Control Systems
Prof. C. S. Shankar Ram
Department of Engineering Design
Indian Institute of Technology, Madras

Lecture – 03
Over view of Feedback Control Systems
Part – 1

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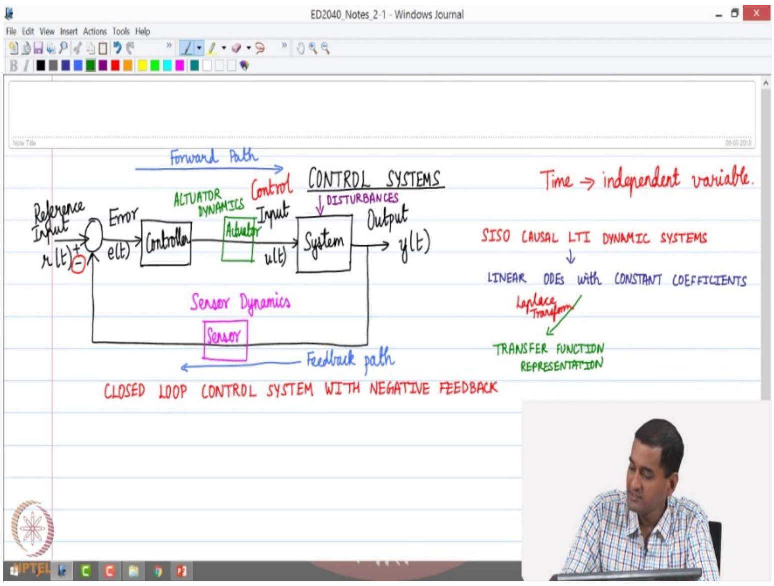

In the previous class, we had a broad overview of dynamic systems. We learnt about a dynamic system and what are the different classes of dynamic systems based on certain attributes. We learned the class of dynamic systems that we would deal in this course come under linear time invariant causal single input single output dynamic systems. Additionally, we learned the definitions of each of these words that we use along with the word system; that is we learned what is meant by a linear system, a time invariant system, a causal system, and so on. And then we looked at what is meant by an open loop system and closed loop system. We also looked at the concept of feedback and we drew the basic layout of a closed loop control system with feedback and that is where we stopped.

We are going to continue from that point and discuss a few more concepts that would provide a big picture view of this particular course, before we go into mathematical preliminaries in the next lecture. If you recall, for us a system is an entity to which we provide an input $u(t)$ and we get an output $y(t)$. If we want to regulate the value of the system output $y(t)$ around a desired point or in a desired region, what we do is that we give what is called as a reference input which is denoted by $r(t)$. Please note that in this particular course, we are dealing with the dynamic systems, time is the independent variable and all other variables are functions of time. We see that the input, output and the reference input in general can be functions of time. We measure this output, and then feed it back and compare the value of the output with that of the reference input. We get an error $e(t)$, the error is the difference between the desired value of the output and the actual output that we are obtaining at each and every instant of time.

We pass this error through an element called as a controller which then calculates what should be the input that needs to be provided to the system so that it can follow the desired output $r(t)$. So, in other words, the controller is the block that takes in the error between what is desired and what is actually obtained and then calculates what should be the corresponding input that needs to be provided to the system.

When the controller calculates the system input and provides it to the same, the function $u(t)$ is then called as a control input. This is a broad visualization of a closed loop control system with feedback, in this case it is what is called as negative feedback. The reason why it is called as negative feedback is because at the summing junction where we are comparing the reference input to the output, here we are taking a difference between $r(t)$ and $y(t)$. So, it is called as a negative feedback.

There can be various other attributes that can be added to this basic closed loop structure, and that is something which we are going to look at now. The path wherein we go from the controller to the system and then to the output is called as the forward path and the part wherein we give the measurement of the output back to the summing junction so that we can calculate the error, which then goes to the controller, is called as the feedback path. And in this feedback path, one can have other dynamic components, which may need to be modeled, depending on the system.

For example, one would typically use a sensor to measure the system output, then one may need to take into account the dynamics of the sensor that is used. In other words, there is an additional attribute called sensor dynamics that may come into picture in the feedback path. What do we mean by that?

Suppose we want to control the temperature of air in a room. If I use a temperature sensor to measure the temperature of air in a room, that sensor may have it is own response characteristics. In other words, if I use the sensor to measure the temperature at this instant of time, it may not show the temperature value instantaneously. The correct value at this instant of time may be showed after a certain response time which needs to be characterized by what is called a sensor dynamics. The question that we need to ask ourselves when we design this closed loop control system is that: what is the time scale of the sensor's response with regards to the time scale of the systems response.

For example; if the system responds in a matter of seconds. And if I have a sensor which can provide accurate measurements in a matter of milliseconds, then I may not need to worry about the sensor dynamics. On the other hand, if the system responds in a matter of seconds and the sensor also has a corresponding response time in the order of seconds, then I may need to incorporate the effect of sensor dynamics.

So, sensor dynamics may come into picture when we consider the feedback path. And correspondingly an additional component called an actuator may come in the forward path. What is actuator dynamics? The controller calculates the control input and provides the control input to the system, but we need some element to physically realize this control input. For example; suppose, we want to drive a car autonomously. So, let us consider the task of steering a car. The angle which is provided at the steering wheel is the input to the system and the orientation of the car can be considered as the output from the system.

Now, if I want a certain orientation for the car, then I design a controller to calculate what should be the steering wheel input that should be provided at each and every instant of time. Now how do I realize the calculated control input in practice? I may put a motor at the steering linkages to rotate them by a desired angle whatever the controller calculates.

Let us say at this instant of time, I want the steering, linkage or steering column to be rotated by 40 degrees. Now the thing is whether I achieve that 40 degree steering angle instantaneously. The answer may be most probably not. If I use a motor to rotate the steering column and I give a command now, it may take some time before which the steering column may be actually rotated by the control input angle of 40 degrees. That aspect or that attribute needs to be characterized by as actuator dynamics.

Actuator dynamics essentially incorporates the response characteristics of actuators that take the controller's control input and realize it in the physical world. So, one may need to consider actuator dynamics. Once again, it is all relative, if the actuator responds very fast when compared to the systems dynamic characteristics. Then one need not consider actuator dynamics. On the other hand, if the system responds in a matter of seconds and the actuator also responds in a matter of seconds. Then we need to consider actuator dynamics while modeling the entire closed loop control system. That is something which we should realize. So, sensor dynamics and actuator dynamics become important when we design these closed loop control systems for real world applications.

What are the other attributes that we need to consider in this a block diagram? Most often we can have disturbances coming into play. Disturbances are essentially unwanted which affect the system output. For example, I am driving a car and there may be some crosswind which is blowing on the road which can act as a disturbance and it may try to change the orientation of the car. So, although in the ideal world, I want the orientation of the car to change only when I turn the steering wheel, a strong crosswind can create a disturbance which can potentially lead to a change in the car's orientation. How does one consider the effect of disturbances and account for them? That is a question one needs to ask when designing this closed loop control system. The effect of disturbances may play an important role, and we have to design a controller that is a robust enough to these disturbances. These are some elements that we need to consider in the feedback diagram,

If you recall the class of systems that we have been considering fall under single input single output causal linear time invariant dynamic systems. It so happens that, if we want to model this class of systems using mathematical models, they take the form of a linear ordinary differential equations with constant coefficients. The mathematics that we use in this course would compose of related topics. We will briefly recap ordinary differential equations complex variables, Laplace transform and so on, that one typically learns in a course involving ordinary differential equations.

Depending on how one goes about analyzing these ODEs to study the systems response, one could have two representations of the mathematical model that characterizes this class of systems. If one uses the Laplace transform, then we get what is known as a transfer function representation. This is the representation that we would predominantly use in this course.

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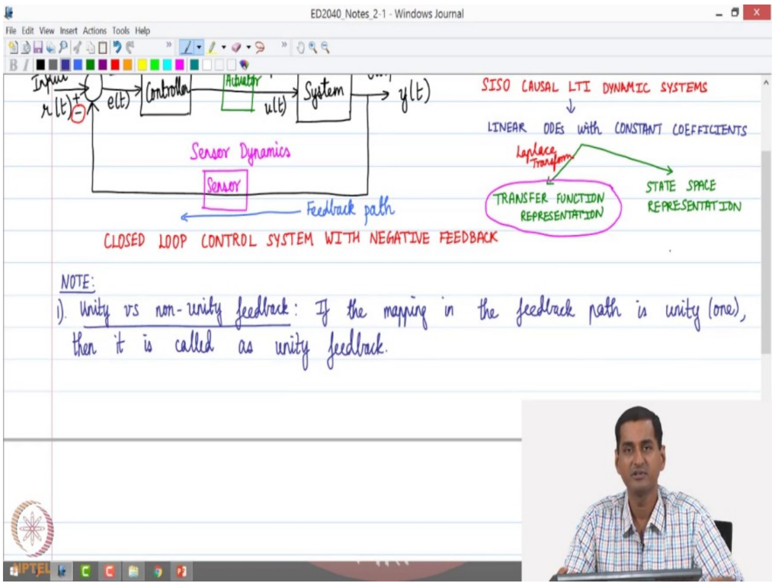

On the other hand, I do not apply the Laplace transform to the governing equations, but I stay in the time domain itself then we rewrite the governing ODE as a set of first order differential equations. And then we get what is called as a state space representation of this class of systems. In this course we would learn both representations. The Laplace transform takes functions that are essentially real valued functions of real variables, and then converts them to complex valued functions in the complex domain. Predominantly we are going to look at the transfer function representation. All the analysis and control design is going to be done using the transfer function representation.

There are a few more concepts that we would be discussing with respect to the general closed loop control system. Let us write down a set of points. Depending on what is the mapping in the feedback path, we can have unity and non-unity feedback. What is unity feedback? If the mapping in the feedback path is unity or 1, then it is called as unity feedback, if not it is called as non-unity feedback. We would have mappings in the feedback path which are going to be represented by corresponding transfer functions.

And if we have unity feedback that particular transfer function for the feedback path would be 1.

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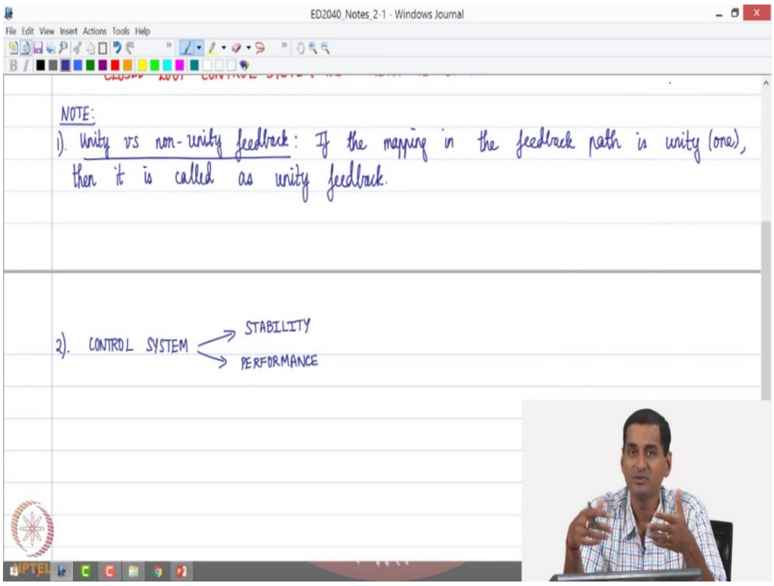

The second point is that, as far as this course on control systems is concerned, any design of a control system has two important aspects. If I am designing a controller for a dynamic system, I always need to focus on two important attributes. What are they? The first one is what is called a stability and the second one is what is called as performance. All of us can get a very intuitive idea by looking at these terms.

For a control system designer stability is paramount; that means, we need to design systems that is stable in the first place. Then we essentially look at the performance characteristics and try to design controllers so that their performance could be improved. Later, we are going to carefully define stability and performance, and also identify quantities and parameters that would essentially be utilized in quantifying our performance characteristics.

For example, I am driving a car, I give a steering input. If the conditions happened to be such that my car may spin out of control. So, one would intuitively call that scenario as the car being unstable. A stable response means I would want the system's response to be as we desire in a very finite range for a finite input which is given.

What is performance? Performance can essentially be visualized through, how fast the system responds. For example; I am designing one steering system and someone else is designing another steering system for the same car. Let us say both of us give the same input to the steering wheel. My car is able to take a turn faster and more accurately, then I would say that my steering system is performing better for that particular car.

We would use a notions like these to come up with parameters that can quantify performance of dynamic system. These are concepts that give us a big picture view of what we are going to learn in this particular course.