Control Engineering
Prof. S. D. Agashe
Department of Electrical Engineering
Indian Institute of Technology, Bombay

Lecture - 03

Let us spend a few more minutes on the traffic control system, unless the traffic control system is of, what I have called a smart kind, you will have notice that it is a system that involves previous timing, it is what I have called pre-time system as contrasted with an online system. Depending on the time of the day, you have a signal cycle operating for a certain period and the system is turned on and turned off. There are other examples of such systems one that comes to my mind immediately is that of a robot, a small one which is let us say, supposed to do a very simple job of picking up an object of a particular kind, may be a screw or a cap of a bottle, pick it up from a place where, it will be there lift it and place it at some other place. May be the screw is to be inserted into some hole or the cap is to be placed on a bottle, not a very difficult job for a robot or an automatic system to do pick up something from a place where, it is expected to be known thing lift it and put it down at some other specified place does not require too much of smartness.

(Refer Slide Time: 02:15)

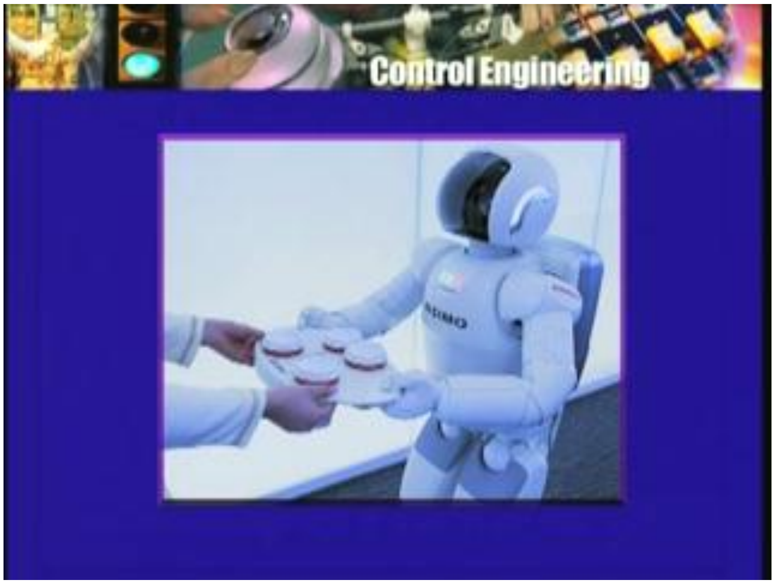
Now, in this case the movement of the robot arm can be completely predetermined. So the robot arm moves in a particular way starting from say some standard position goes down to that object and then, if it is holding the object with a pair of pincers some specific action of the pincers will take place and the robot arm then, will swing around till the object is very close to where, it is to be put and then, the pincers will release the object. So the whole thing can be pre-timed predetermined or pre-programmed. So there is no feedback being used here of course, the robot engineer has done his previous calculations as to how the movement should take place and somehow he has arranged for those movements to take place as the robot goes on doing its job.

(Refer Slide Time: 03:11)

(Refer Slide Time: 03:41)

There is nothing online, so to speak there is a definite sequence of actions and the robot follows that sequence of course, as we can expect that something goes wrong then, the whole sequence will go, the robot will go through but it will result in some problems. For examples, suppose the object which is to be picked up is missing for some reason then, what will happen the pincers will try to close on that object but will fail to close and may be the robot will just swing around and take that object, which is not there in its jaws or pincers and put it down and of course, there is no object to put down.

(Refer Slide Time: 03:58)

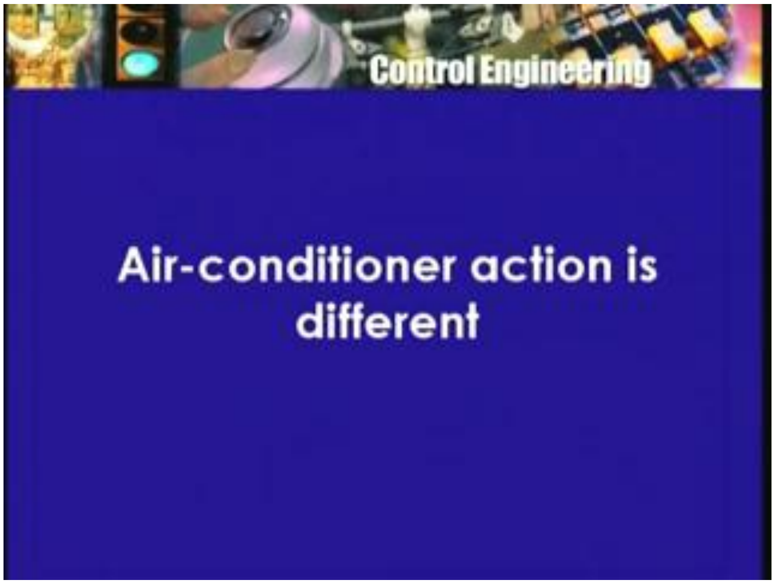


(Refer Slide Time: 04:33)

So even with such simple robots, there may be some over all supervision required or some feed back in the form of whether and object has actually been picked up or not, may be built in. So, once again, as I said earlier there is hardly any control system which does not use any feedback. One more example of a different kind and which is in the news now, nowadays it has been there for sometime is that of a launching of a satellite that is involves firing a rocket from ground and taking the satellite up to a particular height or altitude and then launching the satellite into a suitable orbit.

(Refer Slide Time: 05:28)

(Refer Slide Time: 07:33)



Now, in this case once again, the space agency people do all the calculations, previously as to exactly how the rocket engines should be controlled, how the orientation of the rocket should be changed, when the satellite should be released, when the thrusters which is a satellite may have to oriented it properly should be fired for how long and so on. All these things are pre calculated but once again, there is usually some feedback on top of it. The space people will check whether things have actually happened, the way they were supposed to happen. For example, the orientation of the rocket, the orientation of the space craft and so on. Although, they would have done their calculations beforehand and they are more or less sure that things will go according to their calculation, still finally some element of feedback is necessary because things can go wrong.

So there is this difference between pre-timed, pre-programmed pre-determined control action versus control action which is online. So to speak that is what will happen, will depend on, what has happened actually. The traffic control system was a pre-timed or pre-programmed system, so also the robot doing a very simple job and the launching of a satellite will also be of the same kind but, if we come to the air conditioner example, there the action is a little different.

I mentioned that the air conditioner really does not the thermostat is the element of the air conditioner which does it. It does not really maintain the temperature absolutely constant, the kind of air conditioner that I talked about it was necessary that the air conditioner or air cooler is switched on and switched off. As a temperature outside is high people have come in the room is hot, the air conditioner is turned on the temperature is higher than the desired temperature. So the cooling is kept on n then, the temperature reaches the desired temperature perhaps goes a little below the desired temperature. The cooling will be turned off because of the heat of the people present or changes in outside temperature perhaps, the temperature will start rising once again and this time, when the temperature exceeds the desired temperatures slightly in our example 27.1 degree Celsius the air conditioner will be turned on again.

(Refer Slide Time: 09:17)

So, there is an on and off action, which is going to be taking place all the time. However, all this is not pre-determined or pre-timed, it is not pre-determined that the air-cooler or air conditioner will be on the compressor will be on for 30 minutes and then it will be switched off for 15 minutes and then, again switched on for 30 minutes and off for 15 minutes and so on, unlike the traffic signal cycle where, the signal will be green for 1 minute and then, may be red for the next 3 minutes then back to green and then, red so on.

So the action is not pre-timed, of course if one could know before hand what was likely to happen for example, if one knew that the outside temperature was going to remain absolutely constant at say, 30 degree Celsius or 35 degree Celsius, people in the room were going to be there all the time, there was not going to be any heater turned on or any other source of heat given such ideal conditions. It would be possible to figure out an, on off cycle or it would also be possible to select the volume of air which should be circulated or the temperature of the air which is being circulated.

So, that the room temperature is maintained exactly at the desired value. In our case, it was 27 degrees but all this is under very ideal situations, the outside temperature remains constant, the inside sources of heat are not changing and therefore, a constant amount of heat removed results in a constant temperature of the room and if, one could know about all this beforehand, if one could pre calculate everything then, there is no need for feedback, there is no need for a thermostat to check the temperature and then, turn the air conditioner on or off. One would had made calculations before and set the desired volume of air to be circulated at a specific temperature and one would be sure or one would be confident that the desired temperature will be obtained.

(Refer Slide Time: 12:09)

So this brings us to one of the main reasons for using feedback in a control system, in an automatic control system, when a human being is a part of a control system and is doing the control job. Obviously, he is looking at things he is feeling things and so on. So, he is serving as the feedback device or feedback element but in an automatic control system one will need feedback for reasons of this sort. The system which it is supposed to control one knows about it fairly well, in fact you cannot control something, if you know very little about that system or you cannot device a control system unless you know, what that system is like. Take the simple example of the ceiling fan, what kind of a regulator or what design of regulator? One should have will depend on the ceiling fan is, if the small fan you will require a regulator of a particular rating because so much current will have to flow in it and not more whether, if it is an big fan, an exhaust fan, for a big hall then, obviously current of a different magnitude is involved and the regulator correspondingly will have to be appropriately selected.

(Refer Slide Time: 12:28)

So depending on the job, one will have to select the control system. So you have to know what is the application, what is the motor or what is the oven or a tank or whatever is it, is that you are trying to control. On the basis of that knowledge, you design the control system make all the calculations, think of the rocket satellite example. We know, what kind of rocket one is going to use rocket engine weight fuel the rate at which thrust will be produced and so on and so forth.

So obviously, we have to know the system before we can control it or device a control system to control it but the advice is that one needs feedback. Well, when needs feedback for the reason that although one knows the system to the extent possible, one may not know it to your 100 percent extent. Very often, there are things in the system which you cannot determine beforehand very precisely, there are things which might change with ambient conditions, no system is completely isolated. So that it is guaranteed to behave exactly the way you expect it to.

(Refer Slide Time: 14:18)

Take the room air conditioner example, we have control over the room air conditioner but we have no control over the sun light unless you want to design some control over the sun light. So weather is going to be cloudy or weather it is going to be very sunny, what is going to be the temperature outside, whether it is going to be 35 degree Celsius or 30 degree Celsius, how many people will be in the room, how many lights will be on, may be some other sources of heat, the cooling capacity of the compressor. All these kinds of things although, you try to find out before and as far as possible. Everything is not fully known a general broad term for this could be uncertainty.

You are not very sure about the system or more important than the system perhaps about the surroundings, about the environment in which the system has to work a typical example of uncertainty is power supply voltage, in fact even the existence of a power supply one may be uncertain and so, we has stand by or backups. In case of the power fails like for example, you are watching me on your TV screens, if the power supply goes and you want to continue watching me will have to provide some stand by power supply.
So since, the system operates in an environment and the environment is not fully under our control, we cannot be absolutely sure.

The system has many components in it, we know of course quite a lot about them one particular component is a resistor. So, it has a certain resistance another component is a transistor of a particular type, may be an integrated circuit, may be a motor this that and the other it is true that we do know quite a lot about the components before you put them together but still there is some uncertainty. For example, resistance or resistor the design value or the value that hopefully has been used may be known to me, the circuit diagram for the system or device or amplifier for example, will give may the value of the resistor. I say 1.5 kilo ohms but does this mean that the resistance that particular resistor is always going to have a resistance of 1.5 kilo ohms or even at any time has some one made absolutely sure that that resistor has resistance of 1.5 kilo ohms and you mean 1.5000 kilo ohms not 1500 and one ohm or 1400 and 49 ohms exactly 1500 ohms.

May be, it was measured to be exactly 1500 ohms or 1.5 kilo ohms but when the system is actually working heat is produced.

So for all you know the resistance may increase. In fact, we know that transistor parameters are very sensitive to temperature variation that is why you provide the some kind of cooling arrangements? So there are many such reasons, why you may not know completely or the previous knowledge that you have about the system that you are trying to control is imperfect there is uncertainty. When one talks about uncertainty regarding the resistance value and the possibility that the resistance value may change, one talks about parameter of uncertainty or lack of complete knowledge about the parameter value or we do not know precisely, what the parameter value is.

So this is one kind of uncertainty, parameter uncertainty or parameter variation because of heating that is occurring or cooling that takes place and so on, the parameter value does not remain what it was or with repeated operation, the parameter values may change we say that the motor has become weak, may be the motor has when used the grinder or the mixer motor has been used for a long time and so, something has happened and therefore, it is not as powerful as it was before it has become weak, it happens to human beings, it can happen to machines also.

Of course, it becomes weak perhaps for a different reason perhaps, so part of the winding has got burnt out or something like that therefore, it has, it is not producing as much power as it was producing earlier. So parameter values can change or may not be known exactly. There are some other variables or signals such as the power supply voltage power supply frequency may be, temperature of incoming water or pressure with changes sometimes times, these changes are also referred to as disturbances. So for, an obvious reason because they do disturb your calculation, you made are your calculations everything was nice but now, this things comes suddenly the voltage has dropped and your system does not work properly.

So, sometimes they are called disturbances. So there is a difference between a parameter change or the a of complete knowledge or uncertainty about the parameter value and a disturbance like sudden increase in temperature, say the sun is coming out of the clouds or in the case of an aircraft, there is some turbulence or there is sudden gust of air may be, the weather is stormy, the aircraft is flying through the cloud and what not. So in that case, one would talk about disturbance.

So, you have uncertainty you have disturbances because of which, what you may have pre-calculated pre-determined may not produce the result that you except and so, if you want the system to the be controlled properly, we would like to see what is actually happening and take any corrective action. If the supply voltage has gone down and because of that some intensity of some light is low or some current is low then, I may intervene if an operator is sitting there and try to adjust things. So that the current is brought to the expected value or to the desired value and so on.

So this is the reason for using feedback that what you expect may not happen and so when would like to keep watching constantly, monitoring, measure and then, change the course of action or take an appropriate action. Now, this is what you can say the thermostat is doing, the thermostat monitors, the room temperature and the moment the room temperature goes above a certain value because of may be, environmental factors or lot of people coming in and things like that the thermostat on the air conditioner and after sometime, the temperature goes down may be, lot of air has been circulated or the outside conditions have become cooler, the temperature goes down, the thermostat intervenes again and switches off the air conditioning.

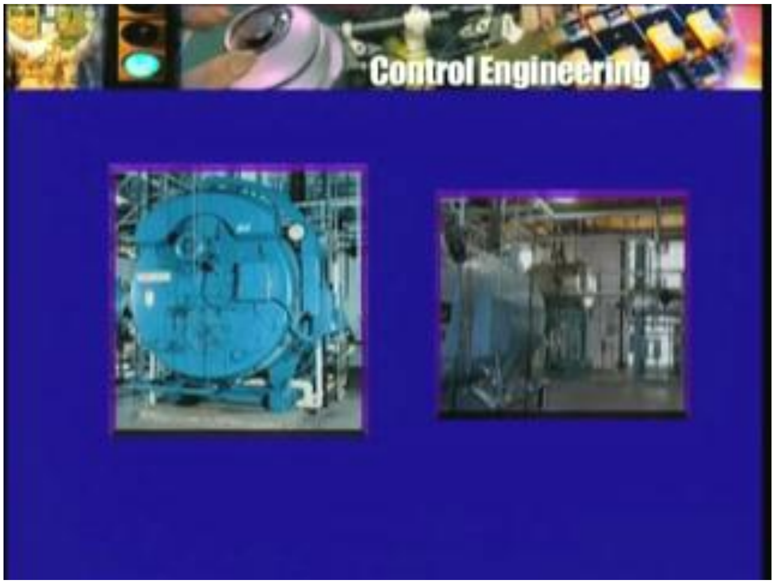
So, we need this my constant watching, monitoring, observing, whatever we want to control, whatever we want to keep constant room temperature, pressure, supply voltage frequency, concentration, speed name anything. Of course, all these are situations which I have called regulator type situation that is, in this case some variable or more than one variable is to be maintained or is to be kept constant at some specified or desired values and one uses the word maintain or kept because usually some action will be required, some intervention will be required as the system proceeds. We cannot simply set it at a pre-calculated value and expect that things will go without any problem.

(Refer Slide Time: 23:58)

So these are known as regulator type systems and in the case of regulator type systems feedback is required for the reasons that I have mentioned. One of the earliest industrial examples of feedback, I do not you know whether you have read anything about it or you have heard about it, I mentioned of course, the ancient tank filling and flushing system and there is feedback used there although, there is no body watching, there is no literal measurement being made but the float valve is an arrangement that provides for the inflow to stop, when the water level reaches a certain height and then, when the water level falls below the flow begins.

So that is the very ancient example, but that was not for an industrial application, one of the earliest with the industrial application was for the control of a steam engine. Before the steam engine was used for locomotives that is for providing transportation, it was being used basically for grinding of grain for meals and then subsequently for various other operations. Now, the steam engine of course, uses steam coming from the boiler, the the boiler has water in it. It needs a fuel supply then, there is the heat which is to be ground the amount of heat, the quality of heat, the condition of the grinder, all of this can result in a situation where the grinding is not proceeding satisfactorily because the steam engine is not producing a proper speed of the shaft of the grinding a wheel.

(Refer Slide Time: 25:04)

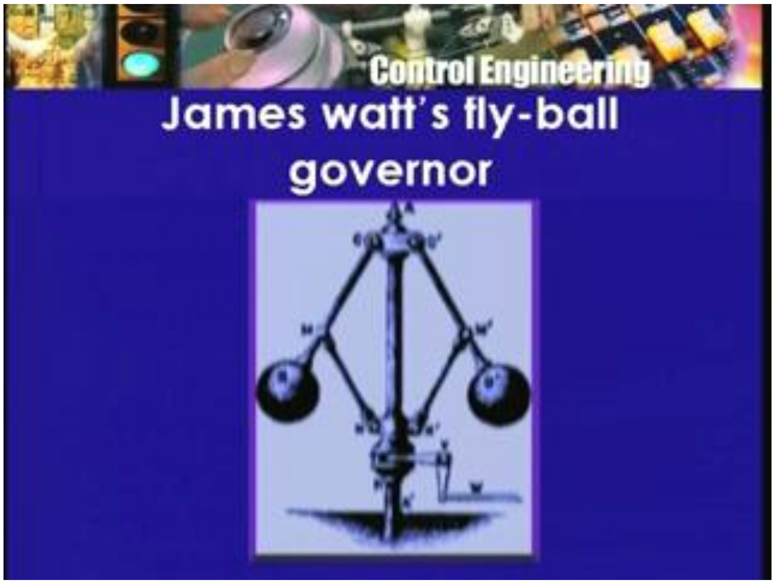


So let say, it is desired to keep the speed of the grinding shaft constant, constant inspite of irrespective of what, irrespective of may be the quality of the heat, may be the quality of the fuel that is used in the boiler and things like that. So, if a human being were to do it of course, we would see that the speed is falling the grinding wheel is slowing down and so he will control a valve which will admit more steam into the steam engine of course, to produce more steam, you may have to increase the heat given to the boiler and because the steam is going to be coming out from the boiler in larger quantity, you may have to check the boiler water level and what not.

So, human operator would do the job and would do the job reasonably well but as we said earlier the reliability, the accuracy these are limitations. So James Watt was one of the earliest the engineer who looked at this problem and designed, what is called the fly ball governor? This is what the fly ball governor looks like such governors. Of course, we will not find in easily today, simply because steam engines have almost disappeared and instead for the fly ball governor, one has found out other way is of controlling the speed or rather monitoring the speed of the engine or of a shaft. In fact, think about this, how the speed of a shaft, today measured or monitored but James Watt was for it sometime ago more than 200 years ago. So, what we can do today was not available at that time.

So, we device this mechanical arrangement call the fly ball governor using the centrifugal, centripetal force kind of action. If the grain say, such that there was less torque required to grind it. So that the grinding wheel would had speeder than the 2 fly balls would fly away at the increased speed that flying away movement of the fly balls by some linkage, led to a valve which controlled the steam flow and which would reduce the flow of the steam.

(Refer Slide Time: 27:57)



On the other hand, if say there was some problem with the fuel itself then, one would have to modify this little more but again the same thing would happen, if the amount of speed that is going is not adequate then, the speed would go down the fly balls would come closer and then, reverse operating would open the valve more. So that more steam would be admitted this is somewhat similar to our room air conditioner example, the temperature is to be at 27 degree Celsius but, we find that is going to oscillate between 2 limits 27.1 degree Celsius and 26.9 degree Celsius.

In the case of the fly ball governor also such a thing is going to happen, the speed will not be absolutely constant but the speed will vary between 2 limits, but the variation can be tolerable. It can be made much less then, what it would be without this a feedback action and we will look at this later on in more detail, this is related to the concept of error and there are some misconceptions around this concept of error in your control theory book or control systems book. There will be a long chapter on control system error types of systems and so on and so forth. But there is some confusion, there and we will look at it in detail and try to clarify, what exactly one needs.

So feedback is used because of uncertainty lack of complete knowledge disturbances and so on. For a regulator type system, when something has to be maintained constant is to remain is desire to remain constant but things may act on it, change which are not known to us disturbances, changes in parameter values and so it is necessary not to just make some free calculations and get the thing going not look at it, at all but to keep on looking at it and then make changes that can bring back the desired variable, the variable which is to be the kept at it is desired value closer to the desired value. This is one of the most important reasons for using feedback there other effects associated with feedback, which unfortunately you people confused with the main reason for using feedback.

During admission interviews, when I ask a question you know, why is feedback used very often, I get the answer to make a system stable as if a system is unstable to start with and you need feedback to make it stable. Of course, there is going to the chapter and there for we are going to devote quite some time on stability of a system but in fact, feedback may make a stable system into an unstable system, if it is not design properly.

(Refer Slide Time: 33:26)

So that is not the reason for using feedback, of course feedback may increase or improve the stability of a system, if it does that is well and good and if does not then, one has to be careful but the reason for using feedback is not to make the system stable, if a there a hardly any intrinsically unstable control systems there are. I am not an aeronautical engineer but to my aerospace and aeronautical friends, tell me that an aircraft with its control surfaces for controlling the various motions of the aircraft is, what may be called an intrinsically unstable control system and in fact, if you just go back to our older example of a bicycle, then a bicycle also one can say is an intrinsically unstable control system. If you have a bicycle say hold it for some time and then leave it, it is not even to stand, it just like that is going to fall and so our human being who is riding the bicycle constantly needs to assess, what is going on thorough, what is called kinesthetic sense and keep from on the balancing the bicycle and once in a while something happens and we fail and we fall.

So, even a bicycle is a an unstable system or what is called may be, you know in in case of stability one talks about various kinds of stability, neutral stability and this that any other. So you can think over this example, where as a so similarly, any two wheeler well most likely the unstable system it requires a blanching act but a 3 wheeler or the 4 wheeler does not suffer from that problem. A motorcar driver does not have to balance his car of course, when he steers around a curve at high, he has to take care but normally, he does not have to worry about balancing. So to repeat the main purpose of feedback is not to make a system stable or the main reason for it is not because the system is unstable because in very few cases, the system will be unstable to start it.

(Refer Slide Time: 34:16)

The main, the reason is uncertainty lack of knowledge disturbances about which we do not know parameter variations and so on and so forth and so, the control system designer has to now think of how this feedback should be used to control the system. When such things happen, when there is disturbance, when there is a parameter is change, what kind of changes in the control actions should made. There are various choices once again, we are going to discuss that later the chapter on control system design is typically what looks at this. So feedback will almost invariably be used in regulator types system, there is hardly any regulator type system which we will find, which does have some feedback in the final analysis some human feedback, some overall supervisory feed back will always be there.

In the case of the rocket launch or the satellite launch also there are so many things that can happen over which we have no control the weather, as the rocket ascends the airflow, the density of air, quality of fuel, variations in it. One does not modeling a rocket motion is not that simple one has to make approximations. So we really do not know 100 percent exactly what is going to happen. So that it will happen so feedback is in use there also at same time in that application one does do some pre-calculations no, system is designed without any pre-calculations and even the feed back is designed is calculated.

So it is not that you can take anything and not know anything about it and use feedback to control, it you may succeed in doing something but there is no guarantee that you will do a good job. So pre-calculations or pre-programmed action is useful important but at the same time use of feed back is also very important and necessary. So this is about one class of systems called regulators or regulator type systems. Let us now, look at a different kind or class of control systems or control actions and I will go back to an earlier example namely steering, steering a bicycle or a scooter or a motor car or an aircraft.

Now, when you want to go from one place to another and you want to ride your bicycle is there anything like a regulator kind of action, is there anything that you want keep constant, it should not change may be, of course you will like to bicycle or peddle at constant speed but no that is not the main problem of the main point of what you want to do? You want to start at a particular place and you want reach another place and there is a road or some pathway which you have to follow.

Similarly, when you take a ride in your, on your scooter or in a car or you have an aircraft which flies from one airport to another. you know the path that you would like to follow, of course, it can happen that you have never been that way before the path could new to you but still there would road reasonably well defined. So that you know what to do and there would be some science that which tell you, what you should do certainly no pilot flies an aircraft without knowing beforehand, the geographic, the location where is a over which over the area over which he is going fly and so on. The word course for this, so there is a pre-determined course which you are required to follow and you get on your bicycle and it gets going road is straight, you ride straight.

The road there is a left turn to the road you do some thing to the handlebars and your bicycle turns left. Of course, when it turns left you take care that you do not hit the footpath or you do not go to far on the right side there may be an oncoming vehicle. So you are constantly watching, what is going on but by analogy you can say that you have to follow a specific course, the course may be pre-determined, if it is a bicycle ride that you have been taking everyday from you hostel to your department and back using a specific road then, you know like know it so well that may be even in your sleep you will be able to do it.

The whole course, the road is all well known everything is familiar but the course may not be pre-determined there may be certain changes. The road is under the repairs, it is closed or left turn is no longer allowed. So you do not know beforehand what is going to happen, what path you are going to follow the course is not completely pre-determined, yet you would like to steer your vehicle and here I by steer, I mean not only direction but also control the speed. So getting on to the bicycle is one thing of course, getting of it is another but maintaining the speed or changing the speed depending on the varying conditions and so on and then, keeping the orientations so as to follow the course and all of that I include, that in the word steering. It is a major control job and of course human beings are doing it day in, day out.

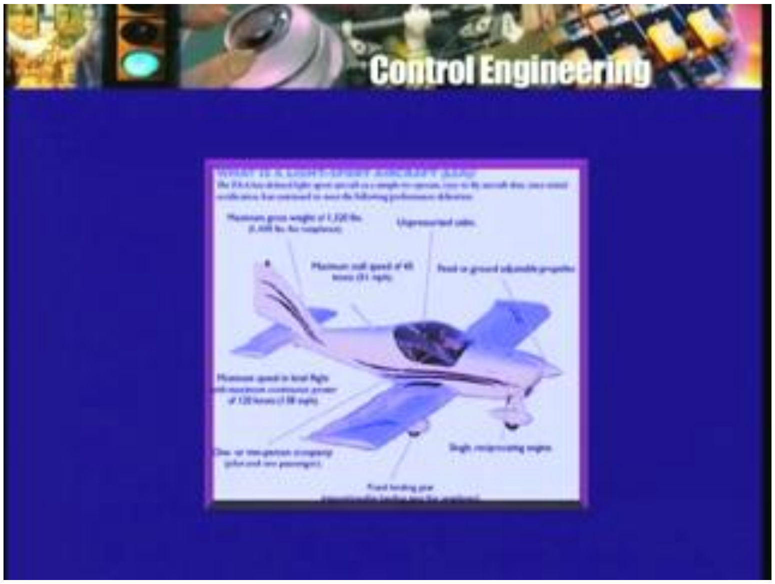
(Refer Slide Time: 41:34)

The job is little easier for perhaps the railway locomotive driver, why because that track is already is their unlike the road where you have to be on the correct side of the road not go to far to the left, too far to the right. There may be a ditch, there may be some pile of dirt and so on. The railway track is reasonably fixed it is maintained properly in fact that is a big job track maintenance and so the locomotive driver has to simply start the locomotive decide upon the speed depending on the speed limit and keep going. Of course that is not true, there are other things that he has to do. If it is the single line track then, you know what kinds of problems are involved. The track condition may not to be the same there are curves and so around curves you have to reduce the speed there may be up grade or there may be a downgrade.

So even there there is some control action required all the time and it is not completely per-determined although ideally and people are trying to have automatic trains that is trains, which will be without any diver and which will go from one place to another. But even when you have such trains the use of feedback will be almost unavoidable because what you knew about the track beforehand, may not be actually the case it may snow, we do not have that problem in many parts of our country, but if there is snow what do you do? Even if there is a track which is completely given to you, so there is no other traffic there is no other locomotive or train which is going to cross your path, there are no obstacles still there could be changes like this rain, snow so on.

So sensing being on the local forwards out there and checking whether the course is correct or if not then making some changes for a aircraft pilot for example, this is what is absolutely necessary because unlike the railway track, there is no track in the air. So he takes off and then, he tries to set up a course and he tries to stay close to that course but then there are things that are not under his control, if it is cloudy there is a gust of air and so on. He deviates from the course and then, takes corrective action from the course, from the actual course. So that the desired course is there again followed they have landmarks and so on.

(Refer Slide Time: 45:10)



(Refer Slide Time: 46:08)

So here is a different kind of control situations which is not of the regulator type, it is not something is to be maintained constant temperature, pressure, speed or what have you. It is that something called a desired behavior position with respect to time or location on the map. Let say, as you fly the aircraft where you should be at this movement of time roughly that is known and you have to try to follow that you have to try to stick as closely as possible to that desired behavior such systems are called follow up systems.

For an obvious reason, they have to follow something which is being specified, the main thing is that what is specified is not usually specified much beforehand but as you go on you are told do this to stay close to this path or whatever. Another name for such systems and that is the the reason for that name is the particular application that was during the second world war, when aircraft were being used and even rockets as we know, where being used as a part of the war referred and therefore, you have to devise a system, you count down enemy aircraft or enemy rocket. Today, of course one would not talk about aircraft and rockets in the word sense of the term what one would talk about missiles and you have to intercept a missile.

(Refer Slide Time: 46:34)

You have to first of all find out whether, there is a missile in your airspace and then track it. This is again another term that is used and then, if possible intercept it in the Second World War, it was simply a question of enemy aircraft. So appearing on your horizon and then you have a gun or a set of guns. So you have to keep on orienting them properly and then at a appropriate moment take a decision to fire a shot and shoot down that aircraft. This was the time when the radar had just been introduced. So it was not really very sophisticated kind of tracking system very soon as the war effort went on radar was developed.

So you had this thing which detected the enemy aircraft be even before, you could see it perhaps or if it was cloudy and so on and the radar would give you the position of the aircraft and also the distance of the enemy aircraft of the target. So you had this target coming to you which, you had to track with the help of the radar but that is not all you just did not want to track it and keep just watching it.

(Refer Slide Time: 48:09)

You have to take action of firing a shell therefore, you have your gun but the gun is not a small pistol or revolver, it is a very massive thing because the shell has to reach may be an altitude of 2000 feet or a distance of may be 1 kilometer or more. So, it is a very massive thing and it has to be moved. So you require mechanism to move it because the mechanism would be an electric motor but you have to move it, keep on moving it. To follow the target and not just wait till the target was over and then, suddenly move the gun because that would not be possible, it will take quite some time to move it. So in a very crude sense the position of the gun should follow the position of the target as closely as possible. There is more to it because it is not enough to know the position, one should anticipate what the target is going to do but atleast, you should keep track of where the target is and the gun should be oriented towards the target as closely as possible.

So that eventually when you take a decision to allow the shell there is a good chance of the target being struck? Today, of course things have become much more sophisticated, you have missiles which are launched from earth which may be launched from an aircraft
all kinds of interceptions are possible. So certainly this is a very hot topic today but this is the application that give rise to term servomechanism, servo refers to or comes from a Greek word which is there in the English word servant, a slave essentially somebody who follows your instructions does anything or everything that you tell him or her and mechanism because obviously, there was a gun which was to be moved which required a mechanism electric power or motor and ways to control the motor like the aircraft there are various kinds of controls or a more aspects of movement of the gun can think of a movement in horizontal plane, so azimuth and then the gun has to be raised or lowered.

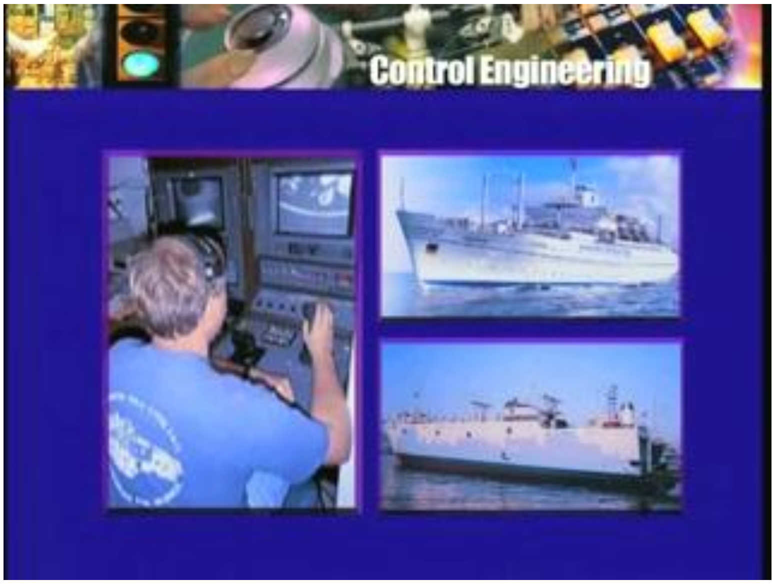
(Refer Slide Time: 50:11)

So elevation, so azimuth movement, elevation, so azimuth control, elevation control and things like that. Instead of a gun which is at a fixed location you may have a gun which can be moved around and again instead of a gun shooting a shell at an aircraft it could be something else a tank military, tank which will fire a missile at another military tank of the enemy. So there again there are similar problems although the guns may not be as heavy but the added problem is that the tanks are moving your own tank is moving as well as the enemy tank.

So this is the different kind of control problem all together unlike the regulator type system where of course there is something desired mainly temperature should remain constant at 27 Celsius or voltage should remain constant at 230 volts AC, RMS there is something desired here but that something desired is not constant not only that, that is something is which is desired is not even known beforehand. Nobody tells you beforehand exactly how the target is going to move because there is a pilot there he might make some maneuvers which are totally unexpected it may be a new aircraft about which you do not know what.

So you have to follow something which is not known to you and yet you have to follow it as closely as possible. So this is a different kind of situation all together and this was of course a very important class of control systems that was the studied during the second world war there were of course earlier applications but they were more like the regulator type system applications for examples, steering of a ship was a major control application.
It is because that to old days ships have been steered for a long long time but when ships became more heavier and had more powerful engines and more speed, more tonnage and so forth the problem become more difficult because again there is the screw or the propeller and there is the radar on the ship which has to be moved in order to achieve a certain speed and a certain direction.

(Refer Slide Time: 52:51)



So when going from one harbor to another, of course one would have a preset course and the course would of course usually will be the known beforehand. So you keep a certain bearing keep going in a definite direction. So in that sense it was a regulator type problem you have to just keep the ship going in a particular direction inspite of disturbances there will be wind, there would be motion of the water waves, turbulence of course storms what not?

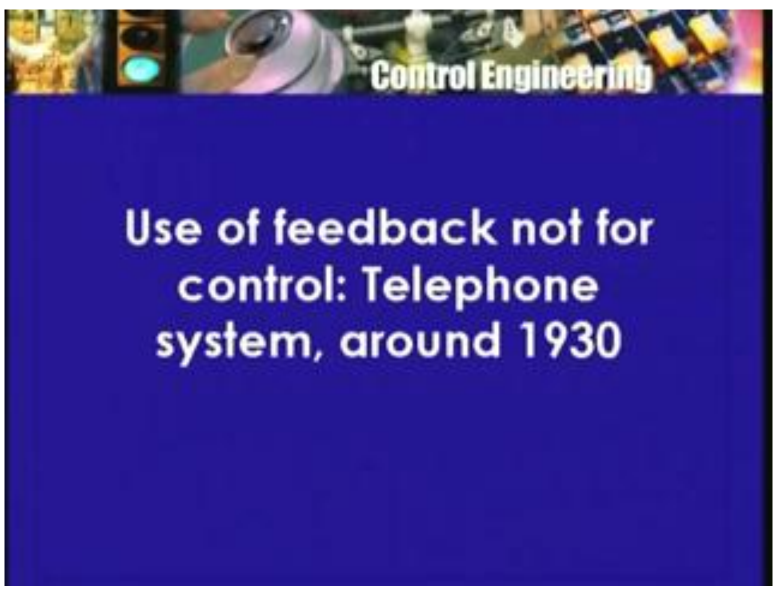
So in spite of that you have to keep the ship on course, so that was almost like a regulator type system, so such control systems were studied one of the earliest work was done for steering of a ship of course much earlier work was done as you can expect for the control of the steam engine and the James Watt a governor. In fact Maxwell whom one knows for his contributions electricity and magnetism or really to the subject which is called electromagnetism bringing the two together also studied the action of the governor form a mathematical point of view and found out that there is some problems or there were some defects with governor and then some improvement could be made that was around 1860's. There were problems of the servomechanism kind even at that time and they were in astronomy and in astronomy you want look at the sky and unfortunately the stars do not stay fixed, they keep on moving from east to west and so you have to keep your telescope moving to follow the stars. Of course the motion of the stars is more or less known accurately.

Today one will say the motion is not that of the stars but that on the earth and the motion of the earth is known fairly accurately is no sudden jerk here. You know the motion of the earth is not stopped suddenly it is not stopped nor had had any jerks but still you have to move the telescope which could be a very massive thing to follow movement of the stars. So it was one of the earliest of the servomechanism mechanism applications and one astronomer is called the royal astronomer of the Great Britain by name Airy did some study of this application. Again it involved obviously mathematical studies because you have to move an object so mechanics so writing down deferential equations and what not so in that sense of theory of servomechanisms is also quite old you can say it goes back 1860, 1870 and so on.

But the second world war is what led to very significant increase in the amount of study in the number of people who were studying in the urgency, in the situation and so on. So a lot of developments took place in what is called theory of servomechanisms in fact there are books with that title, “Theory of servomechanisms” rather than “Theory of feedback control systems” and this continues to the one very important application servomechanisms, follow up systems or tracking systems, can use one of these names so long as the idea is clear there is some desired behavior, the angular position of the gun should be as close as possible to what is desired, the angular position of the target. Interestingly there was a development before the second world war which in a way can can be looked upon as a follow up of control systems.

This was a different kind of application or development, in fact it did not really look like a control situation at all and perhaps it is not looking back one can see that what is involved is not really control action but something quite different. In the USA, in the United States of America there is a big telephone system in operation known as the Bell system, the Bell telephone laboratories which till recently were one single entity and one heard quite a lot about it. They had the telephone network going across the entire United States.

(Refer Slide Time: 58:38)



Now at that time now this is early 30’sor late 20’s, the equipment was of a certain kind. Today things have change drastically there are no satellites at that time, there was no satellite communication, there where no microwave towers, all communication was through cables. So there could be wireless transmission but that wireless transmission was not reliable was not cheap enough and it was not being used and a commercial bases so the telephone system was through cables. Now you speak into a phone in New York and you want be heard let us say in Chicago or in San Francisco.

Now if you have, if you have think of it has just one wire running between New York and San Francisco then obviously you will not be heard in San Francisco, in between amplifiers are required. Otherwise, the signal if you think of a direct transmission will be just too weak, so you have hops or stages may be every 100 miles or every 200 miles, you amplify the signal and then send it out again is a next hop. So this requires a large number of amplifiers put up all over the country at places which may be not so easily accessed after all the whole terrain is to be covered or a lot of it is to be covered. So the amplifier could be at remote place. Now what if something goes wrong with that amplifier eventually one will have to replace it.

(Refer Slide Time: 01:00:31)

Now if we replace one amplifier by another, how do you know that you have replaced the original amplifier by another exactly like it? One of the aspects as you know as electrical engineers who have looked at electronic circuits is what is called the gain of the amplifier. The amplifier amplifies the signal may be by 100 by a factor of 100 or by a factor of 1000 from a certain particular voltage level to another voltage level and so on. Now this gain of the amplifier as you know from your electronic circuits study those of you who have studied electronic circuits, the gain of the amplifier is not constant it can vary over frequency and at that time the amplifiers use the vacuum tubes no transistors had been invented by that time.

So it was dependent on the number of things, let say a replacing the whole amplifier by another would be a problem but an engineer would go to a particular repeaters station as it is called open up a particular amplifier and he may find that a particular tube or valve is not functioning. So what we do we do exactly the same kind of thing today. Take out that thing which is not functioning and replace it by another. So if you see that a valve is not functioning let us say the heater light is not on, so it is gone bad you take it out and replace an equivalent valve or tube.

Now the trouble is the equivalent valve or tube that you have replaced the original with is not absolutely identical with the original tube. So with the replaced tube the amplifier gain may undergo a small change this only one example of a vacuum tube going bad or losing its power, so to speak requiring the change because of the climatic conditions the gain could vary and things like that. So what you needed is an amplifier whose gain will remain nearly constant irrespective of some of these influences, environmental influences may be irrespective of the tube, the exact vacuum tube that you use, the vacuum tube was associated this is some parameters one of them was called the mu of the vacuum tube or the gain of the amplifier of the vacuum tube and so on.

So he wanted to design an amplifier which would not be so sensitive to your parameter mu, even if mu changed by say a factor of 2 it may not change by that it but lets say it change by a factor of 2 or event 20 percent your gain will not change by 20 percent but your gain will change by a much smaller amount. If possible of course no change gain should be absolutely constant irrespective of the value of the mu or irrespective of the tube that you are using or changes in its characteristic. So we have to reduce the sensitivity of the gain of the amplifier to parameter variations, make the amplifier gain less sensitive to parameter variations and one of the engineers of the Bell labs by name Harold Black thought of an idea of doing it and this idea was that of using feedback.

(Refer Slide Time: 01:04:12)

I am sure he got this idea from a control system application typically the application or steering that I have been talking about but this was a first time that feedback was used not for a control application but a different application all together.