Control Engineering
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Lecture - 02

There are a few more examples of control system situations or control systems that one may find inside one's house, may be by this time, you have thought of some of them, which I had not mentioned earlier take the case of the electric iron, if in your house, you press your clothes yourself then you may have used one.

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Nowadays one uses what are called automatic electric irons. So, as you know you not only to turn the electric iron on but you also set it depending on the nature of the cloth or material that you are ironing whether, it is wool or silk or most likely cotton or some mixed fiber and things like that you set the electric iron accordingly and start your ironing. So, it is an example of an automatic control system where, you set something at some desired value or level just as the air conditioner, temperature is something that you set and you hope, that the temperature will remain at that value.

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Another household example is, a washing machine. Once again, in the case of a washing machine besides just turning it on or off, you have a number of choices that you can make depending on the amount of load or the total weight of clothes that you want to put in may be, the again, the type of the clothes, the kind of detergent that you want to use. So, you set various things like perhaps the number of minutes that you would like the clothes to soak and then rinse

and spin and what not? So, there are quite a few selections to be made on the top panel of the washing machine before you put in the clothes and turn the machine on for washing and most of the washing machines today are automatic, there is a timer also. As I mentioned earlier, the soaking will be done for a number of minutes which are preset and at the end of the whole thing the machine will switch itself off or beep or go back to the standby position.

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So, that is another example of an automatic control system which has settings and then operates on its own, outdoors there is one control system with I did not mention earlier. But as you travel on the road and if you use a vehicle then you know which city that is a control system that you will come across fairly, frequently and that is the traffic control system or the traffic control signals at various intersections in the city. It is a control system, it controls the traffic, of course

and it is a control system which can be set the amount of time for which traffic in a particular direction will be allowed to go with a green signal then, changing to amber or yellow and then finally to red, the amount of time for which the flow will be stopped and then, of course there are turns allowed and so and so forth and the whole thing goes through a cycle, after a cycle of may be 2 minutes or 5 minutes the signals go back to the original condition.

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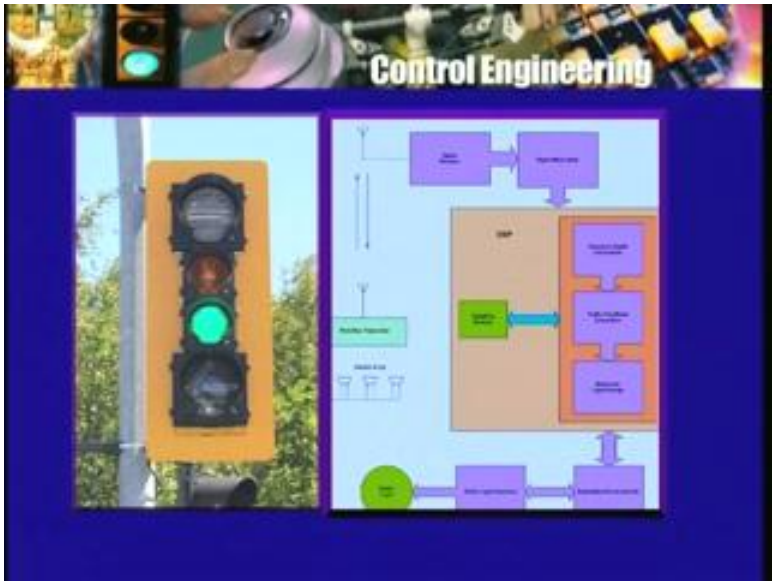

So, here again there are settings to be done and then you let the system go. One can of course, think of many more control systems of an industrial type and we will look at few of them a little later. I have mentioned earlier, some distinctions between the various control systems that we have looked at so far or we talked about discrete level versus continuous level control systems, discrete time versus continuous time control systems and then of course, depending on the physical variable that is being controlled such as temperature or speed or pressure. You can talk about the temperature control system, a pressure control system, a speed control system and so on. But there is one more difference or distinction that one can notice between the various control system examples, that we have looked at and this the distinction is an important one although strictly speaking. It is not that important as we will see perhaps, you have heard the word before in some other context.

This is the word, feedback originally perhaps cut of as two separate words joined together feedback and so one talks about or hears about feedback control systems. In common life, one may come across, what are called feedback forms or feedback sheets. After some program is over or lectures perhaps is over or a seminar is over or of course, you have passed on some sheets or forms in which you fill up your reactions, these are referred to as feedback sheet.

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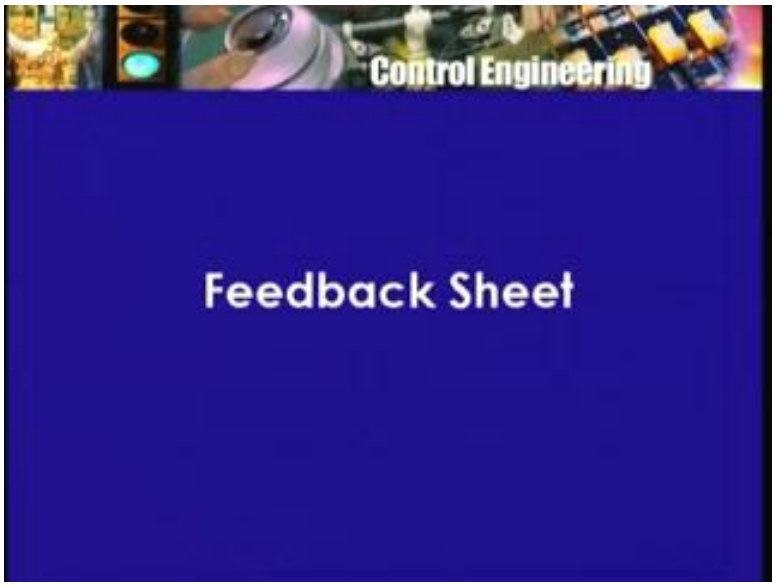

So one has feedback control systems. Now what are these feedback control systems are what is this feedback? Are there systems which do not use feedback at all? We look at the examples that we have already talked about and we will see that you know almost all the cases some kind of feedback or the other is used. In other words, you will hardly ever find a control system in actual use where there is no feedback of any kind whatsoever, there are systems in which of course,

most of the activity control action is pre timed or pre-determined or another word that is used is pre-programmed, take the case of the traffic signal control system.

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As I said earlier, as you know usually there is a cycle of the signals going green and red and its pick, the traffic police people will come in the morning and perhaps start the thing and then they will shut it off, may be late in the evening and during this time, the system will just keep on going, it is all pre timed, pre-determined or pre-programmed. Let us say one lane is green for 1 minute then, goes through amber for 10 seconds and then, remains red for may be 3 minutes and things like that and similarly, for the other lanes.

Now, as against that you can compare, let us say an electric iron or a air cooler where, you set the temperature at a particular level and then you expect that the temperature will remain at that level, if I looks into what is going on then it is not the case that like the traffic signal system, the electric iron its turned on for. Let us say, 1 minute and then, it is turned off for 3 minutes. So that you get some temperature or the room air conditioner is turned on for some time and then automatically turned off for another interval of time and these goes on like this. Such an action is possible, one can design a system which behaves like this that is which is simply an on, off kind of system either, the heater or the cooler. As the case may be or some other variable which can be increased or decreased and so on. The average you get some desired value, the net effect of the electric iron, we know on for some time and off for some time is to produce some average temperature. Similarl,y with the air conditioner and so on.

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But, usually this is not desirable because when the electric iron is turned on, it will produce heat and therefore, the temperature will go on increasing and when it it is switched off, it will loose heat and therefore, the temperature will go on decreasing whereas, what you wanted perhaps is to have temperature as nearly constant as possible.

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Similarly, in the case of the air conditioner, if you turn it on, if you cool down the room, if you turn it off because of outside heat or people present producing their own body heat, the temperature will go up and again this may not be desirable. So, what is happening then it is not just on, off, in fact you just turn it on and then hope that the temperature remains or you turn it off. When you are finished with it, what is happening is that while the system is in operation something is taking place which of course, the designer of the system knows and as students of control systems. You will come to know and you have to know it.

Let us say, we are looking at the room temperature control problem. So, we want the room temperature to remain constant at some specified value. Let us say, 27 degrees Celsius and I am assuming that the ambient temperature, the temperature outside will be higher than 27 degree Celsius. So, that it is really more hot outside and you want it to be cool inside the room. So you remove heat from the room by circulating cool air or cold air in the room.

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If the outside temperature ambient temperature were to go down below 27 degrees Celsius. Let us set to, set temperature and you wanted the room temperature to be 27 degree Celsius then obviously, you have to produce some heating. If outside, it becomes very cold and you want to be comfortable here, then you have to heat the room and so it is not enough to provide for cool air, but you will have to have hot air also which can be circulated and that makes the thing little more complicated. You want not only an air cooler but also a air heater, the two, both of them operating as the need may be.

So, let us look at only the situation when the ambient temperature is higher than the desired temperature. So, let us say you turn the cooler on, so in the beginning of course, for the first 2minutes or it may be 10 minute also the temperature in the room will not reach the desired value, the temperature will of course, start falling from the value it may have been higher to start with but because of the cool air that is circulating. The temperature in the room will start going down. Now, if you kept on circulating that cool air and the temperature, the cool air usually will be less than 27 degrees Celsius, may be by significant amount the temperature in the room will go down below 27 degrees Celsius.

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Now, if you wanted on, off control then somebody will have to switch off the air cooler but otherwise, the temperature will keep dropping. Now, of course in a practical air conditioner, the switching of thing can occur and in fact many air conditioners are really of the on, off type. If you sit close to the air conditioner, you can hear some kind of a click or if you that brings us is an household example, namely a refrigerator in the house where, again there is a similar temperature setting and temperature control problem and in the case of a refrigerator, again one can hear some kind of a click. The compressor motor which was running for some time, after some time it comes to a stop and then it starts again, you can hear the noise.

Of course, now days the air conditioners or in the refrigerator are supposed to be more silent then what they were years ago. But, still one may hear some kind of a sound or if there are some lights on one may see a sudden dip in the light, when the compressor turns on.

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So there is an on, off action there, in fact so also in the electric iron there is an on, off action but this on, off action is not initiated by you by human being, it is automatic and so, how is it obtained inside the air conditioner or inside the refrigerator. There is a device which is called a thermostat, thermostat because of the two words, thermo which comes from thermo, which

means heat and stat or static that means keeping a some kind of a steadiness, steadiness in this case of the temperature.

So, the thermostat is a device which responds to the room temperature and of course, there is an adjustment for it, some kind of a pressure or lever or position of the thermostat which one has to set. As a result of which, when the temperature falls just below the desired value, the desired value is 27 degrees Celsius. Let us say, the temperature has become 26.9 degrees Celsius or 26.8 degrees Celsius. The thermostat mechanism may be there is a bimetallic strip in very simple kind of thermostat but, there are more sophisticated devices available which sort of response to temperature or temperature changes.

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So, because of the temperature going down below a set value or in other words going to another level like say 26.9 degrees Celsius, the bimetallic strip will bend a little more and that is enough to open a switch with the result that the air cooling is stopped or the circulation of the cool air may stop. Now, of course outside the temperature is greater than 27 degrees Celsius and involve even otherwise, say more people come into the room. So, they produce heat as a result of which the temperature will not remain at that value 26.9 degrees Celsius but will start rising.

Now, when the temperature rises beyond 27 degrees Celsius by some amount may be 27, it becomes 27.1 degrees Celsius. The thermostat will come into operation again and earlier it switch off the cooling. Now, it will switch on the cooling, so if as if there is somebody sitting inside the thermostat and who is reading the room temperature and is comparing it with the desired value. The desired value in this case, theoretical case was say 27 degrees Celsius whereas

the actual temperature let us say, went down to 26.9 degree Celsius. As a result of it the cooling was switched on. So it is as if somebody was looking at the actual room temperature which fell below 26.9 degrees, as a result of the cooling and the cooling should be stopped now and so it decides to switch off the cooling.

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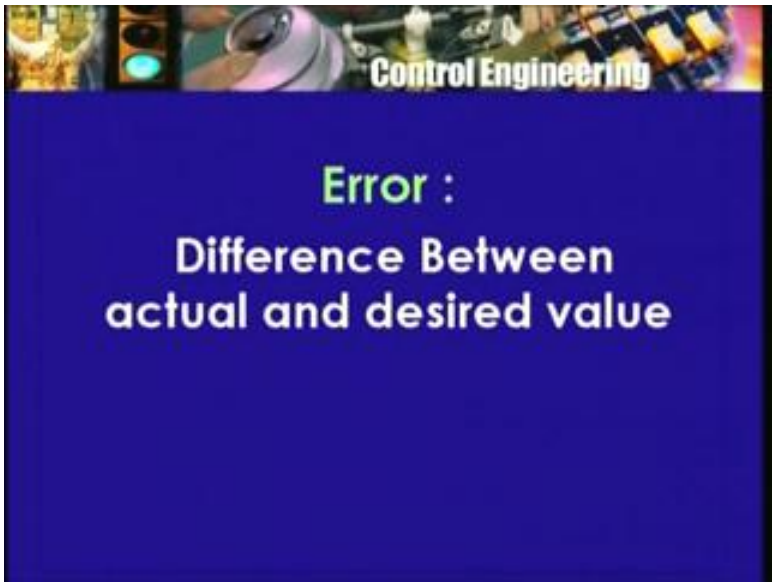

So, this is referred to in control system theory as error. Basically, it is not an error it splits in the sense of the term because in many cases this kind of error is unavoidable. The system, if it is of a certain kind will operate with an error, so it is not really an error in the sense of a mistake. So it is essentially a difference, a difference between an actual value and a desired value. The desired value of the temperature was 27 degrees Celsius, the room cooling had started but the cooling went a little too far. So, the actual temperature became came down to 26.9 degrees Celsius producing a difference of .1 degrees Celsius and this difference the way the thermo-stat arrangement was made was enough to say make the bimetallic strip bend just a little more.

So that some contact is open and the cooling is stopped. So the error of the difference between the actual and the desired value results in some change in the control action, the cooling is stopped then very likely the temperature will start rising and it will cross 27 degrees Celsius and may have to be a little higher. As I said may be 27.1 degrees Celsius. Before this difference .1 degree is once again, but in the direction is sensed or noticed by the thermostat resulting in the reverse action namely the cooling is turned on.

Now, this part of the action namely finding of what is the actual temperature in the room and then as it were comparing it with the desired temperature is called feedback. We say that the

system of the arrangement uses feedback in this case, the room temperature is sensed in some way and provides the feedback for the control system to operate as an on, off control system. Now, there are we look at to many other examples, in more detail as we go on this is perhaps one of the simplest of the feedback control systems that is the feedback feature is coupled with an on, off feature. So, the control action is on, off and you achieve, what you want to do by alternately switching on and switching off a fixed control action. As I said, these are the simplest there are more sophisticated control systems but in such a system as we saw just now, the temperature is not going to remain at 27 degrees Celsius all the time. In fact, it will not be at the desired value except, if the circumstances are absolutely favorable to is for example, the outside temperature remains constant the inside heat generation remains constant and so on.

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So, the amount of heat produced is exactly balanced by the amount of heat removed. So the room temperature remains constant just on its own with the action of the cooling of course. It allows or it unfortunately allows a temperature variation, the temperature may not be guaranteed to remain at the desired value but it could go down by some amount. In our case, it could go down to 26.9 degrees Celsius or it could go up by some amount in our case, let us say 27.1 degrees Celsius and so you can only guarantee that the temperature will be the system is working properly, will be between these two limits.

So, there is some kind of a band within which the control system will maintain the temperature 27 degrees Celsius is desired value but it could drop to say 26.9 Celsius, before the cooling off the cooling is turned on and it may have to rise up to 27.1 degrees Celsius, before the cooling is turned on again. So, there is an unavoidable band within which only one can guarantee the temperature to lie and of course, normally as human beings, we will tolerate such variation and

after all are you and I going to sense the temperature difference between 26.9 degrees Celsius and 27.1 degrees Celsius.

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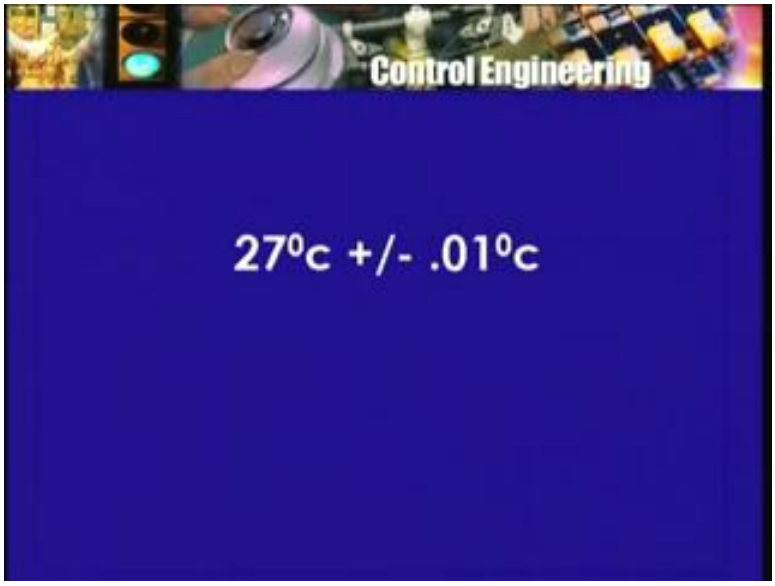

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Our sensors, our skin is not perhaps that is sensitive that we can distinguish between 2 temperatures differing only by .2 degrees Celsius but, in some applications this band, may be not

satisfactory, it may be too large, see you may want the temperature to be controlled not within in this case one will say within plus minus .1 degrees Celsius.

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So, in our case the air conditioner is a temperature regulator there could be a system a control. So there can be a difference or an error of .1 degrees Celsius either on the higher side or on the lower side, but you may want it to be much smaller say .1 degrees Celsius that is you want the temperature to be maintained within plus minus .01 percent, one hundredth of a degree of a desired temperature. There are few industrial situations where temperatures have to be maintained or regulated with such accuracy. As I mentioned earlier, such systems are also called regulators. So, in our case the air conditioner is a temperature regulator there could be a system, a control system which a function of regulating the speed or regulating the pressure and so on pressure regulators, speed regulators, voltage regulators and so on.

With the on, off kind of regulators usually then, there will be some error which cannot be avoided but what we want to note here is this speed back aspects that, what is the actual temperature is sensed in some way and it is as, if somebody is comparing this actual temperature with the desired temperature. Now, very soon we will start drawing diagrams I cannot be talking here all the time as engineers, we have to do things with equations, with diagrams, with figures and what not all ready of course, we have had some figures but we will have quite a bit of quite few of them as we go on.

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So as I said is, as if somebody is comparing so one does indeed talk about something which in effect compares two things, the desired temperature with the actual temperature as a comparator it is also called an error detector. These are terms very commonly used in this context. But as you can very well expect in the case of the thermostat for example, how do you sense the room temperature, we will we all know how it can be done, you can have a thermometer the thermometer will show you the temperature but the thermostat does not have a thermometer in it,

why not because if you add a thermometer then, you would to have a person who will read the thermometer and he will have this number 27 degrees Celsius written somewhere perhaps or in his head and so he will look at the thermometer mentally compare it with 27 degrees Celsius and say yes, I will turn it off or I will turn it on.

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While the 27 degrees Celsius temperatures or rather the room temperature is something which can be actually measured, the desired temperature is not be found somewhere, it is not as if there is a sample of material, it is at that temperature 27 degrees Celsius and then you are comparing that temperature with this temperature. So in that sense there is no comparison being made between one temperature and another and this is the case in most feedback systems the of the regulator type, we are looking at the regulator type control systems right now.

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Say, you want to regulate the pressure you want the pressure to remain constant at a certain value. Now, that pressure could be measured with the help of some pressure measuring device, you should know, what they are called say a manometer or a pressure gauge. But again, the measurement is not done for the purpose of a human being that is an operator is going to read the pressure and then, he is going to see whether it is high or low and then take appropriate action.

Of course, such a thing can happen and strictly speaking that is why I said that there is hardly any situation where, feedback is not used. In fact, the human operator or operator is the element or is the part of the control system which is doing precisely this function of feedback. The thermostatic element could well be replaced by a person who reads the thermometer, the temperature with the help of a thermometer, compares it mentally with the desired value or the desired value, may have been noted down somewhere, so he looks at that and then switches on or switches off the cooling system. In this system, a person will be doing the job that a thermostat will be doing normally.

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So, instead of an automatic control system we have a manual control system but in both cases, we have feedback. In the manual controlled case of course, it is very evident somebody is looking at the temperature and then deciding what to do in the case of the thermostat, it is not evident. In fact you may not see the thermostat element of your refrigerator or an air conditioner or an electric iron or what not.

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It is not immediately visible but those of you, who are want to be really good engineers, can perhaps start with the electric iron and carefully disassemble it or at least to some extent to see where, this thermostatic element inside the electric iron is whether, it is a bimetallic strip or what you can find out for yourself. So, in this sense only the thermostat or the comparator element inside the system compares the actual temperature with the desired temperature.

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I am emphasizing this because in many log diagrams that we will draw and I will just draw a one very quickly, without going into any details, one will draw a block with an input shown by an arrow called the reference input. In chemical engineering contexts, they use word set point I have already used the word setting thermostat is set at a 27 degrees Celsius. Now, that is shown as an input that does not mean that there is something at 27 degrees Celsius which is connected to the thermostat or which is that signal is going into the thermostat and of course, the output of the system is the controlled output.

The room temperature, in this case which is to be maintained at a given value and so one talks about comparing the reference input and the controlled output and see whether there is any difference or not and depending on that taking some control action. If there were a human being doing this job, you are either to do this job of course, we will look at the controlled output temperature or pressure whatever, look at the desired value which is the reference input think of the difference and then, take some appropriate action like turning a knob somewhere or turning a switch on or off and things like that. So, the reference input is not physically of the same as far as the actually system is concerned physically of the same kind as the controlled output the room temperature is something very really and the bimetallic strip does respond to the room temperature.

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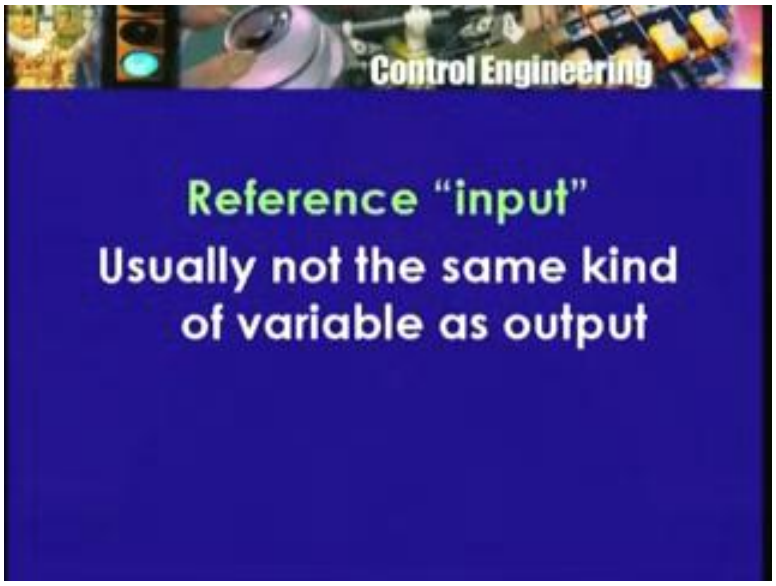

But the reference input temperature is not something real is not something which is at some 27 degrees Celsius inside the thermostat but the very setting of the bimetallic strip. There will usually be a screw of some kind there will be a spring which will push the strip down or up by some amount in the relation to the switch contact that is shows as this, the reference input, there is no physical reference input which is measured or which is stored as a physical quantity.

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Now, I said that there is hardly any system, control system which does not use feedback and there is a good reason and we will see, in fact in more detail, more than one good reason for using feedback. Let us take the familiar example, of riding a bicycle or a scooter or a motor car on the road. Now of course, one is controlling the handle of the bicycle, one is pedaling, so using one speed to pedal the bicycle or using the brakes and then by shifting the weight of the body ever. So slightly balancing the bicycle at the same time. Now, where is the feedback in this case, the human being, the rider is controlling the bicycle, where is the feedback? So in the feedback consisting, the fact that the bicycle rider has his eyes open, he is looking ead in the direction in which he wants to go and his whole body or rather certain nervous parts of the body. So to indicate the fact that the bicycle is going to fit to one side or the other.

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In fact, something which helps us to walk even as simple an activity as walking or more complex activities like climbing a staircase and so on. As children or as infants we all learnt how to walk the hard way, this is because the body has sort of built in nervous mechanism which again I will, one uses the language tells your brain whether, you are standing straight or not or whether you are likely to fall on one side or the other then, accordingly you move your foot or hand to achieve a balance. It is tempting to think of a brain as some person who is being told that no no no, you are going too much to the right, so the brain orders okay the left hand or left foot should move in the other direction and so on.

In fact, incidentally since, we are talking about it the human being itself has been thought of and can be studied as a very complicated system. So, complicated that we still do not understand it very fully and maybe, we will never understand it very fully. But keeping one is balance involves a lot of action a lot of nervous action and muscular action and under certain conditions, you are

not able to achieve it, one is aware of people who have had a little one drink too many, they can hardly walk or if you are blind folded, you may find it difficult to walk certainly. If you want to ride a bicycle unless you have practiced it or unless you want to try it out, you will not ride the bicycle with your eyes blind folded.

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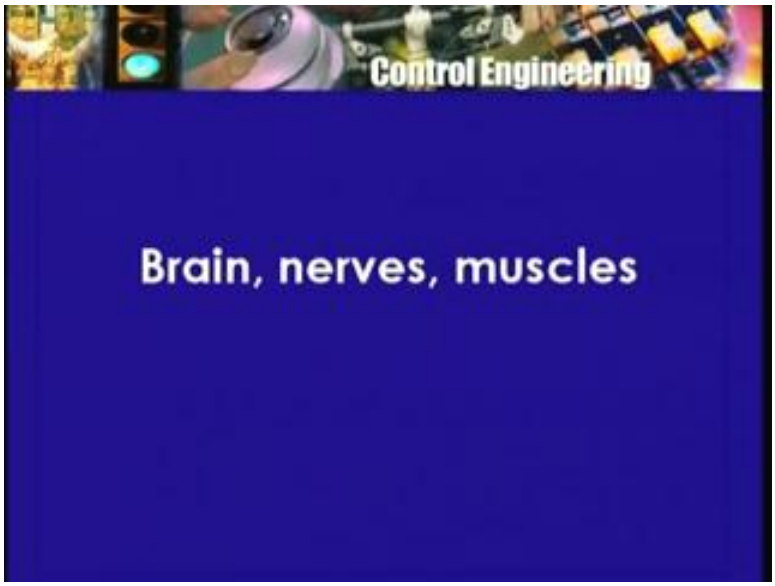

So, that brings me back to the feedback the bicycle rider looks ahead sees where, you wants to go whether, he is going in the right direction, whether there are any obstacles on the road and then, decides to steer the bicycle, accordingly turn left or turn right or keep going. So, in this case one can talk about the desired action should be going straight, the road is straight, you have no reason to turn left or right or you actually going straight, may be the handle was tipped a little bit. So you are going a little to the left of the road, you could have hit the footpath. So, you see that you have gone to the left your bicycle handle is or the front wheel is moving a little towards the left and so, you turn the handle lever, so slightly by changing the pressures on the 2 handle bars, so that the bicycle starts going in the direction straight ahead.

So, there is a desired value if you want called it you you are a steering a bicycle. So, the particular course that you want to take it was straight ahead but you are going to the left. So you make a correction and then the bicycle is brought into the correct course similarly, the speed of the bicycle may be, you are going at some comfortable speed but then, suddenly there is a gradient in the road. The road goes up so of course, your feet immediately sense the heaviness and if you want to maintain the speed, you will pedal it a little harder. So that you can climb up the slope at the same speed.

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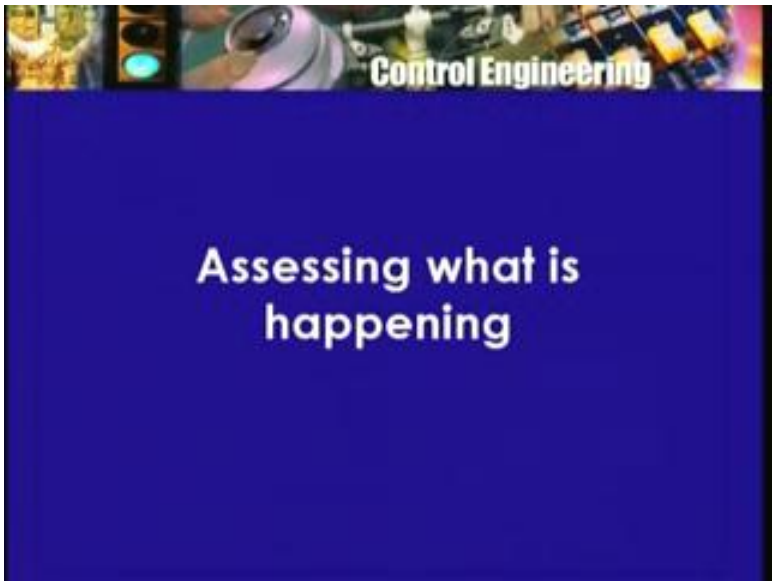

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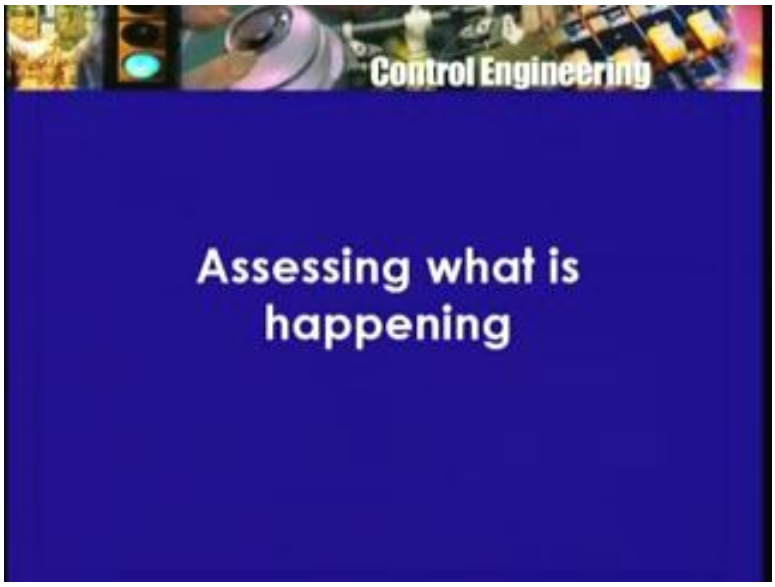

On the other hand when there is a down grade, the bicycle is going down a slope, if you pedal in the same way the bicycle will speed up and once again you may, you will sense that may be, the speed is a little too high for you to be comfortable and so, you may either stop pedaling or apply brakes. If the speed is too high or unfortunately some obstacle comes in your way and you want to avoid a collision or if a collision is seems unavoidable, you will at least try to brake as much

as possible. So, the human being the bicycle rider is constantly using feedback, he wants to, he actually wants to go in certain direction or take a turn either a left turn or a right turn or slow down or speed up and one is assessing, what is happening, one is comparing, what is desirable and what is actually happening?

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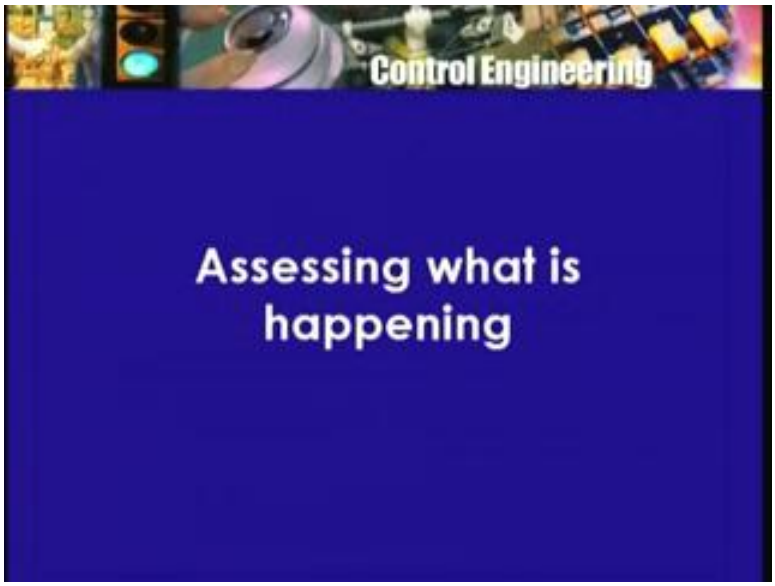

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Well, I should not really say one is comparing not as if, when you are riding a bicycle, you are constantly thinking, no I want to go straight. Let me see, if I am I am going straight no no no, I am going straight, I am going to the left. So I will do this action or you know, I am going a little too fast or I see somebody ahead, I must go slow. So, compare the desired speed with the actual speed and take a decision it is not as, if all this is done conscientiously or consciously rather but certainly something like this must be happening, if you are blindfolded there is a difference, if for some reason, you would lose a part of your sense of balance. For example, some medicines can do that then again, you will find it extremely difficult to ride the bicycle or to follow the turn in the road or to apply brakes at the proper time and so on and so forth. Human beings providing feedback is almost always there, there is some kind of a overall human supervision just do not turn on things and hope that everything will proceed smoothly, once in a while, you will like to check. So, that is a kind of human feedback that you to provide or that one provides, once in a while you will look and see whether things are going on well of course, sometimes you cannot do much.

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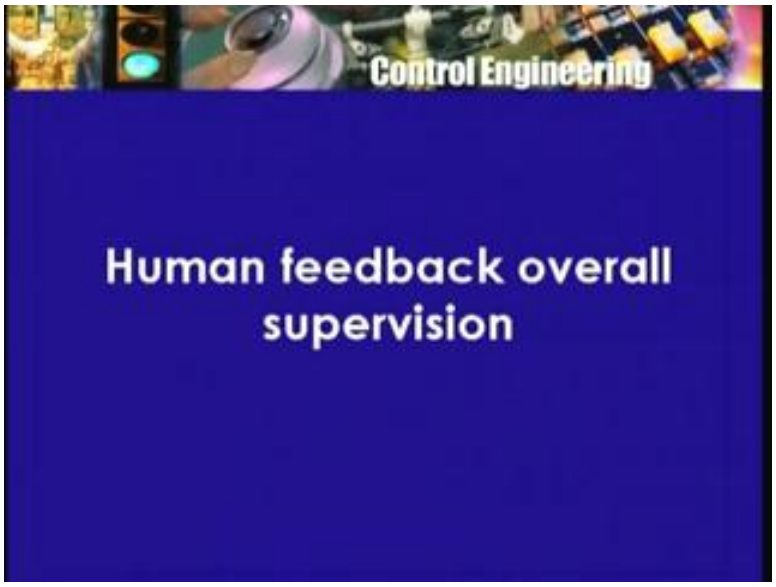

So, there are in industry and even in domestic situations the feedback control system is automatic rather than manual but as I said, the feedback is almost always there what about the traffic signal example, is there any feedback there? Well, if you want to device a traffic control system which is we use a word very often use today is smart or sophisticated then it should have feedback, what does one mean by that well, why have you installed traffic signals in the first place.

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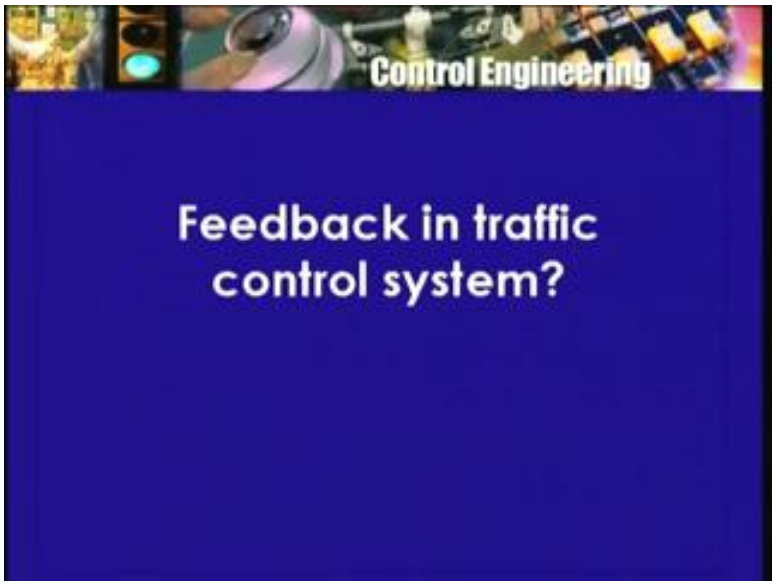

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First, it is to regulate the traffic in the sense it is to avoid collisions in the Indian context, people their cars or vehicles stop in front of each other both of them refusing to move a bit and coming to a fist fight.

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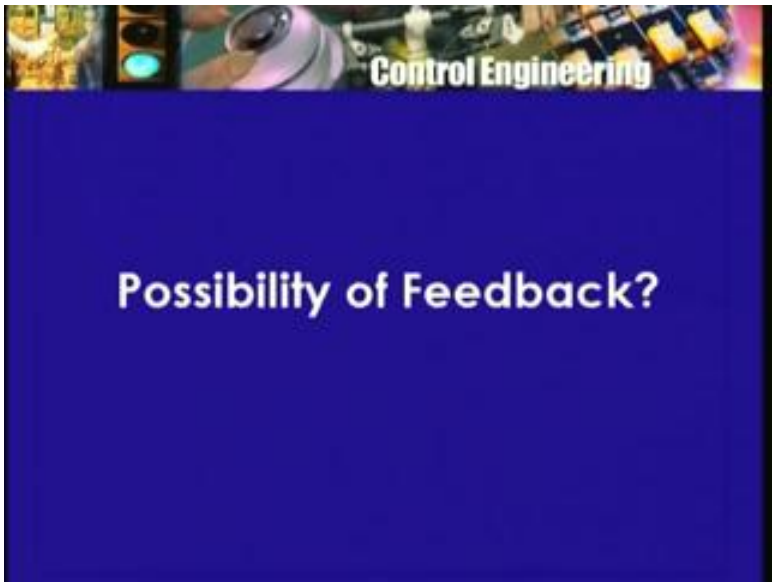

If there is traffic constable present of course, then he is regulating the traffic, he says go or do not go and normally you do not argue with him, you obey his commands. The traffic signal replaces the traffic constable, it allows traffic to go in one direction or one lane for a certain time but since there are other people who has use the road you are stopped for some time. Now where is the possibility of a feedback, well this is something which one notices, when actually walking or

driving on the road I said that the traffic signal system is usually turned on in the morning may be at 8'o clock in the morning because, why because before that time roughly speaking, there is not much traffic. So, the signal will only be blinking to sort of warn you that you should think of others on the road. So, the signals are off, so to speak or there is a usually blinking signal and a traffic constable also may not be there. So one hopes that you are a responsible citizen, you use your judgment and carry on, it is not as if collisions will take place if the traffic signals are off, in fact, collisions can take place even with the traffic signals on, simply because people do not care for it or violate or brakes fail and all kinds of things.

Now, so before 8'o clock the traffic is very thin there are not too many vehicles on the road, there are not too many encounters or possibilities of collision, as a result you do not need to control the traffic. Similarly, late in the night, say after 10' o clock or after midnight, the traffic flow is very little and you hope that people will handle the situations sensibly. So, you do not need again a control by means of a traffic signal or by a traffic constable. In between, the traffic may be heavy and so you have the signals operating. Now, where is the feedback the possibility of a feedback, no, it is not as if at 8'o clock sharp the heavy traffic flow starts and at 10 pm or at midnight sharp, the traffic becomes very thin in between the traffic flow can vary.

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For example, there may be general office timings, say in India typically in some parts of the country it may be 10' o clock in the morning, in some other parts of the country, in the east, it may start little early and so on. So, there would be heavy traffic perhaps between 8 am and may be noon and then the traffic may become a little thin and it will start building up again, say at 4' o clock in the evening and will be may be for another 3, 4 hours till 8'o clock, till finally by 10 pm or midnight, the traffic is really very little.

Now, all this therefore can be taken account of by simply using timers that is say between before 8'o clock. Of course, the signals are off or blinking, say between 8 and 12 noon, the signals cycle in a particular way and this again because the traffic in the various directions are not identical in volume, some roads are heavily traveled, other cross roads may not have that much traffic.

So, may be between 8 am and 12 noon, there is a particular cycle of signals switching that you follow, may be the main road remains on for a longer time than the cross road but between 12 and 4. The main road traffic is perhaps not as much and the cross road traffic also should get a chance. So, you may change the signal cycles, so that they get equal time then again at 4'o clock, you go back to the morning cycle where, the main road traffic is more and so it gets more time to flow and so on.

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Now, in this case what one will be using is essentially a timer it is essentially like a clock or a watch or a timer or an alarm clock, as we use it, something it just keeps time. Of course, 8' o clock something has to happen. So may be somebody comes and turns the whole system on at 8' o clock or may be by remote means you can turn on the signal at 8'o clock. In fact, in a sophisticated traffic control system, the traffic signal should be accessible form a remote centre, remote control centre. So, that from there the signals can be turned on or off or even the signals cycles can be varied. I am not aware of any such sophisticated traffic control system in the city of Mumbai where, the signals can be turned on or off or the cycles can be varied from a control center.

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So, in the absence of such a thing, let us say somebody turns it on at 8'o clock and the timer is set for 4 hours. So for the next 4 hours, 8'o clock to 12 noon, a particular cycle of signal sequence is followed. Then, the timer goes off after the 4 hours, so another pattern then, suppose another timer is set for 4 hours, so from 12 to 4 some other pattern then, back to another pattern from 4 to 8 and then, may be a final pattern from 8 to midnight.

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When the system switches itself off automatically to be turned on the next morning by a person. Now, here is a system which is automatic, which uses timers that is essentially it measures time, you can see or keeps time and it is a pre timed or predetermined or a preprogrammed system. Now is one using any feedback here? Well, in a general sense yes, because the people who have designed this traffic control system. The traffic department presumably have been looking at the traffic flow pattern during the day at a particular junction, somebody from the traffic department has been sitting there and counting the vehicles going by in the various directions. As a result of which he comes to the conclusion that between 8 to 12 traffic is heavy in this direction between 12 to 4, it may be equally heavy in the 2 directions and so on and so forth.

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So, it has broad or overall sense before the switching cycle and this timing change in the switching cycle with time is installed, one expects that somebody has made a study of it. Now that is feedback of some kind is not as if somebody said okay, for 4 hours I will do this and the next 4 hours, I will do that and then somebody else comes and says, no I want 2 hours or 3 hours and so on. But it may just stop there that is someone made a study, let us say, 1 year ago at a particular junction in the city found out that on the average say, over the working days the traffic flow pattern was like this. As a result of which the cycling was arrived at but that is different from a kind of feedback which one could use while the traffic system is operating, it is all right to say, that I made a study, a year ago and this was the traffic pattern. It is to see what the traffic flow actually is at that particular moment, which means that you have to install equipment, which effectively will count the number of vehicles, which cross the intersection or approach the intersection in various direction.

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In other words, assess the actual traffic density at a particular moment of time and then based on that actual observation of what is the traffic situation? For example, on a certain day it may happen that there is some morcha, as typically there is in our country along some road. As a result of which traffic in one direction is completely blocked. So, normally you will have heavy traffic but because of this morcha or because of some dharna, somewhere or the other there is no traffic but your signals will go on cycling as set earlier or a morcha may require a change in the set up. There could be an accident which causes a change in the traffic pattern. So if possible, if one could find out, what is the actual traffic flow situation and then change the signal cycle accordingly that will be a very nice thing to have because, what is desirable is that traffic should go smoothly there should not be too much of blockage anywhere, resulting in traffic jams subsequently people losing their temper and small accidents or big one is taking place and so and so forth.

So, one can use feedback one can install devices which will sense vehicles of various kinds going past the device it could be a scooter, it could be a car, it could be the cars have different lanes, it could be a truck, it could be a trailer where, it is not a such a simple thing and taking into account the actual measurement. So to speak of the traffic situation at a given moment something happens. Of course, one can always have a traffic constable who sees the situation and acts essentially like this feedback element and makes appropriate changes, after all the traffic constable is not quite a programmed device, it is not that he is programmed to allow you to go for 1 minute and then, he sticks out his hand to stop you for the next minute.

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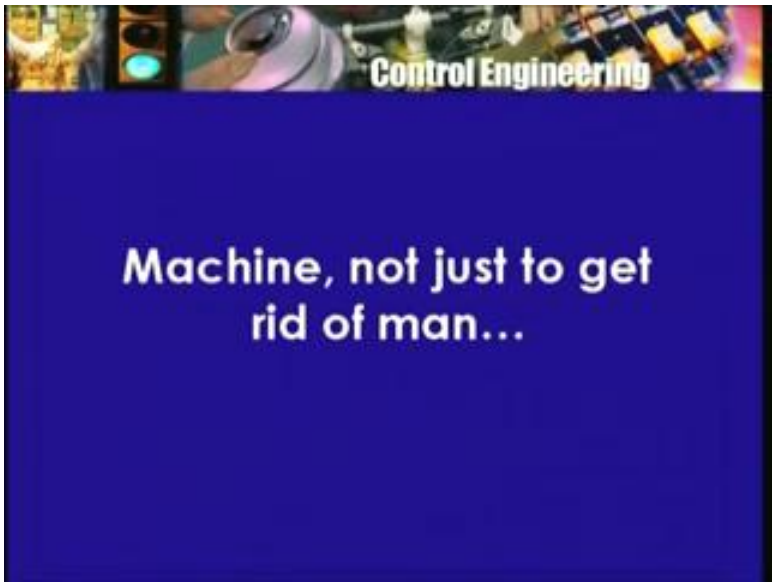

But, you may want to replace the traffic constable by an automatic arrangement simply because as you know, it is really hazardous standing there in the traffic inhaling all the smoke, it is also risky a vehicle could hit, you of course, you will end up in jail all right. But the poor constable

will have a broken leg or could be unconscious and depending on the situation, there may be too many junctions, it may be difficult to get train people and as I mentioned earlier one of the reasons for replacing human beings by automatic devices is not just to get rid of people but ,one expects more reliability, more accuracy, human beings get tired. They can commit errors, their accuracy is limited, a traffic constable can only be looking at traffic going this way or that way whereas, if you have sensors installed on all the lanes at various distances, one can become aware of traffic vehicle that is still one block away or 100 meters away from the intersection and even assess its speed and so on.

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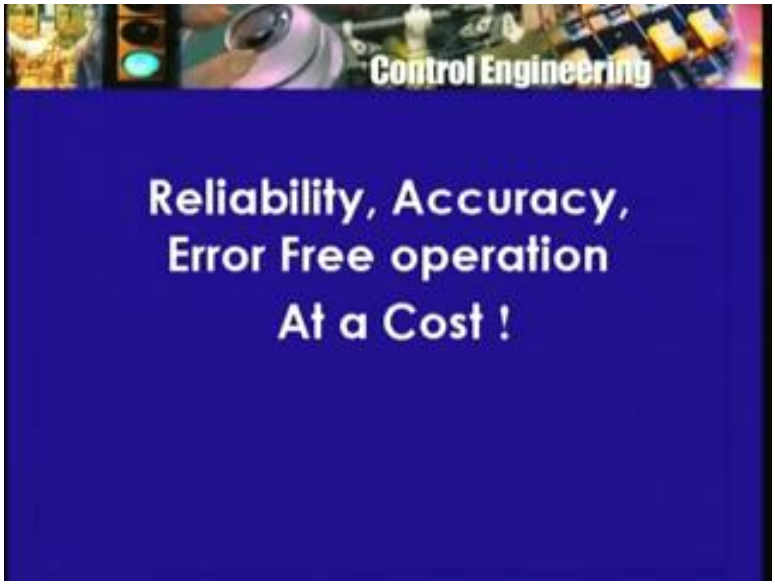

So this is how one should introduce feedback into a traffic control system. Of course, such a system would cost lot of money because you have to install all these devices along the road side and then, additional devices which will do this job of comparing. So to speak what is desirable with? What is actual and then taking a decision allowing the traffic to go or not to go, keeping the signal green for a longer time or changing it to red. So with feedback of course, there is a cost associated with it, of course, as soon as, we make something automatic there is also a cost one has to design that automatic system but one may say that okay, that device thus cost some money but then it is replacing a human operator who also has to be paid anyway.

So that is a delicate matter whether you want to employ a machine to do the job for person, to save money or is it because you want increase reliability, you want to increase accuracy and the human person, may be doing some better job than simply standing there and controlling the situation. So there are very few examples, like the traffic control system of a not so sophisticated kind where, there is no feedback. Although, as I said there is always an overall feedback somebody or the other should be assessing and seeing whether, the cycle that was installed or

thought of earlier is good enough today because may be, some new road has opened up or some road has been made one way or whatever and as a result the traffic flow pattern has changed considerably. So there is this overall human feedback that is always expected but from moment to moment, there may not be any human feedback, the feedback may be automatic.

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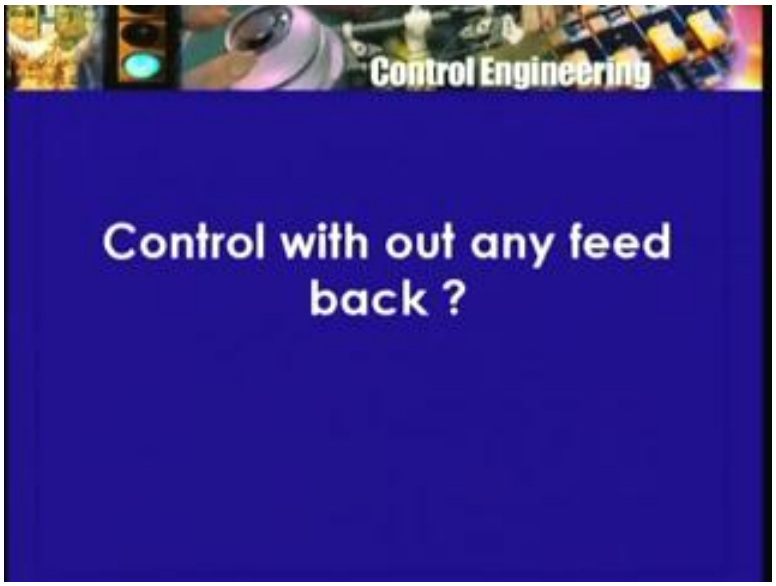

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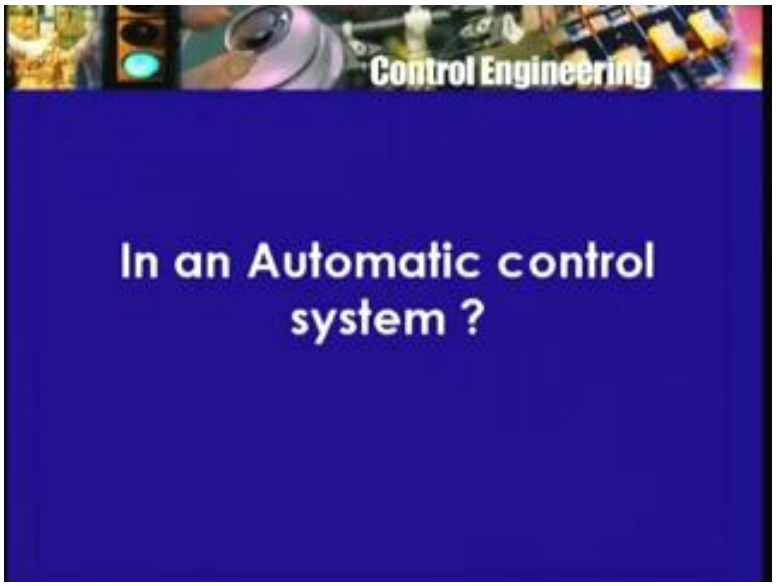

So in this sense, there are hardly any control systems which do not have feedback all the examples, that I mentioned and asked you think of earlier, either they involve the human being as providing the feedback or like the air conditioner a thermostat element provides the feedback and in fact, this is therefore one major part or component of a control system of an automatic control system.

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The feedback element something which senses the actual happening, the actual temperature, actual pressure, voltage what not senses. So sensor and may be now days everything is converted or changed into an electric quantity as an electric current or an electric voltage. So it will be a transducer, so temperature is sensed and with the help a transducer it produces a certain voltage then, you need a part which does this business of comparing. So to speak, the actual temperature value has been measured and converted into a voltage, the desired value. As I said is not necessarily an actual temperature somewhere but in this case it could be a voltage, a standard voltage for example, that is available. Let us say a 1.5 volt cell, if it has not run down will produce a constant voltage of 1.5 volts or some other reference voltage source, as it is called. So instead of comparing temperature with temperature or reading temperature, so to speak as a number 27.1 degrees and the desired temperature as another number 27 degrees then, saying no, they are not the same.

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So, let me start the cooling, actual temperature is one may use the word converted but a better word is represented instead of converted one may also use the word transform but that is not quite correct really, you do not transform a temperature into a voltage, you do not also covert a temperature into voltage, what essentially you do is, you represent a temperature by means of a voltage, by using a device which produces the voltage which depends on the temperature of some part of it. So the actual variable, temperature, pressure etcetera is represented perhaps by a voltage the desired value is also represented by a voltage.

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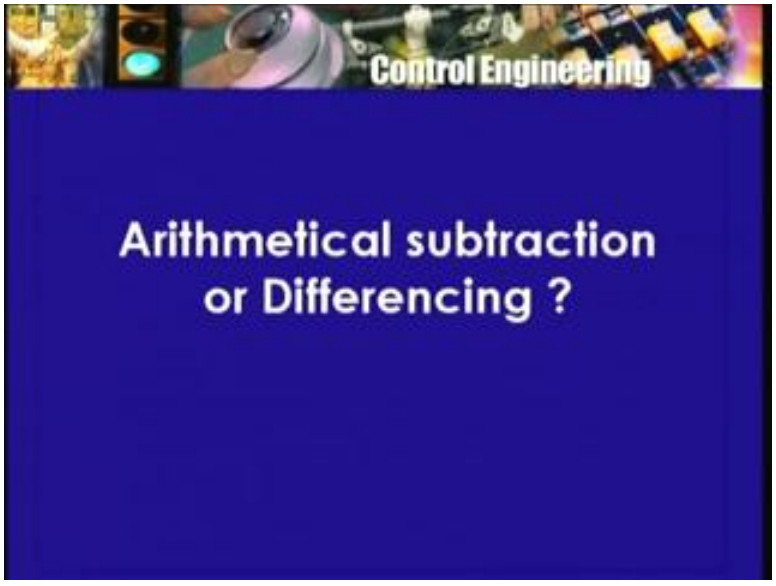

So, what really happens is you have a purely electric device in which your one voltage coming from the output, the quantity being measured, another voltage which is shown on the diagram. As we do earlier as an input and what amounts to a comparison, it is not that something is subtracted from something, it is not arithmetic subtraction necessarily but because of the difference between this temperature or what represents it and the other temperature or what represents it, something will happen or something will not happen. I emphasizing this because

people get this wrong impression that on the diagrams and I, we will be drawing these diagrams but we should take these diagrams with a pinch of salt that something is subtracted from something else, there is nothing of this sort.

You can look at the thermostat inside a refrigerator or inside a room air conditioner, to convince yourself that there is no device there, which is doing any subtraction of any kind, there is nothing there which is looking down and noting some numbers and comparing them or even signals and taking a difference. Of course it is true that one can set up very simple electrical systems in which you have 2 inputs, which are both voltages and you produce an output, this device is an output which is also voltage such that the output voltage is a difference of the two input voltages.

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In fact, electrical engineers and you should be knowing it by this time such a difference in device quite easy to build, a difference amplifier or a differential amplifier is one which will exactly do this within certain limits. It has 2 inputs and it produces an output which is either equal to the difference or proportional to the difference, it may be an amplified version of the difference. But such a device need not be used or be present all the time, all you need is a device which will take representation of the output quantity, the variable which is to be controlled. It will take a representation of the desired value the desired behavior and result in an action like the thermostat, bimetallic strip bends and closes or opens a switch that is what is required. Of course, when one writes down equations, it may be that all this is represented by a subtraction of one signal from another or of one function of time from another.

Now, you should go back at all the examples that I have mentioned so far and see whether, there is feedback being used, whether of course, first of all they are automatic or not. So in the case of manual controlled systems of course, I told you that the human being the person is constantly doing that job of providing feedback, he is monitoring, he is operating. So he is looking, reading and then taking appropriate action opening switches, closing switches, turning knobs and what not, but so look at automatic systems and see, what is happening and see that there is feedback. So to say it one more time there are hardly any control systems where, there is no feedback almost all control applications use feedback.

Now why do they do so, we will look at in a little detail. One of the reasons, obvious reasons is of course, the human being uses feedback and if the human being is to be replaced by a mechanism then the mechanism perform the same function of feedback.

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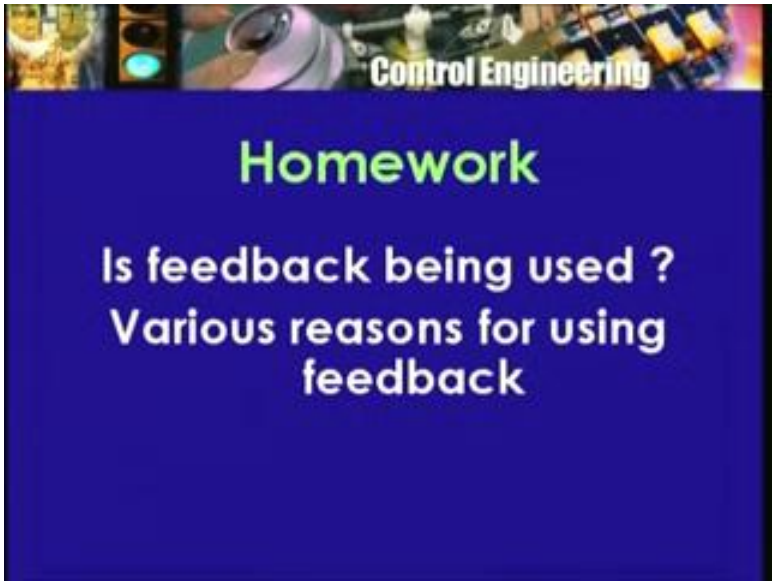

So, we will look at the various kinds of feedback applications or the reasons other than just this one as to why feedback is required.