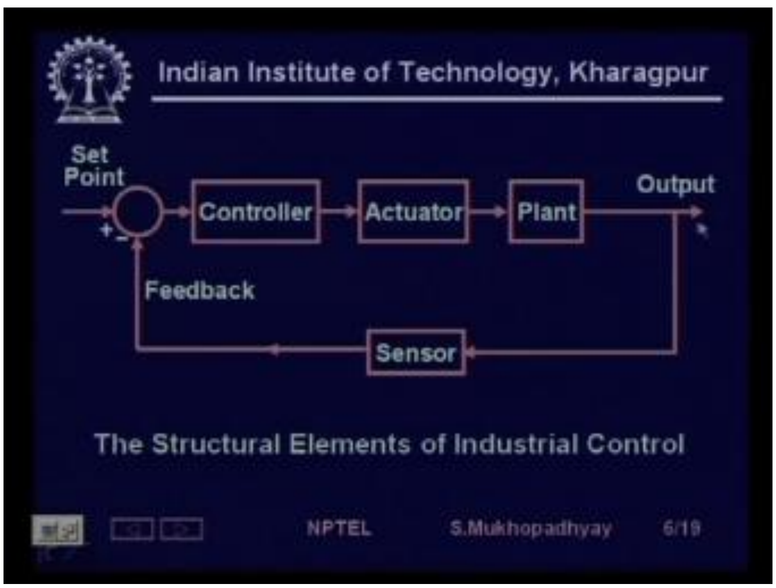

We need to feed the output so that is done by the sensor.

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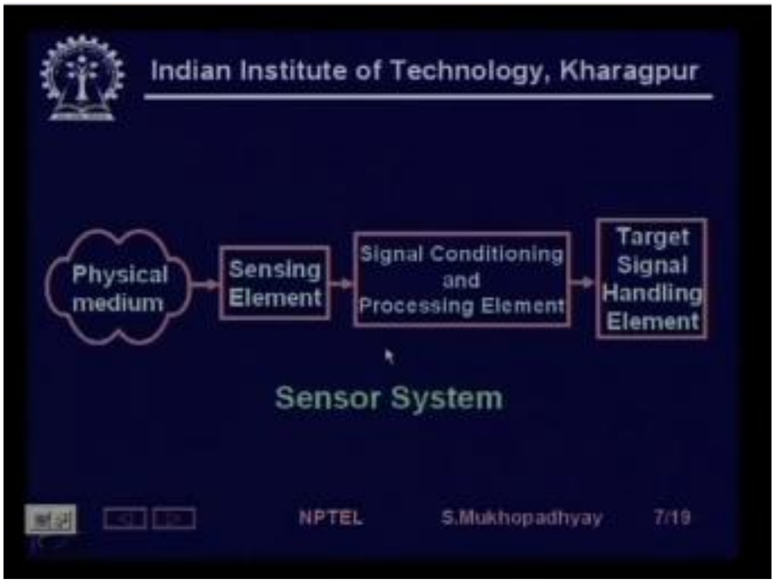

I am sorry this goes back this has to go back yeah.

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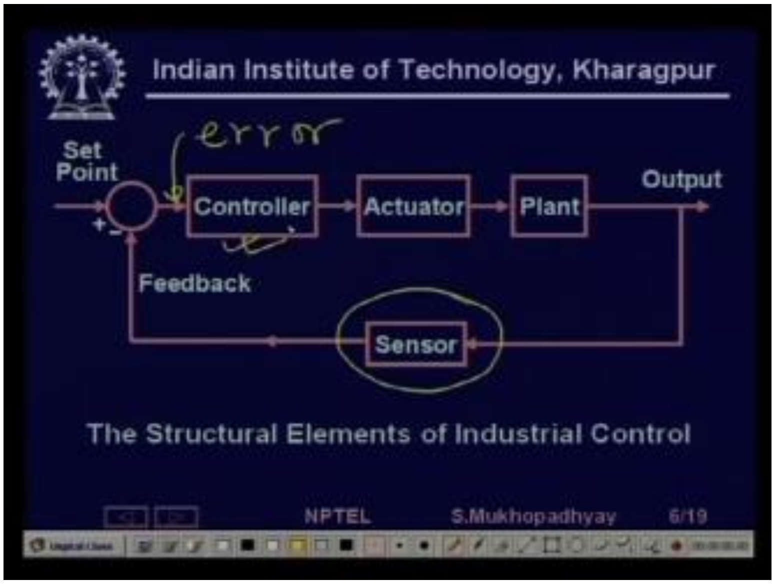

So right, so that you do by the sensor then when you compare you get here, you get what is known as the error. So you give the error to the controller then the controller node knows that what control input to give such that the error is minimized. Now the controller is actually or basically a computing system.

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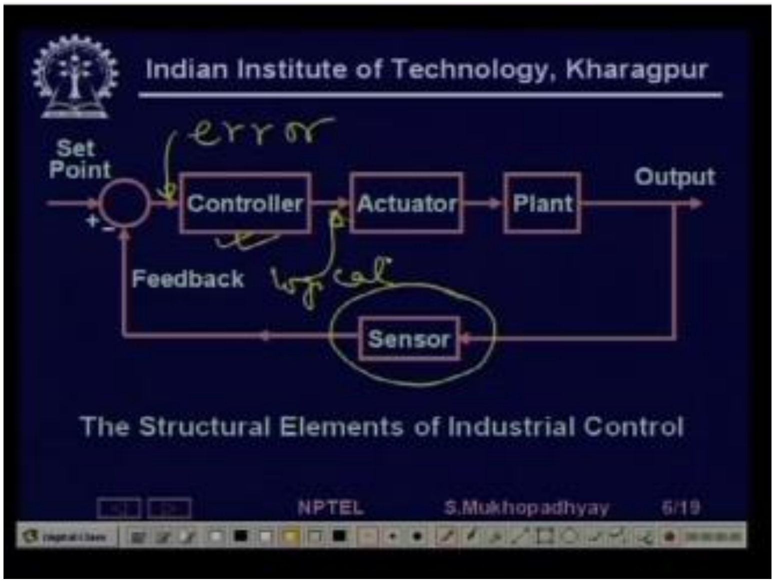

So its input is actually logical it is not physical input. So before giving to the plant in the plant if you want to change some process variable you have to cause steam flow rate change, or you have to cause some motion change, some valve position change etc, etc so some physical change has to occur. So for that you need what is known as an actuator.

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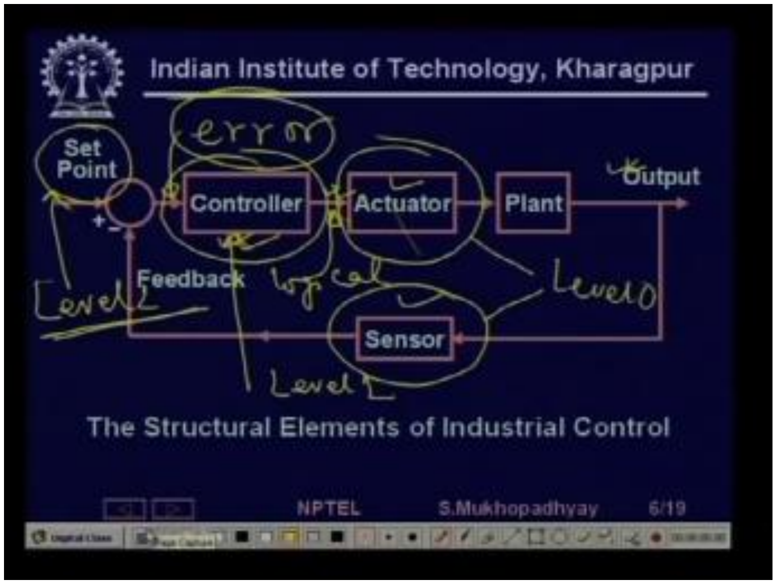

So the job of the actuator is to produce a physical change which is proportional to the logical change which is commanded by the controller. And then hopefully if that physical change occurs then the plant output will change in such a manner that the error will reduce. So this is the job of control.

So now let us see, so we have identified the major element so the elements are sensor, actuator, and controller. Now this desired value what do we get this desired value from, this we get from the level 2 that is the supervisory controller calculates this desired value. So here we have these two we have level zero, here we have level one, and here we have level two. So this is the relationship.

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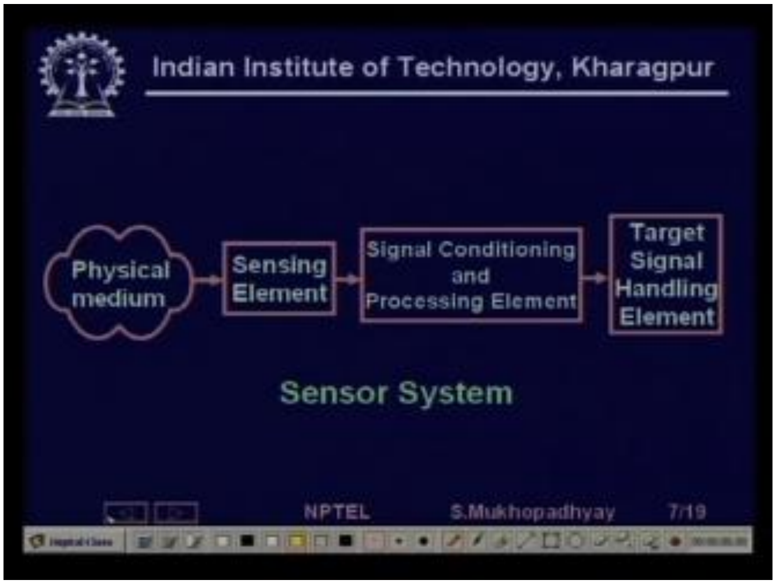

Now let us see each of these levels. So first let us look at a sensor so sensor what is the job the job is to produce an information which accurately represents a physical variable right. So obviously there is some variable conversion required this information is generally first obtained in electrical form and after that it is converted into pure information from using, you know digital electronics.

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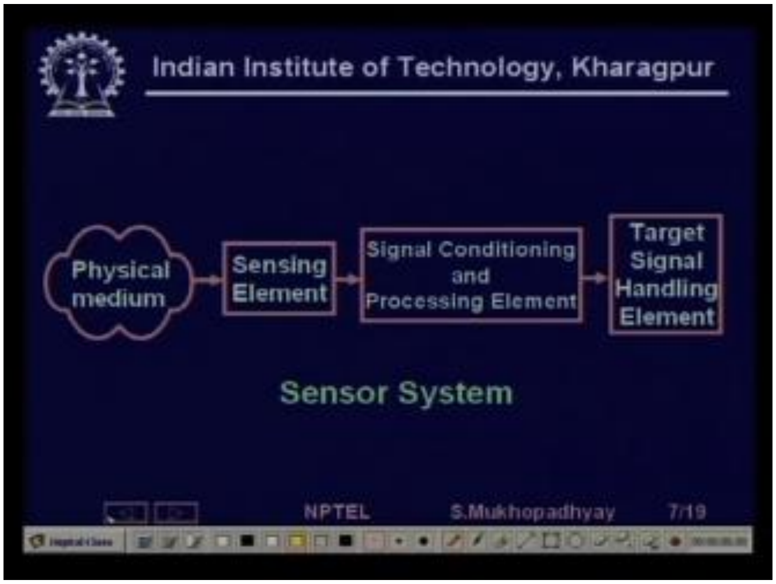

So what is necessary very simple first of all you need something which will convert the physical medium let us say temperature, it will convert into some other form. So that some electrical signal can be generated. So maybe the sensing element will convert this to a resistance change.

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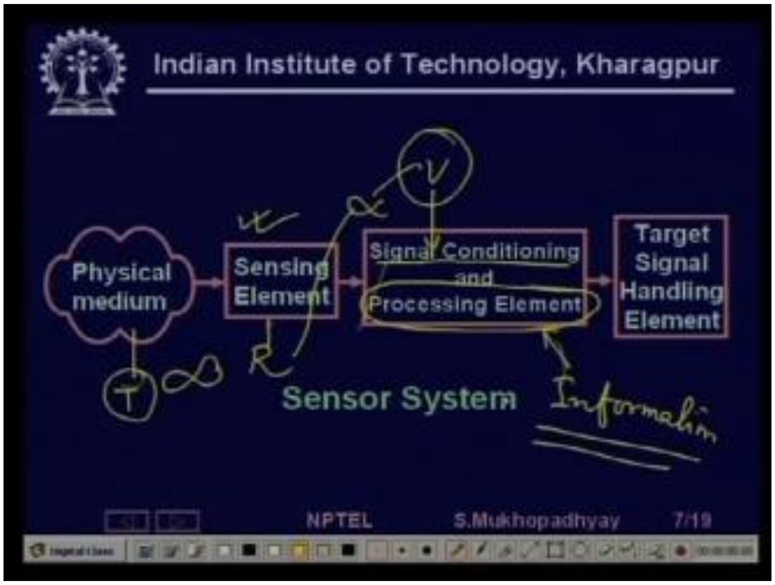

Now this resistance change is still not an electrical signal which can be manipulated so you need signal conditioning, so you put this resistance into some bridge and produce a voltage which is proportional to this resistance. So all these are proportional this is proportional to this, and this is proportional to this. So finally the voltage is proportional to the temperature. Now this voltage may contain various, you know impurities; noise etc, so you do further some signal processing on it.

So that you get more accurate voltages or you increase its strength or do something. Then at this point you have got it in the information form it is no longer a process variable physical, neither electrical it becomes information. So this information now has to be used so used in what sense so you can either display it or you can transmit it to a controller, or you can store it in some database. So finally you have to use this so here you may have a display.

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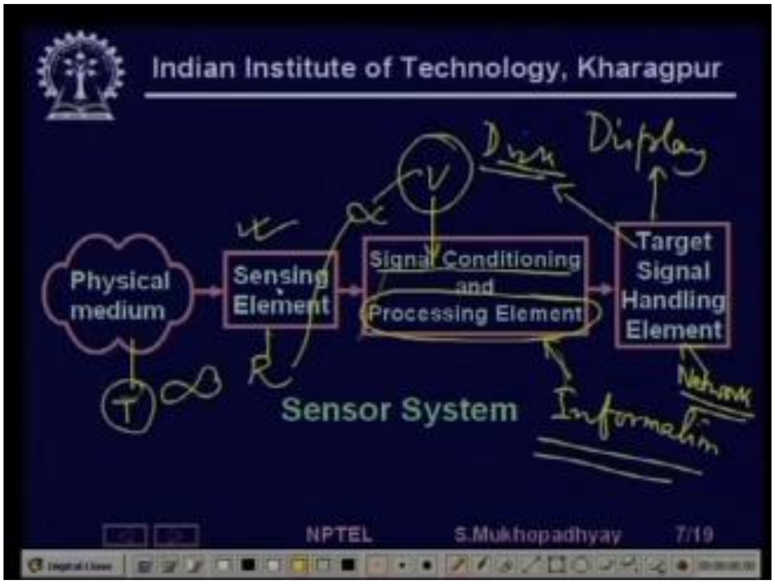

So by target handling element it could be a display or it could be a network card. So it could be a network interface by which that will be transmitted or it could be a disk on which it will be stored. So depending on the usage of the signal you have to deal with it. So basically this is when you say an industrial sensor you will obviously find a sensing element, you will also find some signal conditioning element nowadays because of ruggedness of electronics this signal conditioning is getting transferred into the sensor itself.

You can have some signal processing like filtering and then finally it will be used in a display right.

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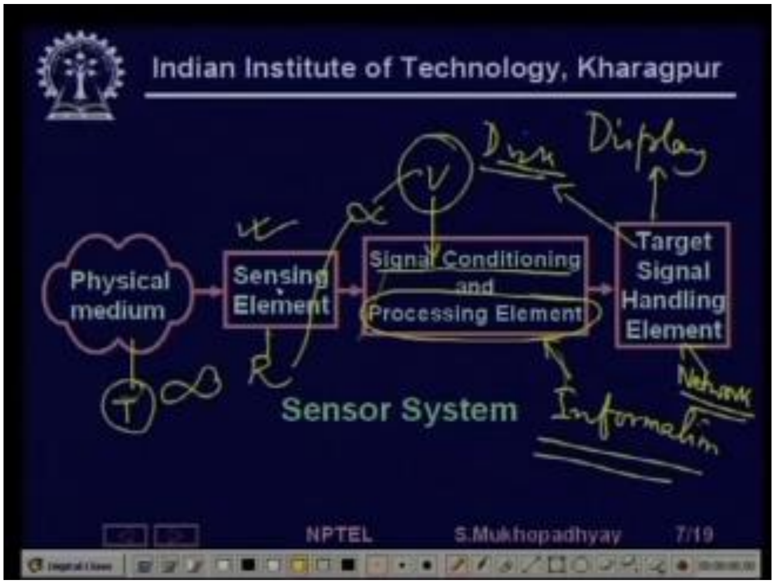

So this is a sensor.

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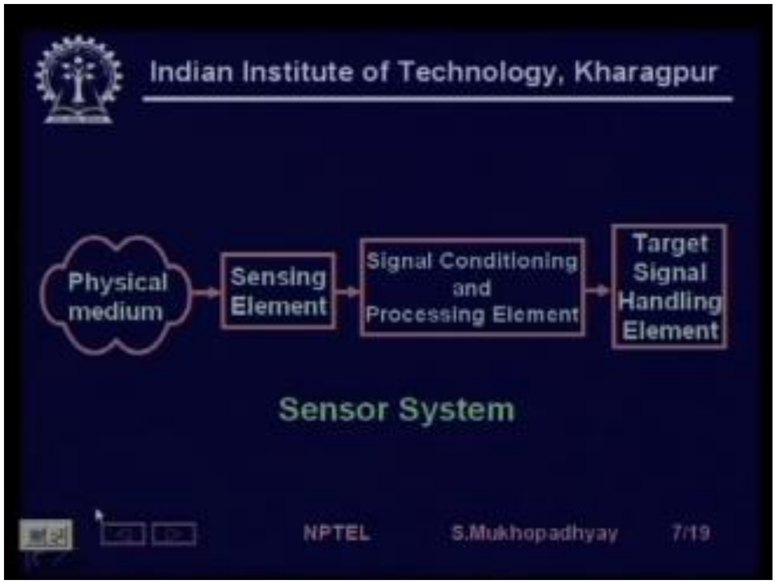

Now let us take a look at.

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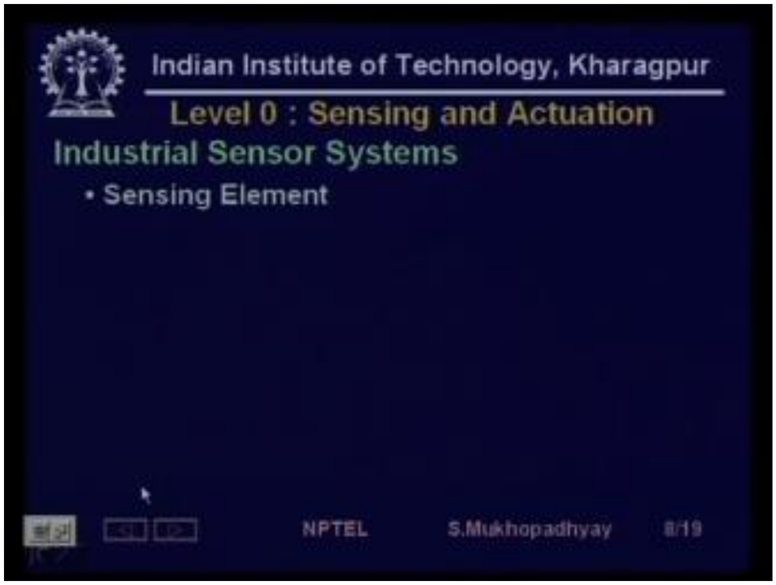

Some characteristics, so obviously you have a sensing element one thing that needs to be mentioned is that industrial sensor is apart from the basic sensing element they also have you know other protective elements like if you have a thermocouple, basically a thermocouple are either as we have seen that they are, as we will be seeing they are actually two pieces of wires. Now when you are trying to measure the temperature industrially you do not put those two pieces of wire directly into the fire.

So what you do is you have what is called a thermo well, so you put the thermocouple those two wires in the thermo well and you put the thermo well in the furnace. So that it does not get destroyed. So when I say a sensing element a sensing element could comes along with its always packaging and this packaging can have some effect on the control performance of the loops, because they have their own dynamics, you know thermo wells have introduced time constants into thermocouples as we will see.

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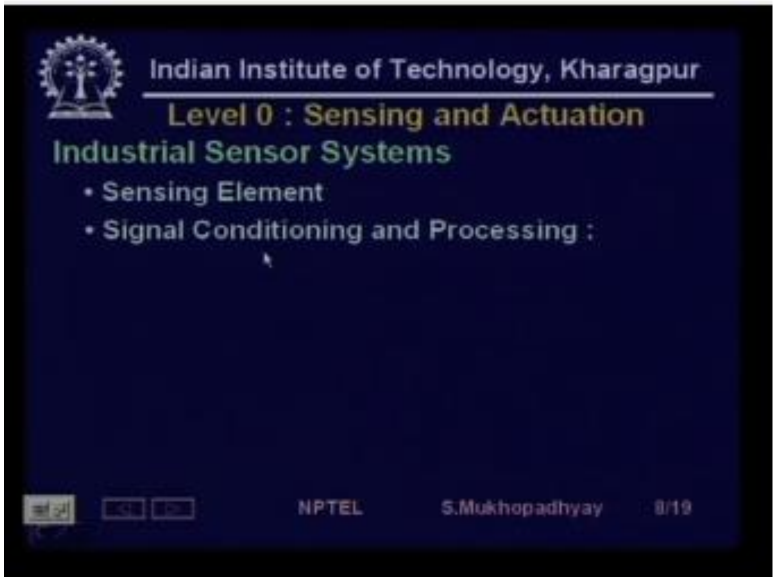

So we have a sensing element now after the sensing element we have signal conditioning and processing. So the job of signal conditioning is to transfer to electrical form and then signal processing is to do further processing for some improvement like, you know making linearization, suppose something that is varying according to square we do we want to make it linearly variable, so we can have a square root operation.

We can have a filter to strip out noise, we can collect bias, we can add bias whatever we want.

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So the in general signal conditioning means that converting to an electrical form generally analog and then signal processing is could be analog it is could be digital also. So you have analog electronic signal conditioning followed by digital processing. Now digital processing could be of various type, digital processing for what, so digital processing could be for signal processing let us say filtering.

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Digital processing could be for diagnostics calibration configuration this is very modern functionality if you have a microprocessor you have a lot of computing power at your hand. So you can do more than just doing filter. So you can for example you can perhaps detect whether the thermocouple wire has broken. So whether the sensor is at all functioning, so that is diagnostics.

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Okay.

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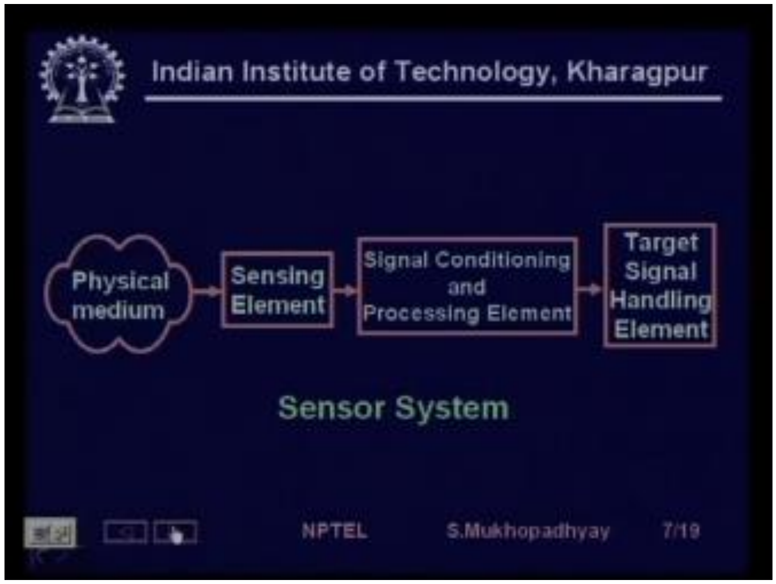

Does it go back.

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Okay, yeah so it does not go back fine. So that is diagnostics sometimes you could have you know sensor characteristics sometimes degrade. For example, suppose the sensor develops a bias you can have algorithms to actually detect the bias and you can do it, its own calibration you can send information that I have never that is the sensor can send an information or sensor can be interrogated and you can find the information that it has developed a bias.

So its readings will be interpreted according for greater accuracy, or it can do its own configuration management, you know people send generic devices which are flexibly configurable. So if it has a filter what will be the time constants of the filter that depends on what signal it is filtering what is the bandwidth of the signal it is filtering. So if it is censoring, if it is filtering a flow sensor its band width will be larger than if it is filtering a temperature signal.

So it may be possible to even automatically set these filters so such things are done by digital processing, plus another major function is communication. So nowadays sensors are all going to be, you know communication enabled so they can be either connect to networks or they will connect to some remote terminal unit so which will connect to network. So there is some, there is digital processing done for this communication function also.

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Followed by finally there is signal protection and transmission that is after finally for everything you need to transmit the signal so you can have a network interface or sometimes you can have a voltage to current converter if you are having 4 to 20 million per transmission then you can have a voltage to current converter, if you are having RA422 kind of transmission then they have specified voltage levels.

So you have to have voltage conversion of that, so a typical what I wanted to show is that if you come across a typical industrial sensor system then what will it contain and what it will contain, what all do they do, so if you should buy a let us say a smart temperature sensor from a company and or if you go through its brochure then you will typically find that these functionalities, some of these functionality will be supported.

So having said that let us look at the next element which is actuators.

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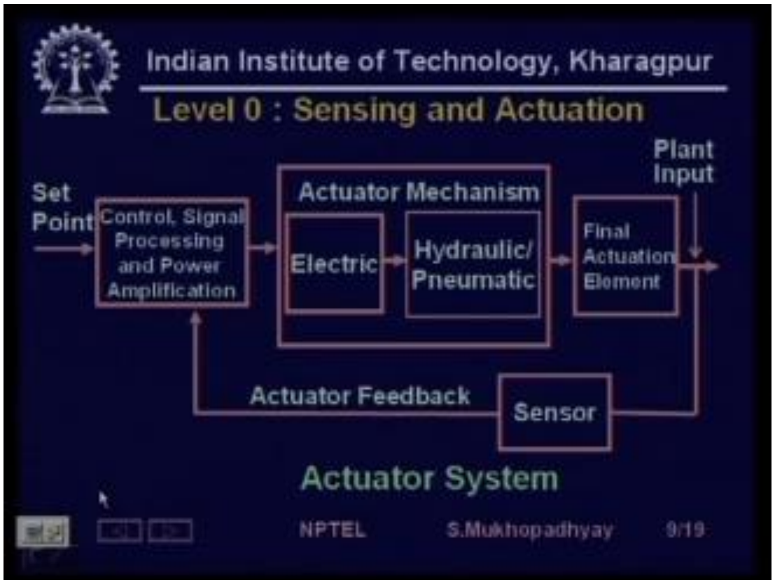

So what do actuators do, actuators as I said that they take the logical input from the controller and then they convert it to a physical plant in that that is what they do. Now obviously what is necessary for this there is variable conversion necessary and generally one thing is very much necessary is that these logical inputs are just logical they do not have power, they have the information.

So you have to do lot of power amplification if you want to increase the temperature in a furnace then just saying that you make giving a signal from a from microprocessor is not going to do it. So you have to take the signal and then you have to, you have to move some big maybe fuel injection valve, then you have to change the speed of the fan which is putting air into the furnace, and you have to increase combustion rate only then temperature will increase right.

So the main, so there are two things done one is variable conversion, second thing is big amount of power amplification is to be done. So that is what is done by the actuator. Now actuators now we have to remember that here we are having a very powerful thing and not only that we want to have precise control because our objectives is to have precise control. So here is a very powerful thing which will have to control precisely.

So for that we always use feedback control. Therefore, actuator themselves actually are feedback control devices they themselves take feedback. For example, if you want to move let us say I mean typical example, I mean non-industrial but typical example is taken aircraft when it is flying, then it has to move its control surface it gets huge amount of aerodynamic load. And these control surface motion must be very, very precise.

So unless you implement this actuator which is the control surface activity in this case, unless this or let us say the speed of a motor, unless you put these in a feedback you can never achieve that precision. So therefore, actuators are typically, the actuators themselves is a control loop.

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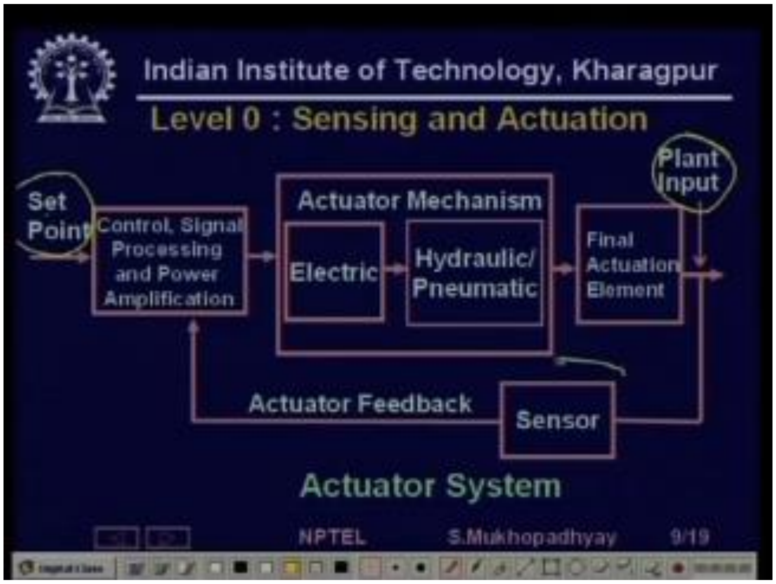

So they have their own sensors, they also have controllers sometimes they have some analog signal processing. For example, sometimes it may happen that you know some the controller may give some control input but in that control input certain frequencies must be eliminated because they cause resonance, they may cause a lot of vibration etc. So in such a case you can do some signal processing that you okay, that input is given but that frequency is filtered out maybe using a notch filter.

So such signal processing may be done and obviously power amplification some amount of electrical power amplification is done. So you use what is known as servo amplifiers. So servo amplifiers will take weak signals and will accurately, exactly, proportionally, multiply them but with lot of power amplification. Now after this, now you have some actually inner actuators so much power amplification is necessary that it is always done in stages. So you have power amplification first one level power amplification which is in the electrical level.

So you take one electrical signal and increase its electrical power but after that you have to, if you want to increase power further often it happens that we go to different forms of energy. So we can have if you have a motor-driven actuator then sometimes it is driven directly from the power amplifier or sometimes it may be driven from it maybe even using hydraulic or pneumatic devices.

You know there are certain advantages especially hydraulics can handle a lot of power in a small volume. So in a small hydraulic motor you can handle a lot of power. So when we have large power devices we use hydraulic and pneumatic.

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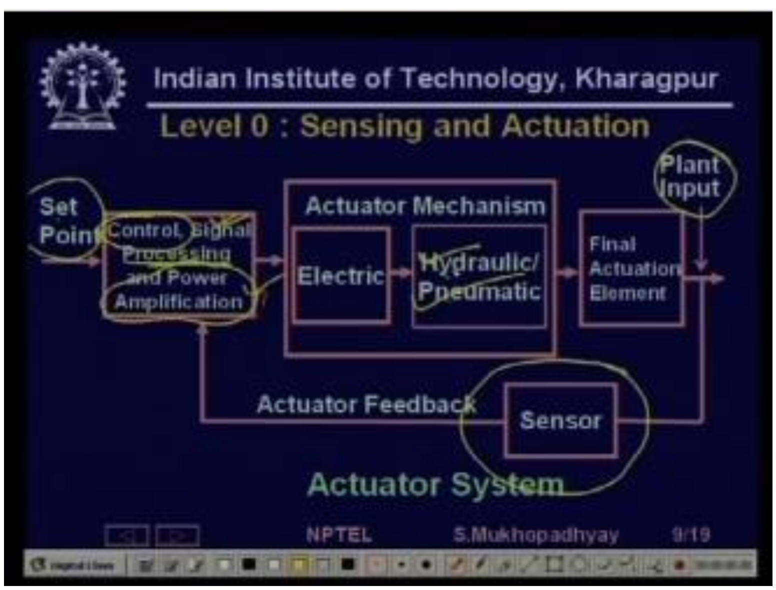

So we, so they are also like amplifier, they are also like power amplifiers only they take an electric signal, so you have electro-hydraulic or you have electro-pneumatic typically actuators. Finally at this point of time you have got, you have generated that necessary process input which you wanted to cause with a lot of power. So that will cause now even that may go through for example if you have a hydraulic element it will finally produce what it will probably be applied to the stem of a valve.

So that tremendous pressure will be created to the stream of the valve which will, so still you have to have the valve because you want to control flow.

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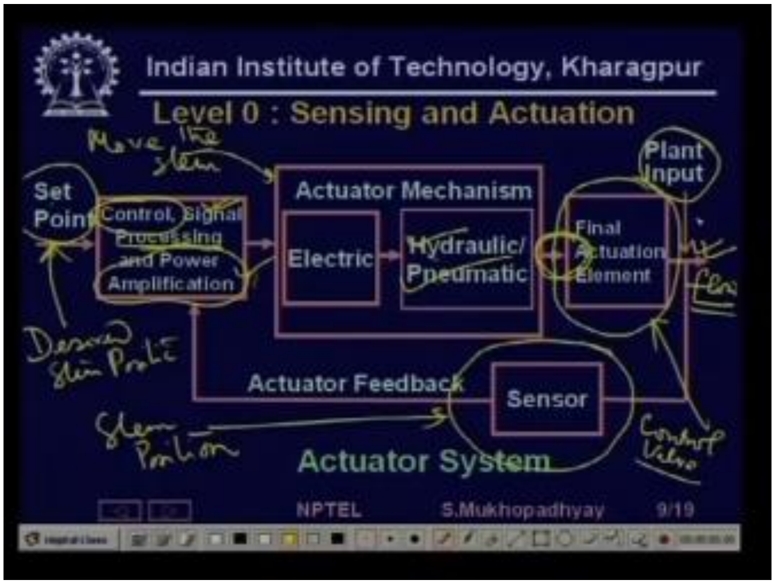

So what you want to control here is flow let us see. So for controlling that you need to move a valve this is the final actual element, so you have a control valve. Now you need to open it or close it now how do you open or close it, so you need to move its stem, so this hydraulic system will actually move the stem, this sensor will send stem position, and this controller will give input such that the here is the desired stem position.

So this controller will give input so this is a total closed loop operated valve actuator which will control flow in the plant, which in turn may control temperature whatever. So having understood this operation let us now look at the actuator.

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What do you find just like we found did for industrial sensor let us see what we are going to do for the actuators.

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So the industrial actuator systems you will find again you will find electronic signal processing, you will find power amplification as we have said, you will find electro hydraulic pneumatic or mechanical elements, you will find feedback control for precision exact value will be reached, you will find lots of auxiliaries because these device have to operated they are generally power devices.

So they need additional auxiliary systems for lubrication, cooling, filtering, etc, you will have, you may have subsystem which are used for remote operation some of these actuators are need not be operated just from clothes they may be operated from a distance right. So regularly done in power systems when you have in unmanned substations so we have, so how do you close a switcher or opera switch you just from some remote control station you give a signal and the switch, and the circuit breaker opens or closes.

So the circuit breaker is actuated. Similarly for safety you will find lots of you know various kinds of really pressure release valves, or various kinds of interlocks, because these are you know powerful devices so if the malfunction they may cause accidents. So special systems are used.

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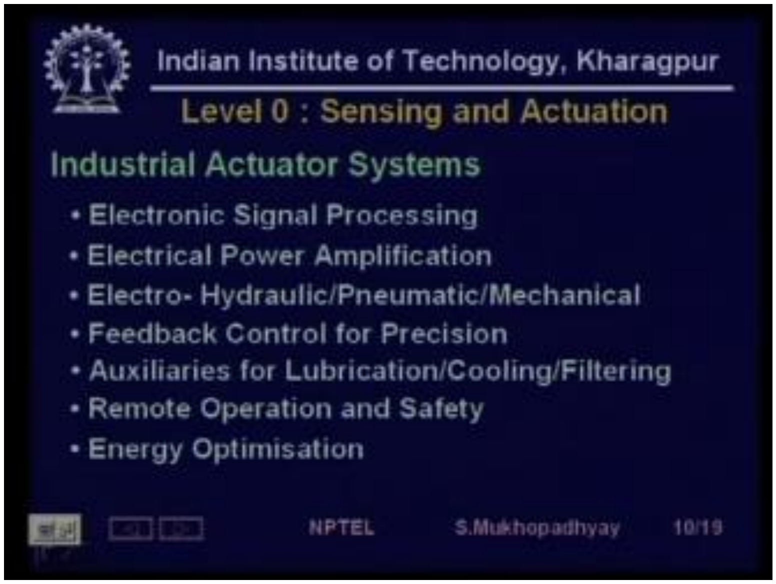

Similarly since they consume some amount of energy you will find special systems which will try to save energy in the actuator itself, you know so some freewheeling or some switching of an unnecessary energy devices you may find technologies for this.

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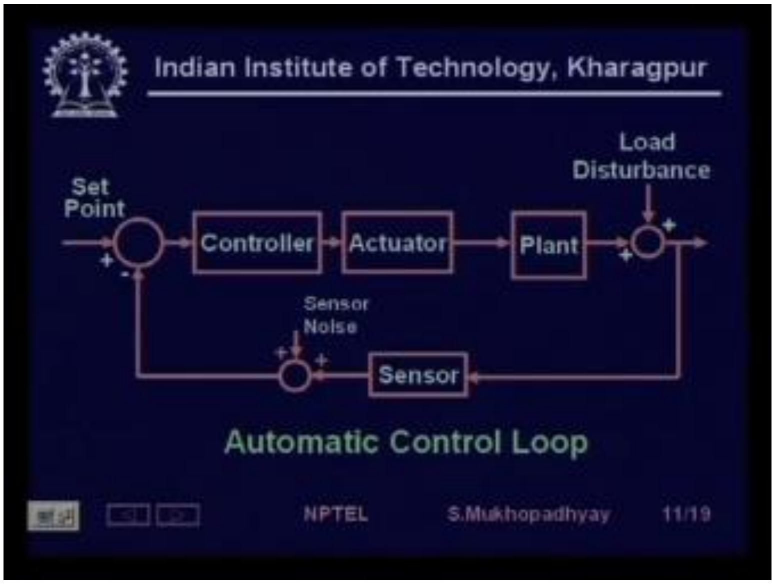

So typically this is what you will find in an industrial actuator and within in the future classes we look at various kinds of industrial actuators in detail. So now we have covered sensors and actuators in level 0, now we come to level one which is an automatic control loop we have already seen the automatic control loop, we at that time we have seen the structural elements of the loop.

Now what are we saying now we will concentrate on what the loop is going to do, what is the job of the loop.

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As I said before the job of the loop this has changed let me go back yep.

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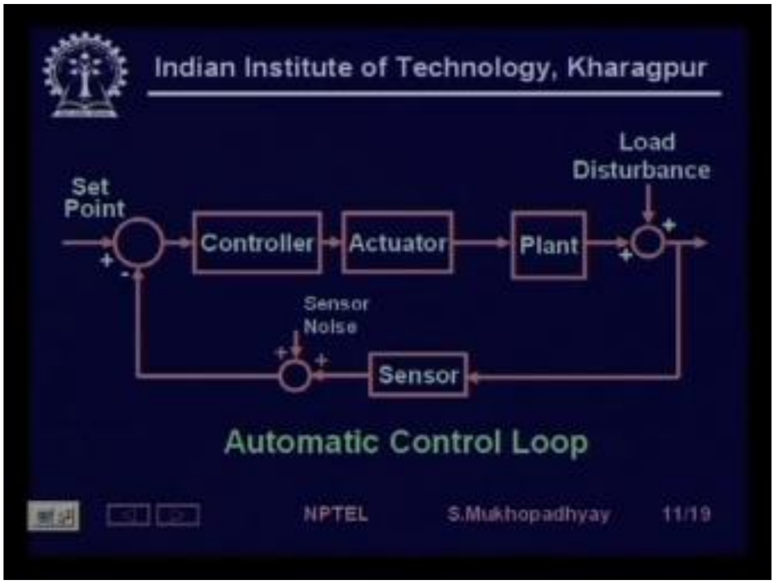

Let me lock this so the job of the controller is to maintain the set point that is its job which is given comes from the supervisory control. So why should the set point change, why is it once I set it carefully why should it change, it changes because of disturbance. For example, suppose you are cutting metal, now the metal is in homogeneous this is the metal which are cutting there is a piece of, there is a steal not homogeneous.

You have set a particular cutting speed depth of cut feed, you have set and the machine is rotating. Now suppose the there is some parts come where the material density is different then the speed will fall, speed may fall. So and its speed falls in metal cutting the quality of cutting suffers and you have no control over what kind of material qualities will be supplied to you in the raw material.

So or for example suppose you have a rolling mill, so your rolling mill be load on the shaft is depends on two things, depends on the material that you are rolling, and depends on its temperature. In fact that I mean we are talking about hot rolling. So as you are varying is so if the temperature varies the load on the motor will vary enormously and therefore the speed will vary. Now you do not want to allow that.

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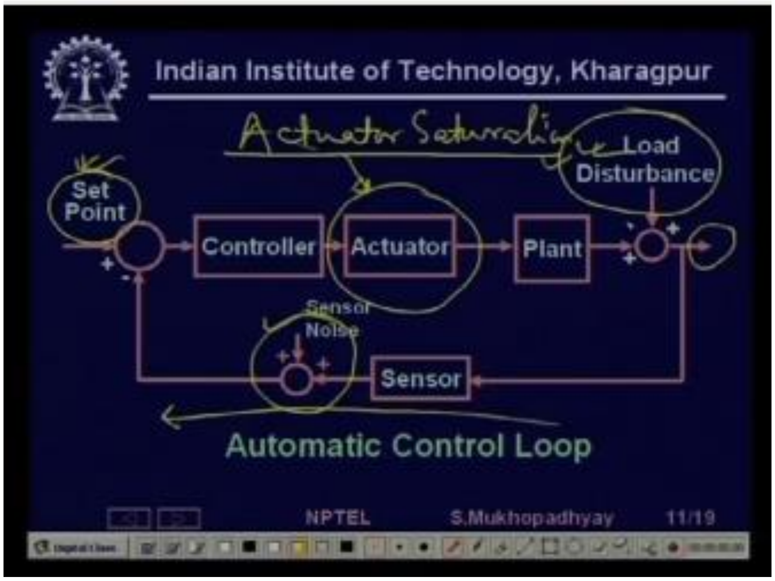

So what I am trying to say is that because of these load disturbances if you set a particular speed that may not be obtained. So to ensure that you have an, you have feedback control right plus there may be a sensor noise also there is feedback may be erroneous. So it is basically because of these two that the control problem becomes non-trivial plus many other things may happen. For example, one of the things that is very regularly happens is that the actuator saturation.

This is a very regular thing in actuators saturation, that is the actuator cannot really drive enough input into the plant as the controller wants, actually the controller makes unreasonable demands on the actuator, the actuator cannot give. So it is because of these things that the control problem is not elementary and you have various kinds of difficulties.

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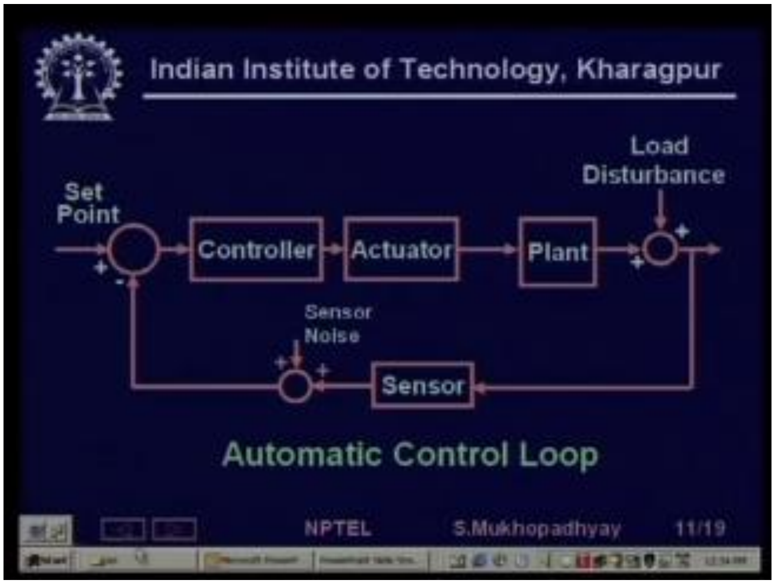

So we will look at now, we will look at the having said this let us look at the various kinds of things that you find in an industrial controller oh, sorry.

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So when, so let us look at automatic control, automatic control again I must mention this, this I have not mentioned can be of two types the first type is what I call continuous variable control that is what we are familiar with you have already, most of us have taken a course in that called automatic control system, or control systems, or control engineering. So there we study mainly continuous variable control where we are interested in controlling the value of a variable, let that, let the temperature be 200˚C that kind of control where the temperature is a continuous variable in the sense that it can continuously value over time. It can take any value.

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So this control we control analog continuous process variables that is fine and typically we apply what is, what we understand by closed-loop control which you have seen. So the main objective is to track or hold set points that is the output should follow the set point if the set point changes it should track it, if the set point is constant it should hold it, irrespective of disturbances it should reject disturbances, both in the sensor as well as load disturbances, as well as in the actuator.

Now for this purpose we, it is said it is that more than about 80-85% of all industrial controllers are a particular class of controllers called PID controller so they are generally this control algorithms used as a generic. Though in some cases you may use some special purpose controllers.

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Now because they are generic they have to be tuned for a specific plant, so you have to set controller gains for that specific plans and that is called tuning, so these controllers are tunable and they require tuning from time to time. And they are implemented typically on digital real-time systems like basically a processor system with an interface, with the sensors and with an interface to the actuators.

So it is a kind of microprocessor based system, and these are generally very inexpensive, typically a control system is less than 5%five cost of the plant it controls. So the controller is actually very cheap although it does a very critical job. So now, so this is what you find in automatic control.

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Now let us automatic continuous variable control. Similarly you have sequence or discrete event control. Now in discrete event control what you have is that you have control of discrete valued process variables that is variables which cannot take continuous values, but either they take discrete values like, you know on and off or low, medium, high. So you have to control so now if we value that all constant values so there is not much point in trying to control the value.

So what do you control so you try to control the sequence, so what happens after what or you control timing that is when exactly will this valve closed that is five minutes after the valve opens you should switch on the pump. And similarly, two minutes after the pump is switched off you should switch off the valve, so such things such control is called discrete event control. So obviously they use sensors which are also discreet that is they like you know limit switches just sense whether something is in this position or that position, pressure switch sensors whether the pressure is high or low, photo switch sensors whether a part is placed on the conveyor belt or not.

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So you use this kind of sensors, you have lot of you know interlock or alarms so you do interlock and alarm processing in this typical hardware, which is used for discrete event controllers are programmable logic controller, sometimes industrial PCS, and sometimes could be very special purpose dedicated processors right. So they obviously do not need tuning and they are, so you have started sequencing and timing control, so one good thing about them is that unless the control logic changes they do not need tuning.

So this is the story of automatic control now we will one last thing that we will consider here is supervisory control and we will stop here today, because production control and enterprise control or functions which can be, which we are not going to cover in great detail in this course. So we will introduce them later if we have, when we have one or two introductory courses, introductory lectures lessons in this course.

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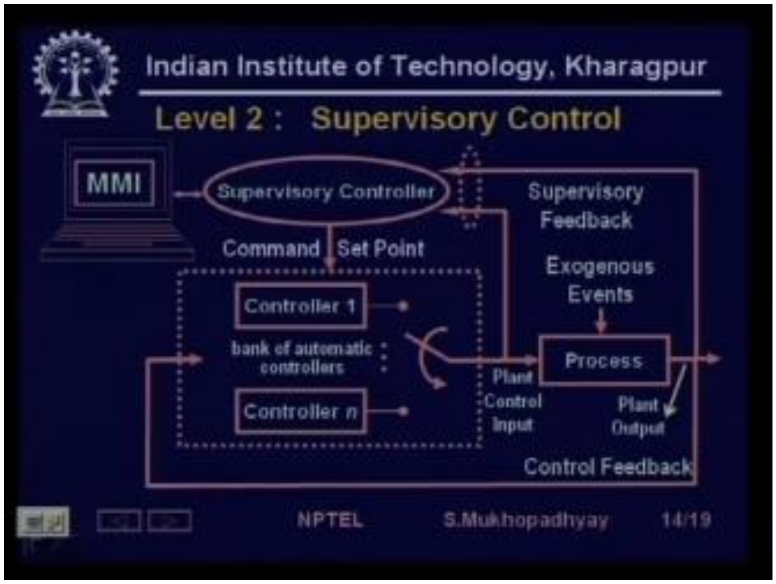

So let us look at these pictures, this picture explains what a supervisory controller does. So previously we had seen one control loop, now I find this is the process that we want to control. So this is the process, this is the feedback of the control loop but we are having a number of controller here. So suppose one controller is working so as we have said that what does the supervisory controller do, it gives command, it gives set point that is the automatic controller just maintains a temperature.

It does not know what temperature to maintain if it is told that you maintain 200˚C it will do its best to maintain 200˚, but whether to maintain 200˚ or to maintain 115˚ that the automatic controller does not know, that information must come from the supervisory controller. So it is give set point, but it does another very important thing that is it is not always that we are going to use the same controller for example the controller that you may be using during the time that the plant is started up from there is a cold condition or when a plant is shut down they actually totally different control laws. So you may have more than one control law.

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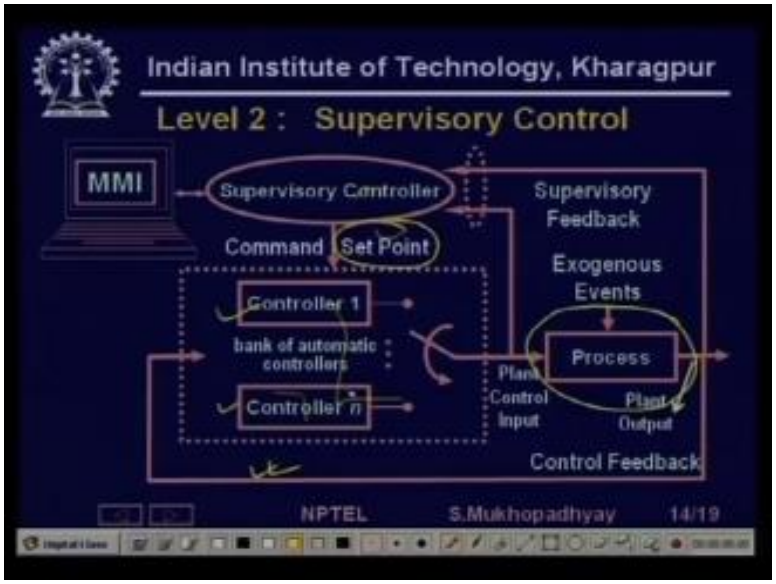

So if you are doing startup you use this controller, if you are doing shut down you use another controller, if when you are doing normal operation you do, you use another controller. So you must give commands as to which controller to use when, so that command comes from the supervisory controller. So it gives various kinds of commands for example suppose there is some accident, or there is some there is some malfunction in the equipment immediately you have to do emergency shutdown.

So the supervisory controller must understand that there is a malfunction, how does it understand because it also gets the process inputs and outputs. So based on this process inputs and output it does lot of calculation to always check whether the system is working nicely. If it find some problem immediately it will give various commands to ensure which controller to use when. So a supervisory control actually manages a number of automatic controllers right.

So having said that let us see it is basic how I see, so what are the features of supervisory control. I am sorry, what is this happening here.

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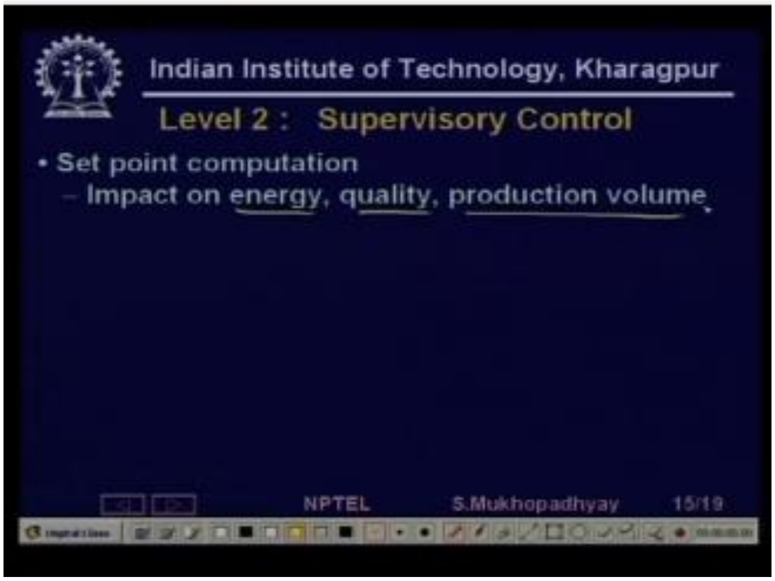

Oh! So first point is set point computation one very important thing is that set point computation is very important in manufacturing from the point of view of energy quality and production volume, unless you give proper set points you will not get product of certain quality, you may be wasting lot of energy in producing it, and the amount of production will also fall. So that is why supervisory control is so critical and it is sometimes and it is often done by very experienced operators manually. So it is very critical for manufacturing.

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So it does start up shut down and various kinds of emergency operations, it does control reconfiguration and tuning you may have to change the controller from time to time, it does performance monitoring, is the loop properly tuned, is there a sensor malfunction, it continuously checks, it provides an operator interface, it provides with nice graphs to the operator who also sees. They are generally based on obviously all this can be done based specific to an equipment it cannot be done otherwise.

So and they work as I said in hard, soft hard and soft real-time scenario. So having said that we will, they are also very expensive because they are specific to a process.

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We will speak, we will skip this slide all together because we do not want to, so we are just looking at the various elements in this thing like product process scheduling, material handling, maintenance management, inventory management, quality management, and resource optimization technology. They are as I have mentioned that they may be online but they are non real-time, some of them may be online.

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So finally we have a lesson review, so what we have done in this lecture we have looked at the hierarchical structure of industrial automation, we have looked at level 0 the sensors and actuators what they do and what technologies are found in them, we have looked at level 1 automatic control, we have also looked at continuous variable and discrete event control and distinguish them, we have looked at supervisory control and we have understood how they are different from automatic control.

And finally we just look a cursory look at production control, enterprise control we are not going to even to have a look at not going to have a cursory look at where this is essentially a business management operation.

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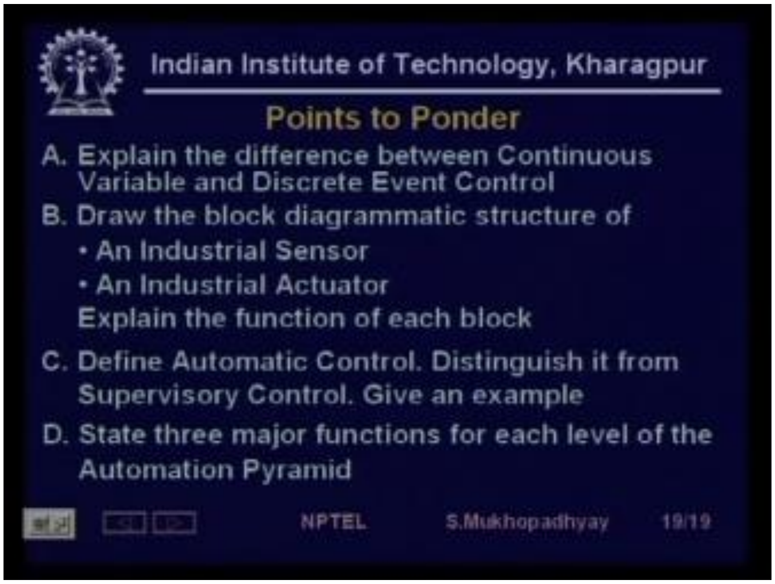

So here we have some problems points to ponder for example, can you explain the differences between continuous variable and discrete event control, can you cite two or three differences, can you draw the block diagrammatic structure of an industrial sensor and give an example. Let us say you locate some industrial sensor and then try to identify that what are the various block diagrams, and what are the various subsystems in it, what are their functions. Can you define automatic control and distinguish it from supervisory control with an example, and finally you can you state three major functions for each level of the automation pyramid. So these are problems for you to ponder on and thank you very much.