Course Name: INTELLIGENT FEEDBACK AND CONTROL

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Week - 02

Lecture - 08

Hi, in this video, we'll take some examples to understand why the controllers like PID are working in practice. In a way, even if we do not model very rigorously why the PID models are working and is giving us kind of a way. All right. So let me first introduce you to a particular biological example where controller design is actually used in modeling or understanding the behavior more understanding the behavior in a better way. So this is the example of our retina, which has cones and horizontal cells.

And you must have noticed that when the light falls on your eyes, your brain takes certain actions in order to increase or decrease these cones in order to make sure that light entering into your brain is an adequate amount all the time. So even when the light is less or illumination is less, then one has to consider that, okay, we still have to be able to see the environment even similar to what even if it is illuminated. And this is one reason that you are able to see even in the dark. So what is the phenomena here is that these cones are primary receptors stimulated by the light and these cones are then stimulate the horizontal cells. And these horizontal cells provide negative feedback to the cones.

In order to make sure that these light which is entering into your brain is less or they adequate or it has a particular set point that has been set for individual person. This way of understanding gives that, OK, this is how the negative feedback is working. But what kind of controller this is? Since if I consider modeling it as a proportional controller. I can explain certain answers but as compared to the p controller if i consider a pd controller it is giving more rapid response and at the same time less offset in the set point adjustment and so on.

So this way, pd control fits better as compared to the just applying the proportional control in this case So what we have now, if we model this cone and horizontal cell phenomena as a negative feedback, what we get is some signal flow graph like this, that I have a set point for the illumination set, and this is the output that I should be getting. In this same case, this particular cone is also a first order system, whereas this horizontal cell is also a first order system with different time constants. So if I design a controller, so if I put them into a feedback loop instead of any other structural form, it turns out that this particular form is nothing but gives you a PD control kind of a structure. You can work out the transfer function between the output Y and the input YSP.

And you will see that the response is turning out to be similar to the transfer function turns out to be the process, which is cones and the PD control. And it turns out that the response is, of course, overshooting, but it gives a faster response as compared to reaching to a particular step input values. For a particular K, TC, and TH, this is what turns out to be my typical response of the retina or cone photoreceptors in retina. What is more exciting to understand here is that the PD control way of understanding the behavior helps us in understanding whether my feedback is working or not. If my certain cells, nodes are not working properly, what will happen is my signal feedback, which is represented by this link, is not working properly, means my sensing is not correct.

If my horizontal cell is not behaving properly, my response is going to be slower, which happens with the aging. And so we can say that this gain and this particular time constant of the PD control is kind of sacrificed, and accordingly medication can be given. If my cone itself or the process plant dynamics has changed because of aging or because of certain things, one can see that the transfer function itself has changed. So what kind of response can you expect? And since we have bifurcated the problem in terms of giving the process and the feedback form, one can look forward for identifying many different problems that can occur because of the feedback and because of the control characterization and so on.

All right, so this is why at times this understanding of the PD control and its behavior helps us in modeling the natural behaviors and identifying the possible problems then. If we have the simplified models, such as the first order model, so these are certain other examples of first order model and the second order model, ee had seen in the last video that if I am having a true first order model or a true second order model, then I should be able to apply PI control or PID control and so on and so forth. So, which are those first order models? These are typically if I want the mass, storage of mass, momentum and energy is captured in terms of a one variable, then it becomes a first order model. Certain examples are velocity of a car on a road, angular velocity of the rotatory system, level in a tank or concentration in a volume with good mixing.

Whereas as compared to the same methodology for a particular system, control objective is position of a car as compared to velocity. Then I need to represent the storage of mass, momentum, and energy captured in two variables. Similarly, stabilization of stiff satellites or level in two connected tanks becomes the problem of second-order modeling, problem associated with the second-order model, and one can resort to an appropriate PID structure. Giving another example of designing integral control in a very simplistic manner. Now, integral control, we know that it is possible to, it is more effective when we have to apply it on the faster dynamical systems.

So, for such systems, for example, my transfer function is a simple first order system and its gain is given by constant K, which is nothing but G at the transfer function at S is equal to zero. So, the loop transfer function of this under integral control can be given by K times Ki times divided by S because my integral control is Ki by S and that gives me loop transfer function as K Ki by S. The corresponding closed loop characteristic equation is given by S plus Ki equals 0. All right, so now if I want to place the behavior of the system such that my desired time constant should be equal to TCL, or the closed loop time constant should be equal to the TCL value, then what we are considering here is the characteristic equation as one plus STCL equals zero, or when we consider here, one by TCL equals K times KI here. Therefore, we can say that my KI should be equal to one by TCL times K, and K is now replaced by G of zero.

Okay. So now the integral gain is fixed at the desired time constant times the transfer function with the static gain and so on. So this kind of integral time designing the integral time control is valid if my time constant of the closed loop system is much higher than the gain K. All right. So now when we have systems which had not represented by just a constant gain, then I can represent I can apply the same same methodology for the system with some other higher order terms.

So G of S then is this particular gain is then approximated by the first order approximation of the Taylor series expansion. So now this becomes G of 0 plus S times G prime of 0, which is the derivative of transfer function G of S with respect to S at S is equal to 0. And therefore, my loop gain, my L of S is now can be given by K I G prime of zero. And this is what is nothing but the the appropriate form that we are writing in terms of this. So what we will consider here is that this Ki times G prime of 0 is set to 0.5, minus 0.5, because that is going to give you the loop gain.

This is setting up as a constant value, which is nothing but 0. A little lesser value as compared to what is happening at S. So this shifts, this adds the bias and this bias should be approximately the half of what we are considering as the changes into it. And that's the reason we'll set this to 0.5. Of course, normalized values of normalized 0.5 value.

So, this gives me the condition for setting up the Ki, which is equal to minus 1 by 2 g prime of 0 from this particular bias formula. Whereas, if my time constant for the closed loop is selected as TCL, then it gives you minus 2 by 2 g prime by g of 0 at s is equal to 0. All right, let's apply this particular integral control on a wonderful example of atomic force microscopy. Now, this atomic force microscopy is used for measurements, imaging, and manipulation, and this particular system is thousand times better than the optical diffraction limit. And why is this better?

You will appreciate it because of the controller design, and the way the controller design has been, or the system has been designed to utilize the controller options. Now, one has to look forward for resolution at the atomic scale, so that is what the microscope is designed for. So this uses the control through a piezo element, and that controls the vertical position of the cantilever beam. Let's understand this through this particular diagram. For example, your sample is placed.

So here, the sample is placed on the piezo drive, and this piezo drive is driven by a sweep generator, which is moving this particular sample in X and Y directions. At the same time, there is a controller, which is changing the Z position of the piezo drive, depending upon what the sample depth is at an atomic level. And how is that measured? This is there is a cantilever here sitting here and which has a tip sitting at the sample. If there is a deviation in the depth, then this cantilever shifts and the photodiode or laser and a photodiode captures that deviation.

Now the objective of the controller is to maintain this particular deviation at zero. So we will try to maintain this piezo sample drive at a particular height. At a micro atomic level, if there is a small deviation in this, we will adjust this Z in order to or the height of this sample such that the deviation is small. Deviation is almost zero. Now, this controller that makes sure that this particular height is adjusted, the recordings of this particular Z input is helping us to map the atomic level disturbances into the sample.

Now, understanding this working is fairly okay. Now, what should I design as the controller for it? Let us understand that. So there are multiple modes for the AFM. We will look into a tapping mode operation which is dominated by the cantilever.

What is this tapping mode? When the sample is moving in X, Y direction, this particular cantilever is tapping onto the atomic, onto this particular samples. Otherwise, this will not be, this doesn't stay here and then you are able to move it. So this tapping mode is dominated by the cantilever vibrations of the system. And this vibrations then can be averaged out with the can be modeled with the help of a spring mass method, which is which is shown here.

Now, this system is having a low damping. All right. So the amplitude of these vibrations decay by e power minus zeta omega n, and therefore, my transfer function can be approximated as a first order system which is given by a by s plus a, and a is given by zeta by zeta omega naught. At the same time, this is averaging over the process because it is averaging over the vibrations that has happened. And that gets recorded in the Z variations and so on.

Now, this averaging process and this low damping part combined together gives you the transfer function of the system, which is given by A by S tau. Tau is given by 2 pi n by omega naught, where the omega naught is the fundamental frequency at which these vibrations are occurring. So, given this kind of transfer function, what we have is that we will use some kind of a control in order to get this Z. Now, why are we choosing integral control in this case? We are choosing integral control because this is a very fast process with high noise levels.

We see that even vibrations are attached to it. At the same time, we want this particular tapping also should happen rigorously and so on and so forth. And at the same time, process is dominated by the dead time. When we model it here, we see that there is an E power of minus S tau term coming up. It means it is a lag dominated system.

And also it has higher order system with all time constants of the same magnitude. So we can't say that there exists a particular dominant pole over here. So, in such a way, in such a case, I am resorting to the integral control and the integral control design we have already seen with the help of g of 0, which was the simplest way of designing the integral control. In this case, my g of 0 at s is equal to 0 is equal to 1 and the first derivative of g with respect to s and s equal to 0 gives you this and with a proper substitution, we get the integral control gain given by A by 2 plus A tau. All right.

With this, we get when we plot the Bode plot, we get a fairly enough, fairly good stability margins, which shows that the design is appropriate. What we have gained out of this is, first of all, the idea behind how the atomic level measurements have to happen with the help of the control design. Now, the second level was which controller to apply. And only integral control has given an answer to us to a satisfactory extent. It was amazing to look at.

And that's the simpler way of designing the integral control has given the jugaad for the atomic force microscope coming into the market. That's all for this video. These set of examples are available in this particular reference. We'll take a look at another example of an unmanned aerial vehicle in the next video. Thank you.