Control Engineering

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Lecture -05

The third type of control situations or control systems arose fairly recently although some of the situations have existed earlier, but there was no serious attention paid to them and no theory was developed till recently, by recently I mean about 50 years ago. It looks like this class of systems or rather the study of this type of control situations started in the 1950's with the beginning of the space age. I mentioned earlier the Russian spaceship which took the dog Laika around the earth and then later Yuri Gagarin followed.

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Now this required the launching of satellites or spacecraft which was carried to large distance from the earth with a large velocity by rockets. There where also critical problems of fuel, the rocket itself required a lot of fuel to a send up to any substantial height and to carry, what is called the payload of the spacecraft. The space craft also since it was eventually to make a landing had to had some fuel on load but again you could not carry too much fuel it was because that would add to the weight and therefore it would require a bigger rocket and so on. Apart from that in addition to the fuel problems they had to be much greater precision with regard to the altitude and velocities which were to be attained and the subsequent control of the space craft itself whether from ground as it was the case in the beginning or by the cosmonauts or the astronauts moving around in their space craft, subsequently of course we had the man on the moon experience not only man on the moon but come back from the moon.

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So this led to problems which your might call terminal control problems or 2 point control problems in which you have a system such as a rocket with a space craft sitting at the top or the space craft itself perhaps as it prepares for a landing where the initial position and velocity are known the rocket is on its launching pad at rest and it has to ascend to a particular height or altitude and reach a particular velocity. Similarly, the spacecraft when it begins its re-entry maneuver will be having a particular position at a particular velocity and then it has to make a safe landing.

So come down and reach the surface of the earth with a sufficient least model velocity. Of course reusable ships such as the Colombia came later. So here is what has been called terminal control or two-point control problem. Take the system in this case the rocket or the spacecraft from some initial positional velocity to some desired position and velocity there is nothing like a maintaining something constant. So this is different from a regulator type situation and on first glance there is nothing but in the servomechanism or the follow up or tracking system kind of problem because there is nothing which is to be followed.

So the situation is different and the design consideration specifications are also different. There is of course the concept of error you would like to be, you would like the rocket to reach a particular altitude with a particular velocity with as little error in position and velocity as possible. So there was this or there is the conception of what can be called terminal error that is error in reaching the desired terminal state as it is called but there is no question of any oscillations and settling time, rise time and so on.

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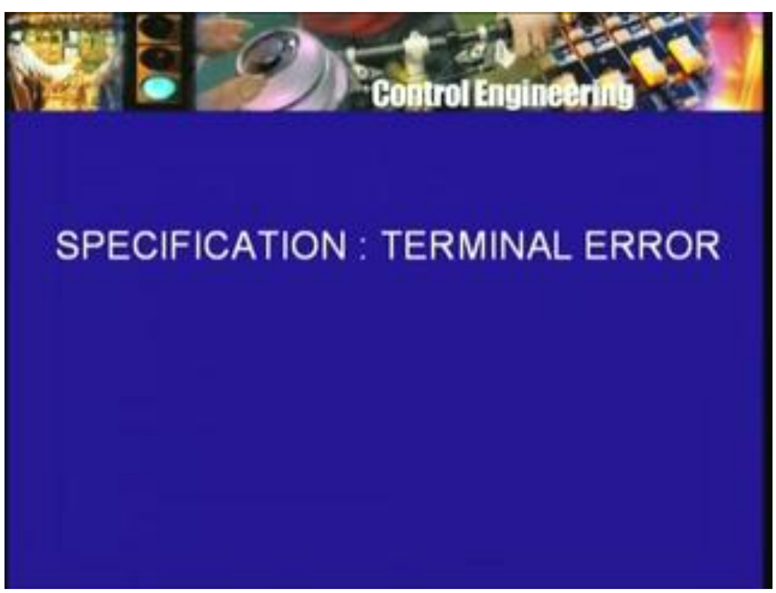

However there other important considerations, one of the most important being the total amount of fuel that is required for let us say the ascent of the rocket which will constitute a substantial part of the total weight of the rocket itself and then for the spacecraft re-entry and landing the amount of fuel that will be required therefore that much fuel has to be provided on board the spacecraft and naturally one would like to use as little fuel as possible not because a fuel is expensive because the whole effort costs lot of money anyway but because fuel is dead weight, weight, so it sort of adds to its own problems.

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So idea such as minimum fuel control were naturally considered and this led to a considerable use of optimization techniques, I mentioned earlier that with followup systems also one can talk about integral squared error criterion and the design of the system takes into account the total integral of the square error and if you have to choose between two designs, one which gives you a smaller value of error is naturally to be preferred and if you could have amongst the class of designs one with minimum integral squared error or what would be called optimum or the best, one would choose that. But here also optimization problems were one of the most important part of the whole thing classical design techniques based on frequency response ideas going back to Nyquist body and even time domain techniques involving study of the differential equations were not adequate and new techniques, new theories were developed in the 1950's, 60's, there were what were seen as breakthroughs in some of the theoretical work.

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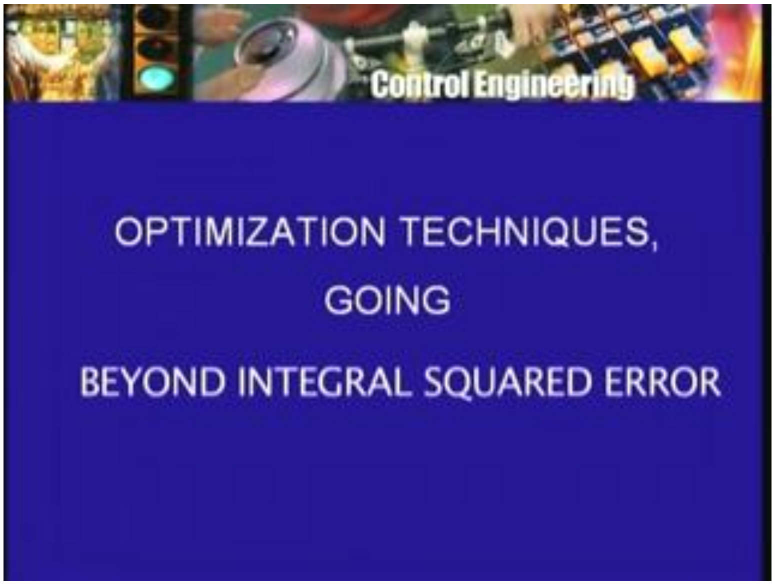

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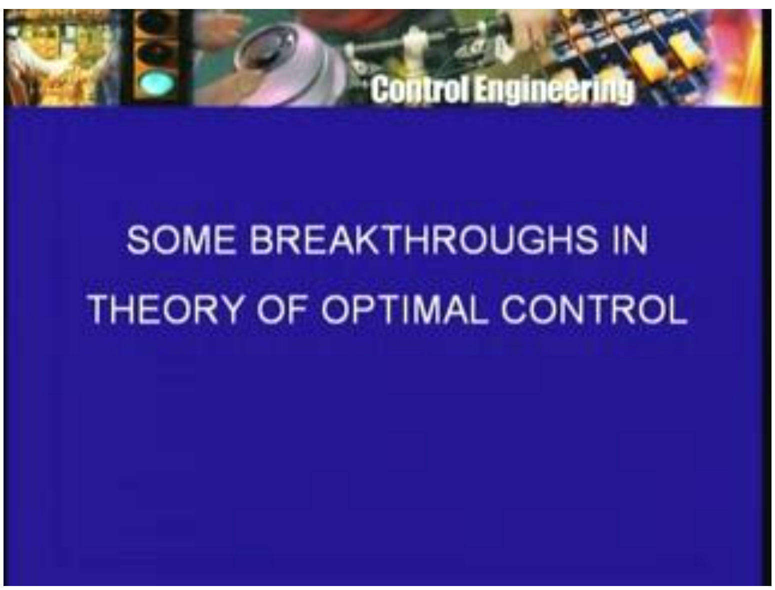

Of course that material usually belongs to an advance course in control system theory or optimal control. You will not be able to spend much time on that except may be some one or two examples but that was the new class of problems, of course in a way such problems you can say existed earlier going back to the times of launching of projectiles at enemy troops or fortifications and the gunnery and then later on in the second world war of course the rocketry with the German V-2 rockets.

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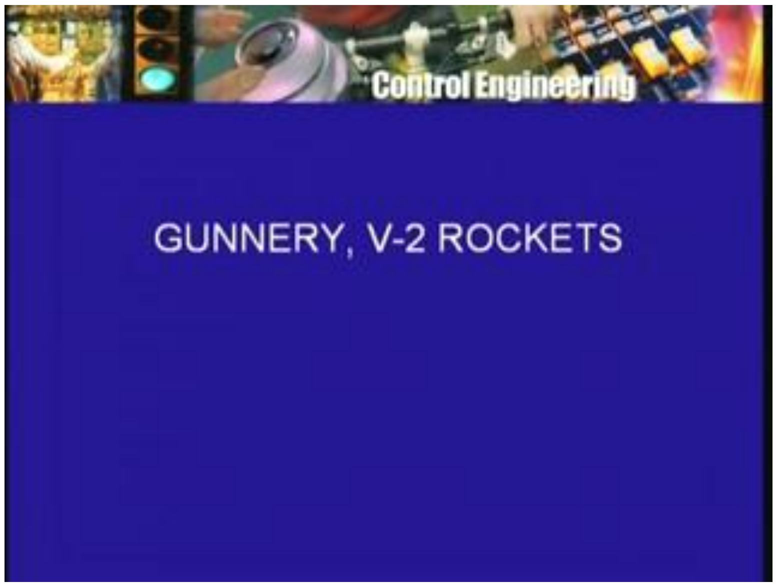

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So especially when you had the pilot less rockets to a terminal control problem would arise, the rocket would be launched from somewhere in some secret place and the desire would be to hit an enemy a target could be a city like London naturally there were lot of worries and the on the other those wanted to launch the rockets. Since, each rocket would be quite expensive one would be worried about accurate launching of the rocket as accurate as possible. In this context one talks about the concept of state of a system instead of saying position and velocity of the rocket at the beginning of the launch and at the end of its ascent phase, one talks about initial state of the rocket and the final or the terminal state of the rocket.

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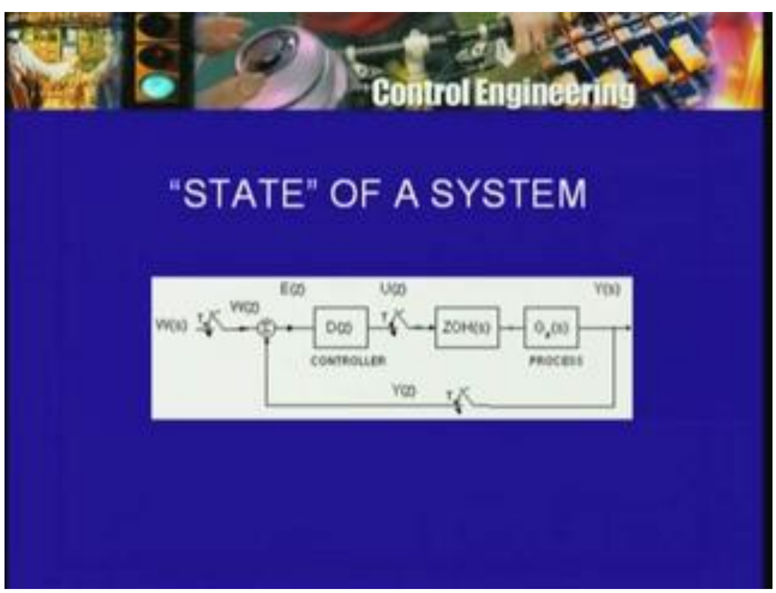

Now of course in another situation or another problem it could be something else it could be several variables associated with the system such as temperature, pressures, speed positions of various parts of the system and so on velocities. So all of this would constitute the state of the system, this concept of state of a system and what is called the state variable description of components and we will look at in detail later on and so these problems could also be called state transfer problem or state transition problems.

You have take the system from a specified initial state to a specified a final state, there is no regulator type idea here. There is no desired behavior to be followed although subsequently it turns out that you solve this control problem of state transfer trying to optimize usually trying to minimize cost or fuel or people and we even talked about what is called minimum time control problem or time optimal control problems and this is again one of the problems which arose in the 50's, we have your fighter planes waiting on the air force base and you get some notice about enemy air craft approaching. So you like your pilots to have their jets in the air may be at a desire or at a specified altitude as early as possible. So as to be able to intercept the enemy aircraft or chase them and so on so this leads to what is called a time optimal control problem we have to take this system from a specified initial state to a specified final state as quickly as possible, minimizing the time that is required for this action. Now this problem can be calculated or rather solved beforehand and of course this is what is done.

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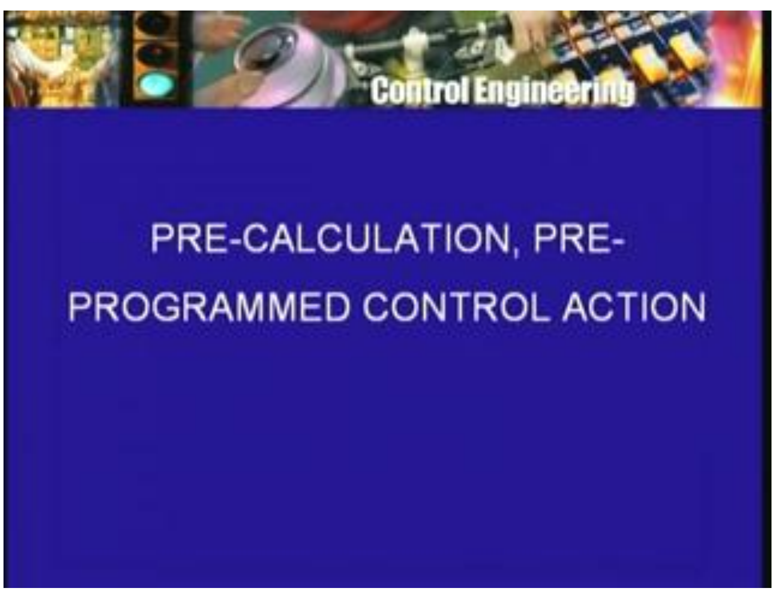

You work on this problem of rocket ascent months and may be years before the actual ascent take place and using all the tools at your disposal, you solve the problem try to find out how the rocket should be controlled from its ignition and take off till separation of the spacecraft or the satellite from the rocket, how the engine thrust rocket engine thrust is to be changed valves are to be open more or closed stages one talks about various stages of the rocket, so one stage is consume. So it separates so all lot of actions all take place.

So all these then can be calculated based on the knowledge about the rocket about the atmospheric region and so on and so this naturally results in what is called pre programmed control action whether it is state transfer without any optimization or state transfer with optimization one will calculate the whole thing resulting in a control action which in principle if implemented will result in what you want. So there is this preprogrammed control action was sequence and every launcher is preceded by such calculations but as we saw earlier feedback comes in again and for the same kind of reason.

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We do not know everything that where as we should about the system we make lots of assumptions, we make approximations and all that because of which if the pre program control action is actually applied the machine may not be 100 percent successful and so naturally we keep looking at what is actually going on when the preprogram control actually is implemented and then as you proceed you make corrections people talk about midcourse corrections because such corrections may be made not continuously but after one phase is over you try to make corrections.

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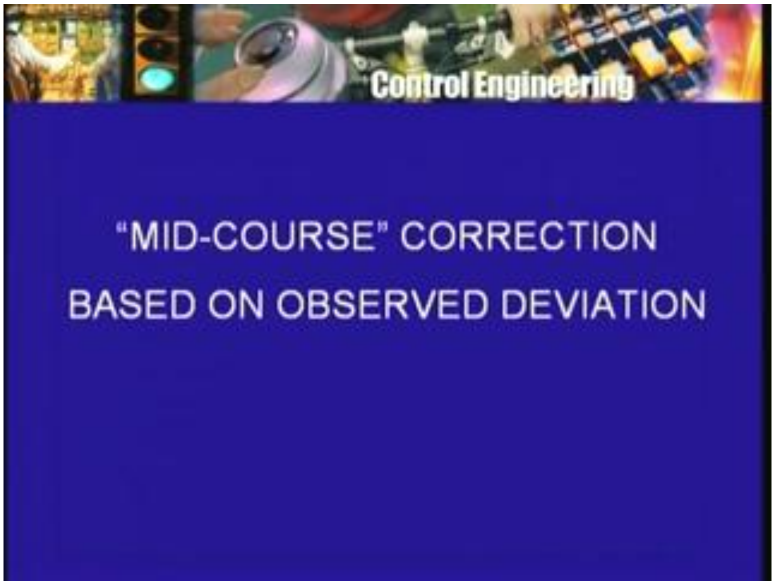

Now even these corrections can be figured out previously that is you can say okay at the end of phase one if I am off by so much amount then what should be my new control action. However, this requires that you must know where you are and how far you have gone wrong which can be a problem knowing precisely the position of a rocket at various points in its ascent or the position of the spacecraft as it goes around the earth before coming in for a landing this requires lot of measurement and communication techniques and so there can be difficulties there and so once again one may provide some kind of a feedback mechanism or arrangement where by depending on what you think the error has been or what you think is the deviation from the desired situation based on pre-programmed action you make changes.

So even in this third type of control situation mainly terminal control or 2 point control or state transfer problem .One may and one does usually use feedback and so in all the 3 kinds of control situations or control applications you find that feedback is used and so what I said in the beginning that is hardly any control application, control situation where absolutely no feedback is used. Now in this context one hears two expressions the feedback system in the system with feedback is said to be a closed loop system. So when you look at the block diagram of the control system you see what is called a loop? In fact in many block diagrams or in many system applications you will see more than one loop perhaps because there are many variables of the system which have to be controlled or regulated or followed and because various feedbacks have been used such systems are referred to as multi loop systems.

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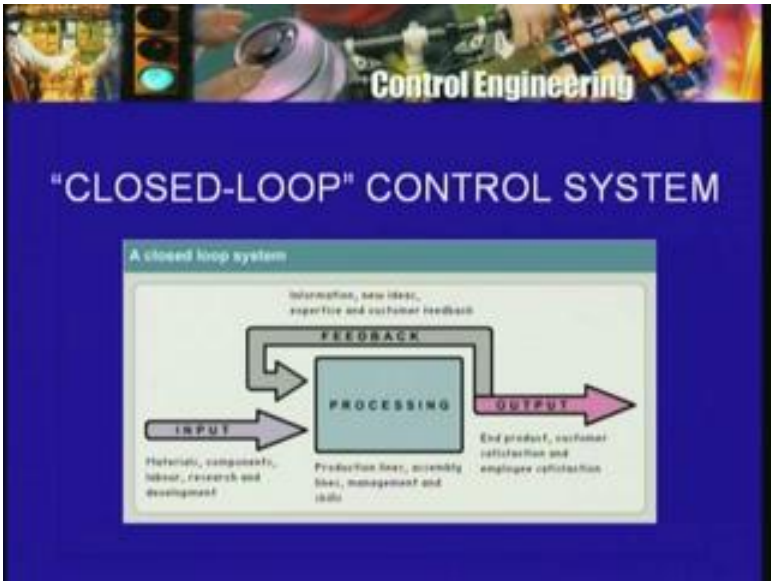

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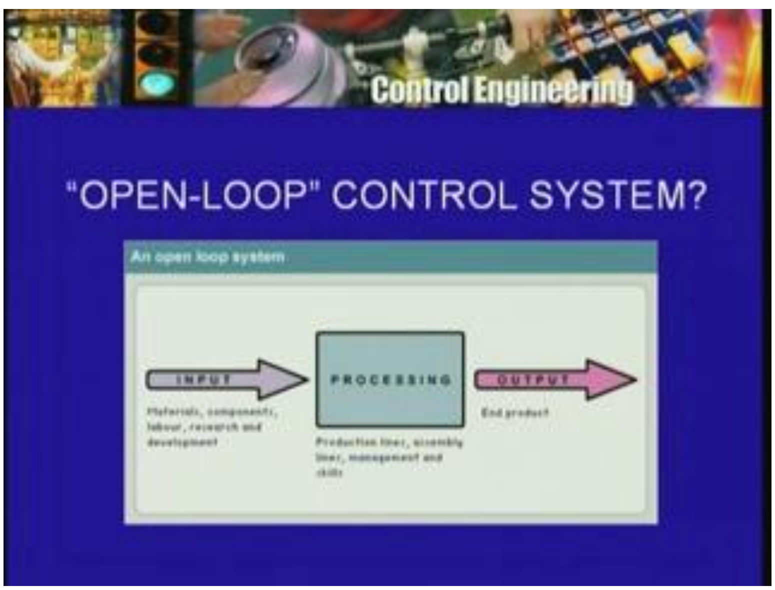

So in the block diagram of any practical control system situation, you will see that there is at least one loop and so such systems are referred to as close looped systems. Now in contrast to these one sometimes you have mentioned the expression open loop control system now I am mentioned earlier pre-timed or pre-programmed control system in which is there is no feedback but if there is no feedback and there is no question of a loop, so it not as if a loop has been opened.

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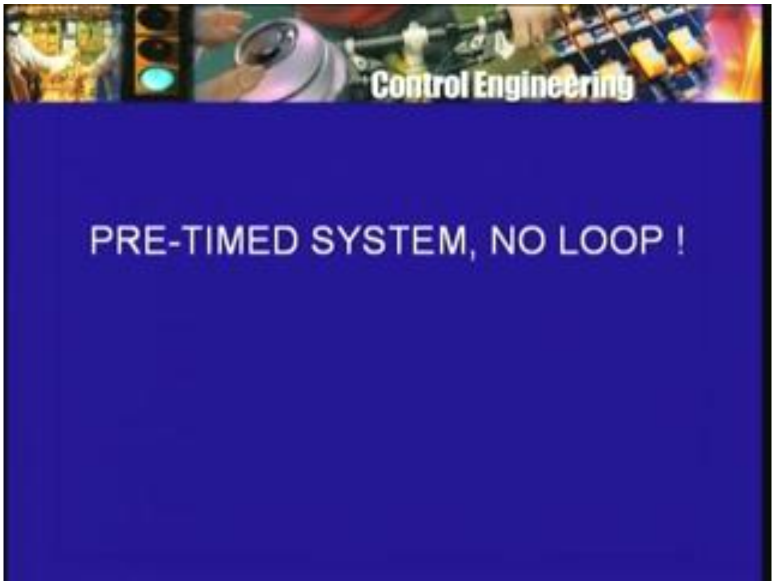

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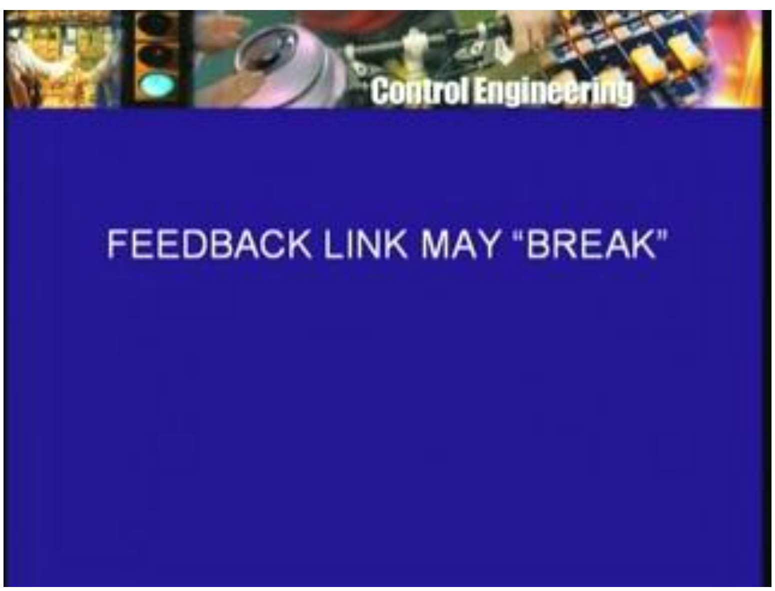

So in that sense it is not quite correct to call it an open loop system because there is no loop to be opened, there is only the pre-determined or pre timed control action you apply that to the system and that is it. However, in the case of a closed loop control system where there is feedback or more than one variable may be monitored may be actually measured compared with what it should be and so on. It can happen that one or more the feedback links may be broken could be lack of communication just some cable developing a fault or whatever instrument transducer going bad or what not. So in a closed loop system perhaps it more than one loop and with several feedback links one or more of the feedback links could be broken. In that case, we can legitimately say that the closed loop system has become partially open and naturally one would like to consider the effect of such a situation and of course one would like to immediately act.

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So from the point of view of reliability, you may have redundancy, you may have more than one transducer doing the same job, you may have more than one link, you have back up and what not so only in such cases one can talk about the loop being opened. Of course when you study the closed loop systems, you are looking at the block diagram and then you are at liberty to play with the block diagram and one does take such liberties in other words instead of the given block diagram, you look at somewhat different but related block diagram. So in this context one talks about thing such as the open loop gain it is not mean that the system is actually going to be opened up the loop is going to be opened and then you are going to measure the gain open loop gain is something which you can calculate in theory knowing the model of the system.

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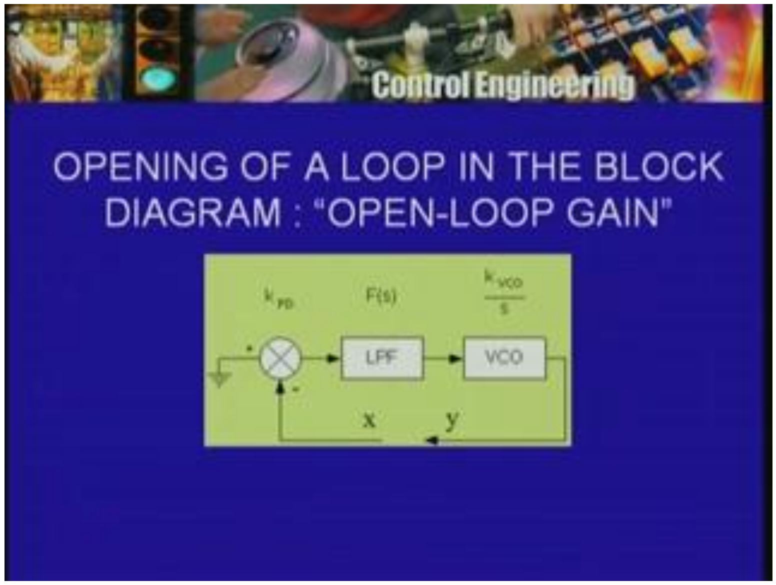

So keep this in mind that almost all control systems are closed loop or feedback control systems but one may study situations the deliberately not actual ones in which a loop may be opened or quantities may be associated with something where there is no loop. So in that sense one can talk about open loop quantity another aspect which I mentioned earlier very briefly is the use of the digital computer.

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Now as you all know today digital computers find applications everywhere perhaps the latest ones are in digital high definition television, digital techniques or digital communication techniques have been used now and are being used almost to the exclusion of analog techniques in many parts of the communication system.

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Of course as I said earlier continuous time or analog systems or variables have not disappeared, room temperature by its very nature is something which you can think of as a continuous time signal and not a discrete time signal also it is a continuous valued signal or continuous level signal and not a discrete level signal but because of the developments in computers digital computers and as one is aware of the reduction in cost and size, increased availability and so on so forth. Digital computers have found use in control systems again this is not recent this goes back to the second world war time to some extent where computers were being used for making all these calculations ballistic calculations with regard to missiles and rockets and so on or bombs to be dropped from aircraft and what not great deal of computation was to be done and therefore computers were being developed at that time analog computers also were in use digital computers were being designed they were not called digital computers at that time some of them were called differential analyzers and so on.

So this was of course when use of computers that has started namely to do computation previous computations to determine the control action. But in the late 40's then early 1950's something else also was taking place as you can realize in a control system application large distances may be involved especially if you are going to have remote control as in the case of rockets and satellites and missiles and what not and so information about more than one variable of interest has to be communicated from one place to another.

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In a control system that is not spread over a large distance one can have cables, electric cables because usually the signals will be electric signals running from one part of the system to the other without any big problem. But if a large number of variables or signals have to be communicated from one place to another you may want to send them on the same cable and so what is called multi-plexing was thought of that is on one and the same pair of setting covered as telephone lines you put several different signals and in fact such a thing is possible today even in a telephone system that is on one pair of telephone wires you can put more than one voice or conversation by multiplexing.

Now when you do multiplexing, you are looking at several signals turn by turn the multiplexer looks at say one signal for a very short time, notes down the value of that signal then moves to another signal another transducer perhaps and notes down or stores the value in the out put of that transducer goes on like this in a cycle till it gets back to the first signal let us say. So this results in data which is although basically it is of the analog or continuous level type, what you receive are only values at several discrete movements of time.

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Let us say a for a particular variable, you get a value once every millisecond let us say. So you know the value of say a particular voltage at some moment of time and then you get a new value one milli second later and another value another milli second later and so on. So this results in a signal which you know looks more like a discrete time signal, of course what happened, what is happening to the signal between two measurements.

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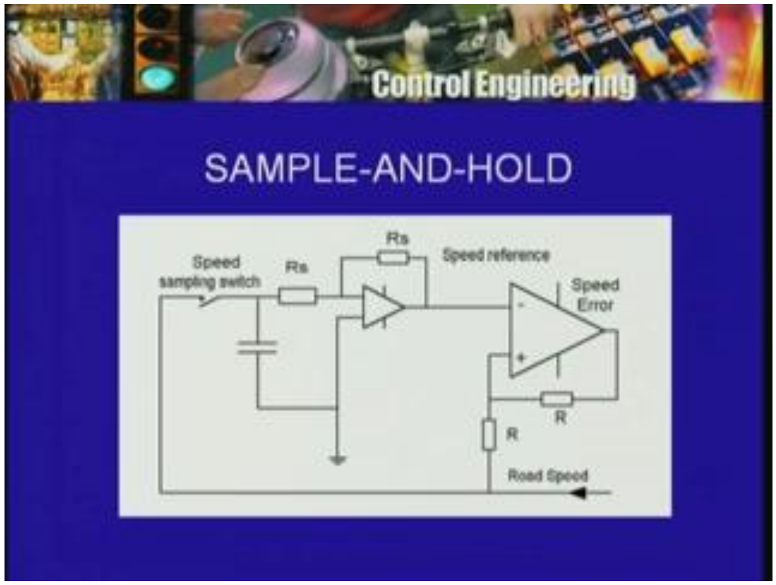

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Now in principal we cannot say anything but in practice one can make some assumption and this process is known as sampling and the kind of thing that you do as you go from one sample value to the next sample value is referred to as the hold and so one talks about sampling and hold or sample and hold techniques the simplest thing, of course is to keep the previous value think that it is constant in the next sampling instance then you have a new value then assume that this is constant till the next sampling instance and so on. This is the simplest thing that one can do, so this is called 0th order hold this is of course the simplest of the schemes that can be used but this results in signals which have this kind of a peculiar feature, what where if you could measure then continuously for example, if you could do a recording connect the transducer output to some recorder you will get a continuous chart such as one finds that in a weather, bureau or station where the temperature is recorded continuously or in a station where the earthquake activity, seismic activity is recorded continuously and so on.

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But instead of that you are getting these discrete values or discrete time signal. So such a signal is referred to as a sample data signal or a sampled signal and systems which have to make use of such signals are known as sample data system and in particular in control systems this is likely to happen, a large number of output signal of the control system may be sampled and so this results in a sample data control system. Now naturally if your data is going to be sampled one might do it the other way round that is the input also may not be continuously varied but may be changed only from one sampling movement or one instant of time to another. For example, if you pre calculate the control action let us say in principal I should find out the value of let us say a particular input, let us say the amount of heat produced or the voltage or whatever control variable is involved, its value at each and every moment of time for the interval of control action starting at some time and going up to some other time at each and every movement of time I would like to keep this input a particular value depending on my calculations but of course such a thing is not possible.

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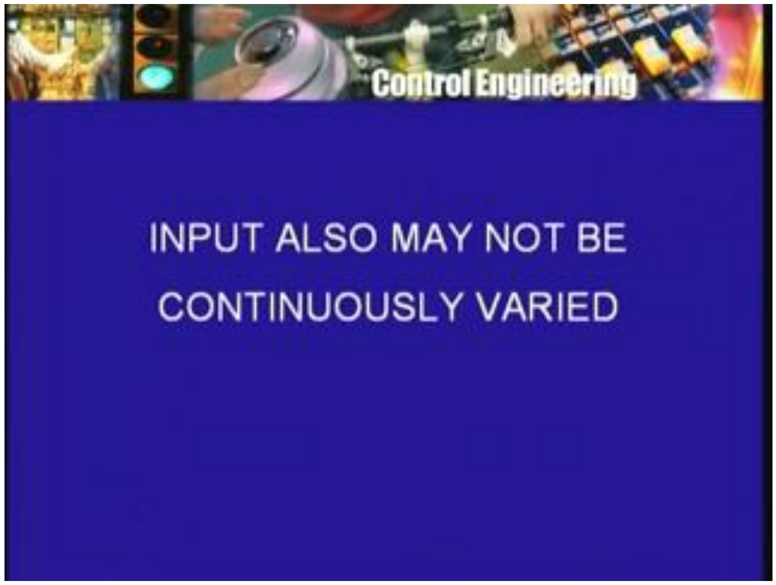

So what is possible is that you store a large number of values, successive values of the input not at each and every movement of time but over each interval or sampling interval. So in a system the input signals also may be about look like sample although they are not really sampled signal but they look like output signals about which all you know is that it has some value at some moment of time and then another value at another moment of time. Now especially in the chemical process control applications where the system may be spread out geographically either horizontally or vertically and there would be a large number of signals to be monitored such techniques were introduced in the 1950's and this resulted in a almost a separate branch of control systems theory known as sample theory of sample data systems.

Now in such a situation of course computers would come quite naturally because you are looking at the monitored variables only at the discrete moments of time the output start with the input start with the change also at some discrete moments of time and so the feedback link instead of being a continuous time link could be a computer and thus started computer controlled systems and of course that has been going on, a space effort, today is unthinkable without the use of computers all over the place. Of course along with computers you must have communication systems display devices and what not of course one advantage of using computers is that one can make calculations fairly fast more accurately, computers can a store a large amount of data and so on. They are, they give you a lot of flexibility which is not so easy to obtain otherwise.

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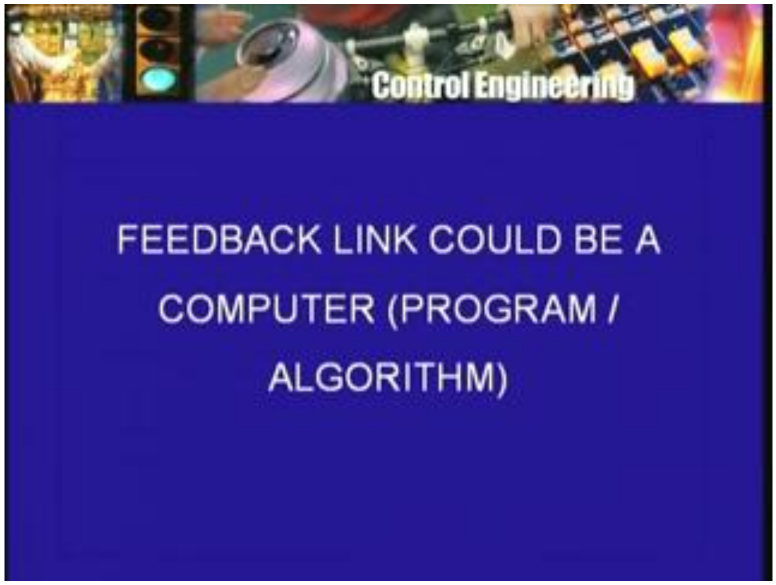

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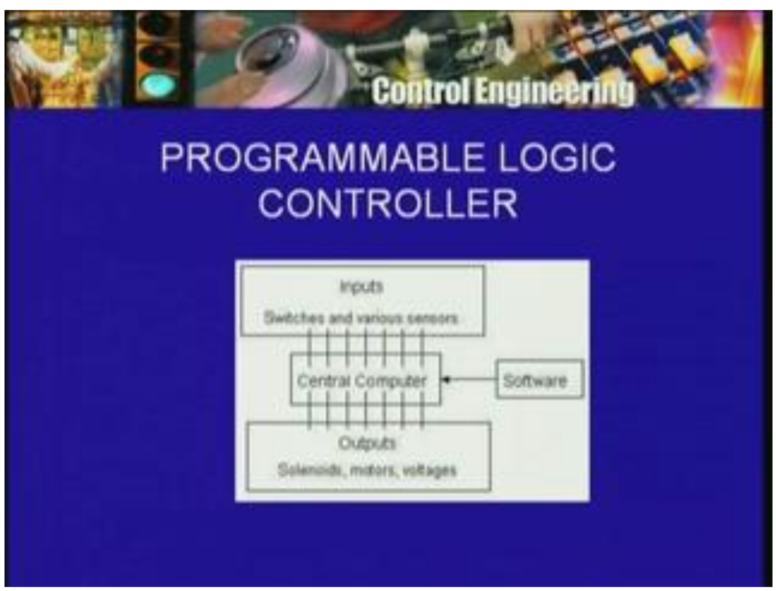

So keep this in mind that in many control system applications that you may come across later on you will find where have digital computer because it may not be so called it may be called programmable logic controller and it may be using a microprocessor this chip rather than a personal computer or a much bigger computer system. But this feature of discrete time activity is taking place or changing only at some moments of time therefore they are governed by a clock and so on.

These are quite common place, in our subsequent study however we are not going to look into all these details of the computer control. There are certainly of an advanced kind and they require a good enough knowledge of more elementary material but I talked about using feed back comparing, what is actually happening with, what is desirable and in some way finding about what is the difference or deviation as it is called or error and then take an appropriate action to reduce that error.

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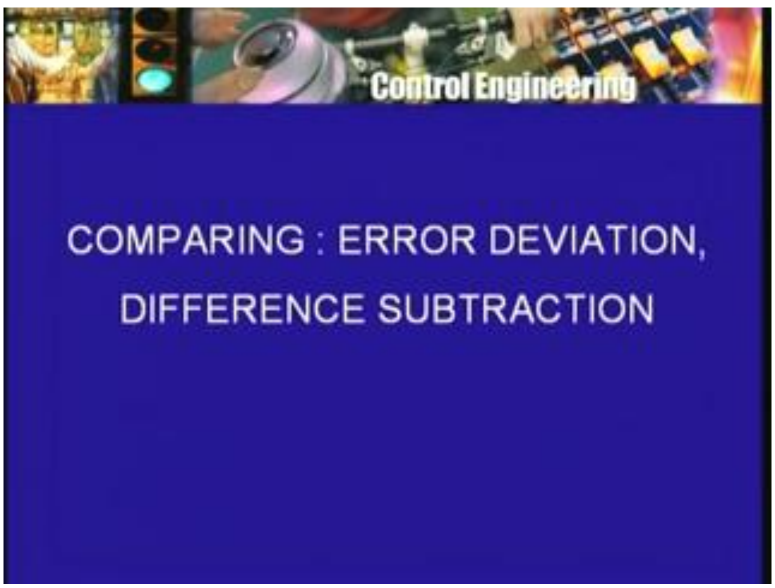

So this operation of taking the difference between 2 signal, I said it looks like subtracting one signal from the other. But in the earlier control system applications there was no arithmetic subtraction it is not as if somebody took one reading and then another and then calculated the difference. In fact on had to build components which would do this subtraction in a in an indirect way or effectively it could doing a subtraction and I mentioned the thermostat bimetallic strip as a simple device which does this kind of subtraction operation as it were does not directly subtract one number from another. But it produces an outcome which depends on the difference between two things, in the case of bimetallic strip the temperature of the 2 metals if it is different the strip will have a particular shape and the temperature is changed the strip will bend more or less.

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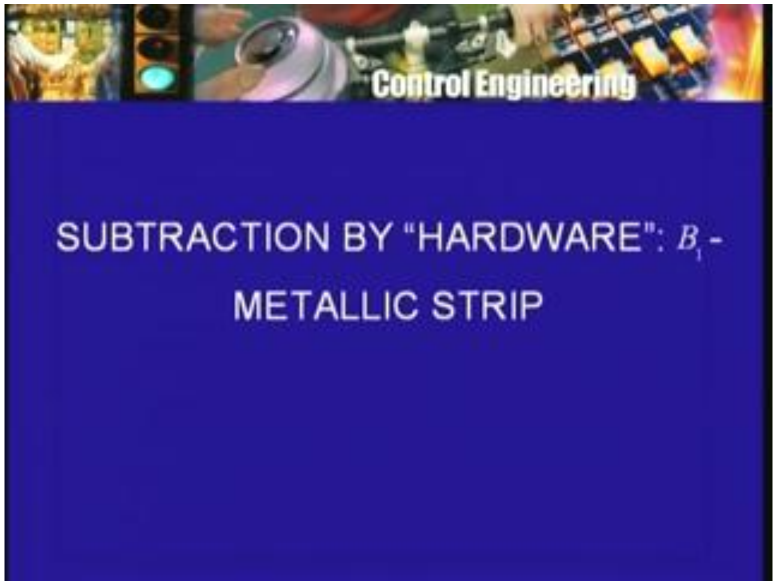

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Similarly, a potentiometer with two sliders instead of one can be used as a device which does subtraction in effect and again in the early days there were many devices or components specially developed to enable you to obtain a signal which was related to the difference between two signals, one such device per such devices always came in pairs what what is called as synchros one talks about pair of synchros which allows you to get a signal which depends on the difference between 2 angular positions you have 2 shafts and let us say one shaft is to follow, the angular position of the other shaft naturally you will think of the earlier gun pointing at the target situation.

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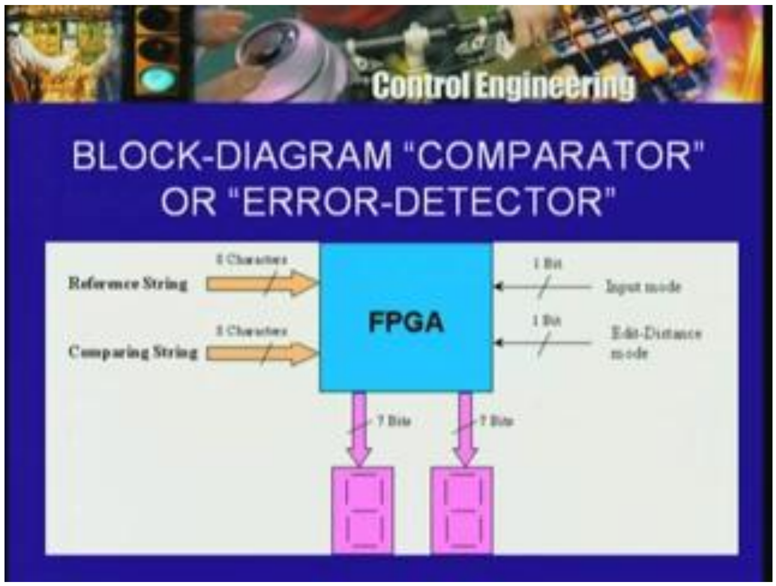

So pair of synchros will produce an output voltage which is related to an good extent if it is not too large proportional to the difference between the 2 angular positions. On the block diagram of course it is very simple to show this by a plus and minus sign and we will be doing that later on but remember that this is not an arithmetic device it is some physical component which is doing this it is called the errors detector or comparator.

However, when you use computers and have you use digital computers, the subtraction is very close to numerical subtraction. With the help of a computer program you can find the difference between one number and another, in fact one simple arithmetical instruction does the job. So you can do away with some of these control system components which were earlier required to do this operation of responding some how to the difference between what is desired and what is actually the case.

So go back to the thermostat, the air conditioner example once again the desired temperature is set on the knob I said that it does not actually result in a particular temperature being produced, the bimetallic strip if it is the element used its initial position some spring making a take up of a particular position will be compression in the spring will be adjusted. The actual temperature of the room is of course there in bimetallic strip will respond to that temperature and so in effect you have an action that is the result of that depends on the difference between the two signals.

Now instead of that you could have the desired temperature which say 27 degree Celsius can be actually stored as a number say 27 of course not in the decimal form in a computer but in a binary form and the actual temperate would be measured by means of a transducer, the transducer will produce the voltage which will be related to the temperature, this voltage then can be sampled and quanta is resulting in another number. Again it will be usually a binary number and not a decimal number and now we have actually 2 numbers in the computer and you can do this operation of subtraction quite easily.

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In fact, many operations which earlier were done with the help of physical devices or hardware. In the control system context they were called compensators various kinds of elements in the control system many of them can be replaced by computer algorithm, by a program, of course programs are alone are not enough computer programs will only generate numbers where as you need physical variables such as temperature, pressure position, velocity and what not. So along with these will move mechanisms that go both ways from the physical variable to the number and from the number to the physical variable.

So on the measuring device which usually one talks about as a transducer and then you have a device which on the basis of the number produced by some physical variable.

These are usually called activators, so it is not that you just have computers doing everything but a lot of what looks like calculations or transformations of signals instead of being done by physical devices can be done with the help of computers. So this is one significant difference in modern times but keep in mind that computers do not enable you to get rid of all hardware, many people get carried away with the idea that software computer programs can do everything. Well a computer your PC or whatever microprocessor cannot produce heat I mean it may have its own heat being generated so you need some kind of a heat sink but if you want to a heat room you do not use a computer to heat the room.

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You need some other physical device, so there is hardware still required but many of the things which looked at one time fairly complicated things to do, can now be done with the help of a computer program. Although in a lot of analysis that we will do, we will not be thinking of a computer as the actual tool to do whatever transformation or whatever processing of of signals is to be done. In a practical situation, one may find that one is using computer programs to do something that amounts to what is to be done. For example in chemical process control and in many other systems one talks about proportional, integral, derivative feedback.

Now almost by the very meaning of the term integral or derivate you are thinking of a function of time and it is derivate or its integral. A temperature as it varies in time or a speed, as it that varies in time you could be looking at its derivate the derivate of the temp of the speed will be acceleration, so it amounts to calculating the acceleration, of course the acceleration may be directly obtained as a physical variable by means of what are called accelerometers and so on. But today it may be possible to replace these devices by simply numerical operations that can be done with the help of computer programs.

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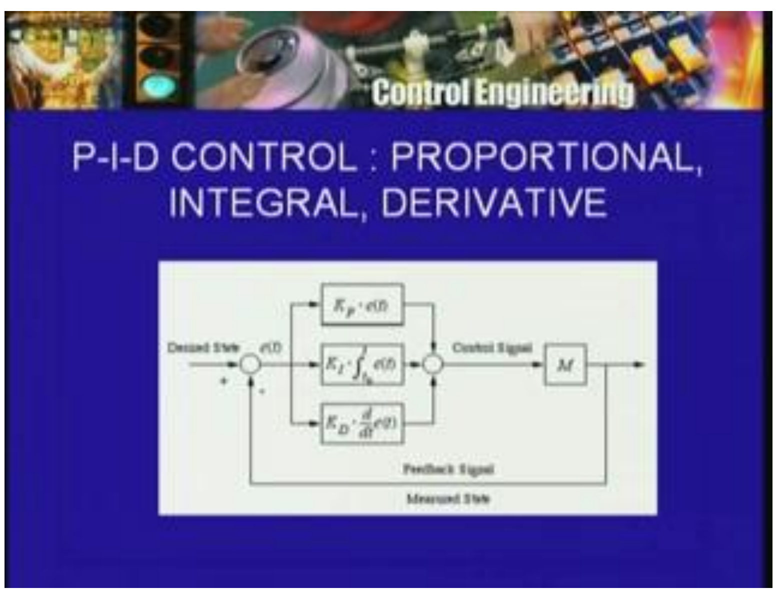

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You have a particular signal instead of using a physical system that will carry out the operation of integration. You do the integration through a formula or through a computer program of course one may not do it because the hardware that is required may still the inexpensive enough or simple enough, you cannot have computers everywhere after they are also piece of a equipment they cost, they are also liable to malfunction. But they are used and they are being used in industrial applications that is something which one cannot deny and one should really get acquainted with them, when one comes across an actual industrial application.