Course on Foundations of Cyber Physical Systems

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Module No # 06

Lecture No # 27

Delay – aware Design; Platform effect on Stability/Performance (Contd.) Corrigendum

Hello and welcome back to this lecture series on foundations of cyber physical systems. So, in the last lecture we almost were done with week 5 so we will just resume from there and we will just have a few corrections appended here.

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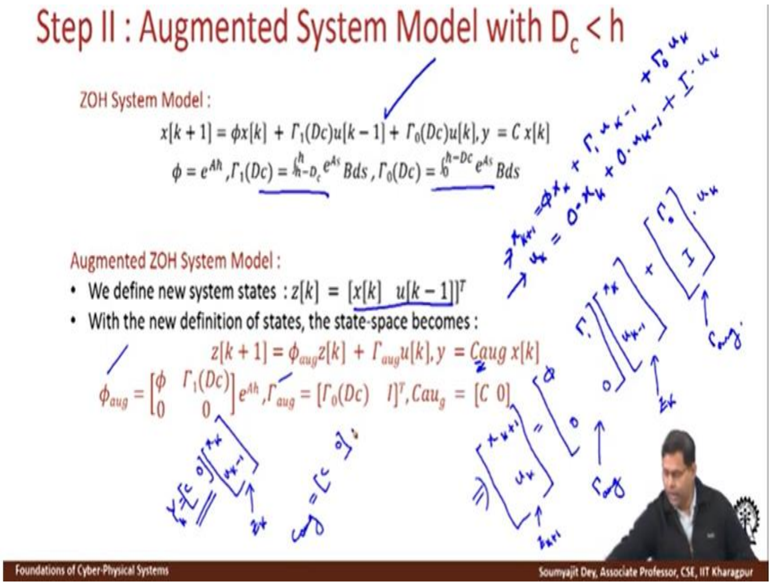

So, if you remember our system modeling with the augmented system. So, this was our augmented system model that we started creating. So before that we had these delay sensitive system equations. So, it was something like this that once we have the delay factored in then we instead of having a Φ and 1 Γ, we are having this Γ_1 and Γ_0 which are kind of given by these 2 terms. So, the next thing that we said was that well let us create the augmented system where we consider system sate with x and u(k), this x and u(k -1) from the previous state. So, this was our decision of taking the augmented state.

Now I will just use some short hands here to create this augmented system model. It is already done here. So, please mind these are should be in the subscripts here so I simplifications this is how the equations would be looking like. And we have the equations for u k. So, please note that I am considering x(k +1) but u(k) because if you see we have x(k) and u(k-1) here. So, I am just writing these equations now u k as we know that it does not depend on x like that. So, u(k) is 0 times x(k) plus again it is 0 times u(k – 1) and this is the identity map. So if we just try to reproduce in the matrix form. So that is your phi augmented. So, this your z(k + 1), this is your z(k) as per the definition. So that is it and if you were writing the output equation well. So here then you have this thing defined and let us define the other matrix here.

As you can see, I have omitted the in-bracket D_c and also, I have written k is subscript for simplicity here. So y k is C x(k) but when my state definition is this is my z(k) so them C matrix in the augmented case is given by C and 0 row vector here. So that is about how we write this definition of the augmented system. And also, there is another thing I wanted to talk about was so if you see from this definition I believe in my last slide I left this thing here as K-1 but it should be K like we have T. And let also go to the response plots which we discussed, so let us have a recap here again.

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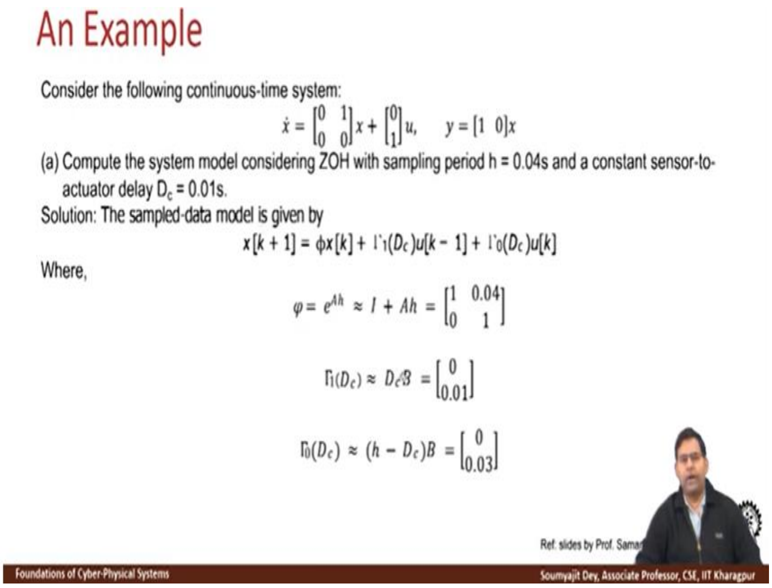

So this was my original system that I took as an example and then I said that well the system has a high sampling period and there is also a scene I mean let us say there is a 25% of the period is consumed by the delay.

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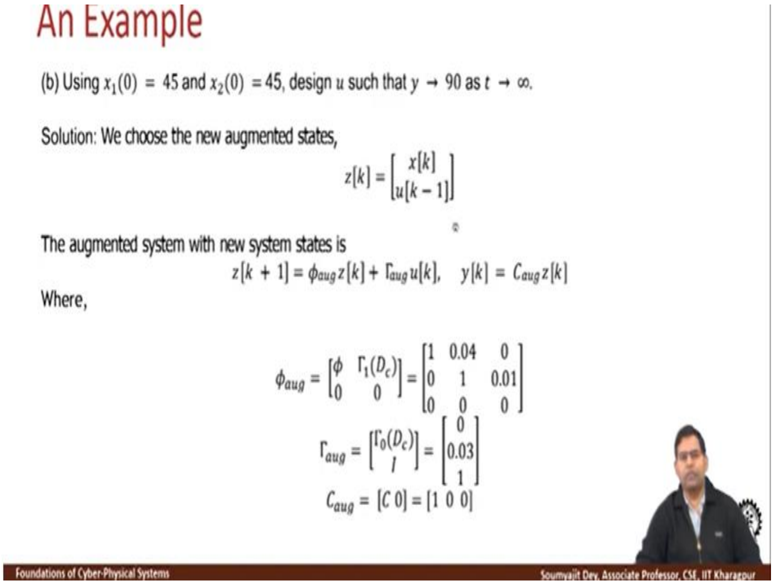

And then we did a modeling delay-aware modeling of the system and for that delay-aware model, we are trying to create this controller. So, that the controller forces the systems output to reach 90 and stay around 90 like that. So, when we created this say augmented system model and from that we created the controller.

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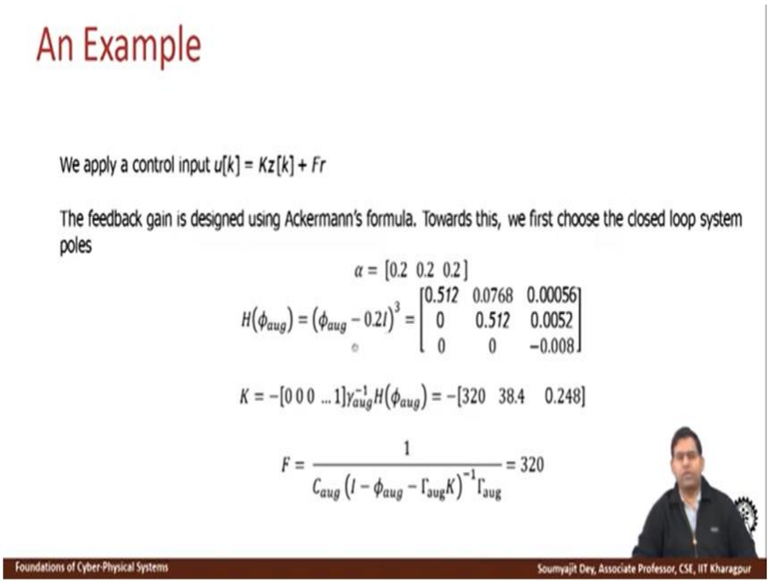

So, you can see that we are able to create the controller of feed forward gain.

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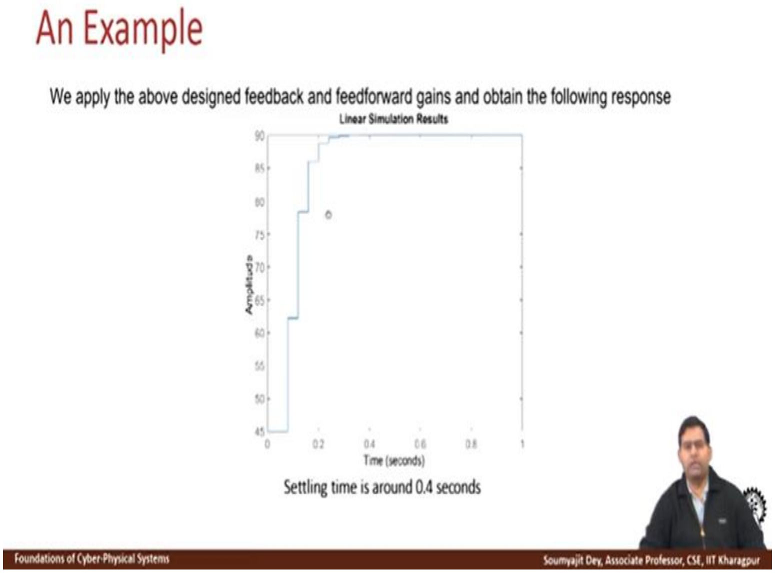

And when we run the system well it is definitely stabilizing around 90. The output is stabilizing around 90 with a setting time that is 0.4 seconds because that are when reaches within that 2% goal of 90.

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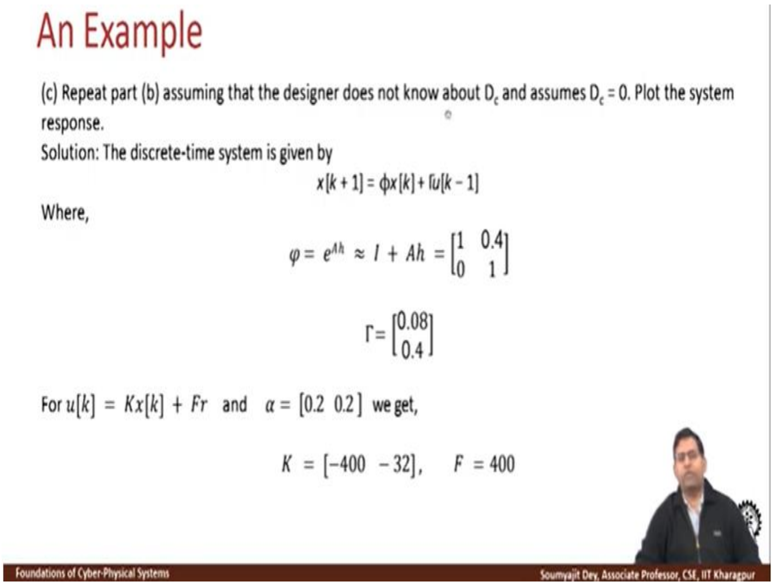

Now the next thing that we did is well we thought that we are unaware of this delay here. And based on that assumption, so I will just have the standard derivation of Φ and Γ and based on that I will just design my controller. So, if you can see the difference between the controllers, here this is your controller. Here it was something different and similarly your feed forward gain value is also something different here.

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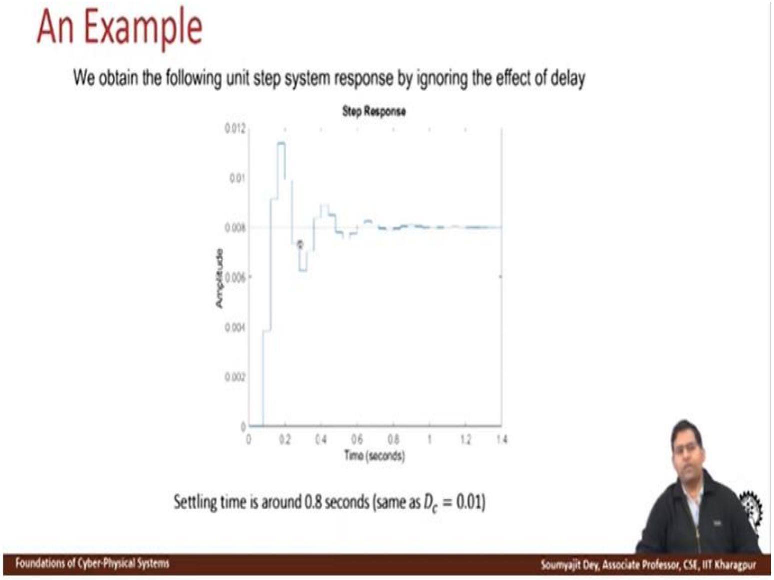

And but still settling down. In your previous case you had a settling time which was 0.4 and here the settling time is 0.8. So, there is some overshoot and then under shoot so you have oscillations and eventually it is settling down. So the performance may not be as neat as the previous case but well you are able to meet your control objective. And we that primary reason is happening because I am sampling the system suitably first. So even if there is a delay that does not really matter.

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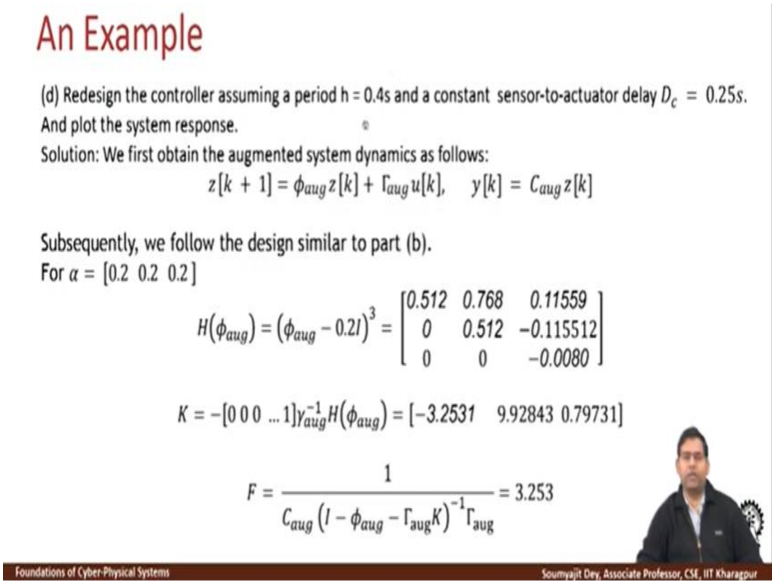

And then here we took the system again and created the augmented system model. But, here we are sampling the plant at a higher sampling period. So less frequently and we have a significant amount of delay here also so almost 50% or more of the period. So for this system again we created here with that a same principle of augmented system design. We can see that well its again settling down around 4 seconds.

And the settling time has also increased but of course the period of the system has also increased. But still it settling down may be its lowering much slower with respect to your previous design here where it was 0.4 or something. But here, I am I sampling is also much less fast, so it is taking much more time to settle down but eventually it is indeed settling down.

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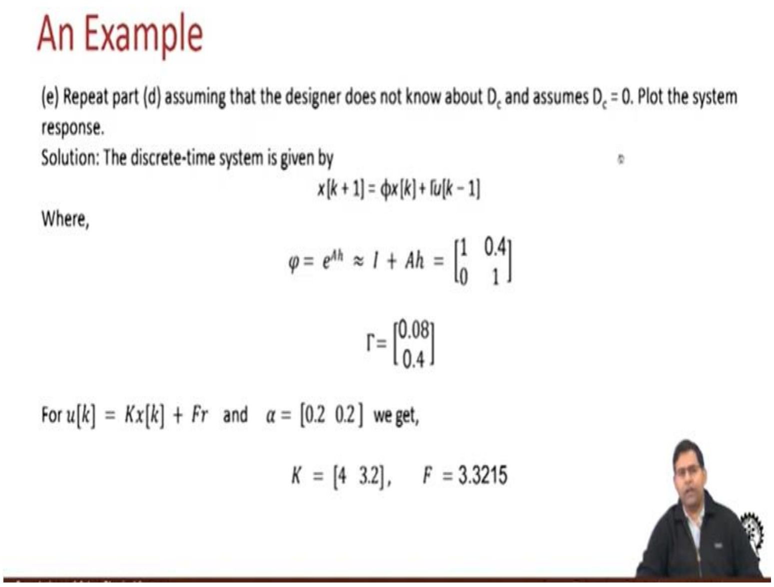

Now let us say you say you create this system, again you assume that there is no delay here. And you can see that well there is this perturbation indeed. So coming back to this example if you see this was my original system and here of course based on this fast sampling what we did was, we created this Φ, Γ_1 and Γ_0 using our previous definitions of Γ_1 and Γ_0 as a function of this delay. And then you go on creating the augmented system and for the augmented system you create the corresponding controller like we saw here. And we were happy with this fast response and smooth settling time here.

And then we ignore the delay and after ignoring the delay here while doing the control design we found that well still the response kind of setter down here and may be with a bit more settling time. But then in this case I just I would like to point out one thing that how I mean, there are 2 plots we are actually showing you so when we are designing the controller for this system without considering the delay at all then what are we doing is, we are first creating this system model without factor running in the delay.

And then we are creating the controller and then we are plotting here, I mean the control systems response where the control gain or whatever this control gain is and its corresponding control update that is coming in every cycle, we are making the system work with that control update control but with that actual delay. Because although my design process here of the controller does not take account for the delay. But the delay still exists in the loop. That means when I am stimulating, I will like to update the control with the delay with precisely this value of the delay which we have here.

This D_c equal to point 0 for 1 second so, then what we are doing is this is our kind of approximate model where we have a controller whose design process did not take account of the delay. But when the control update is coming and here in this plotting it with the delay. And here in this plot if you see that what we are doing is we are actually doing a unit step plot. So while doing this unit step plot we see that well here the setting time is around 0.8 seconds.

Now since the system is that I mean in effect we can say that well with respected to a unit step it is setting down that means the system design is stable. Now since the system design is stable then let us go for updating the reference value. And if you see that here we have the target reference value which was 90. So then let us go for creating the reference value and find lets we need to create the feed forward gain which we already did here.

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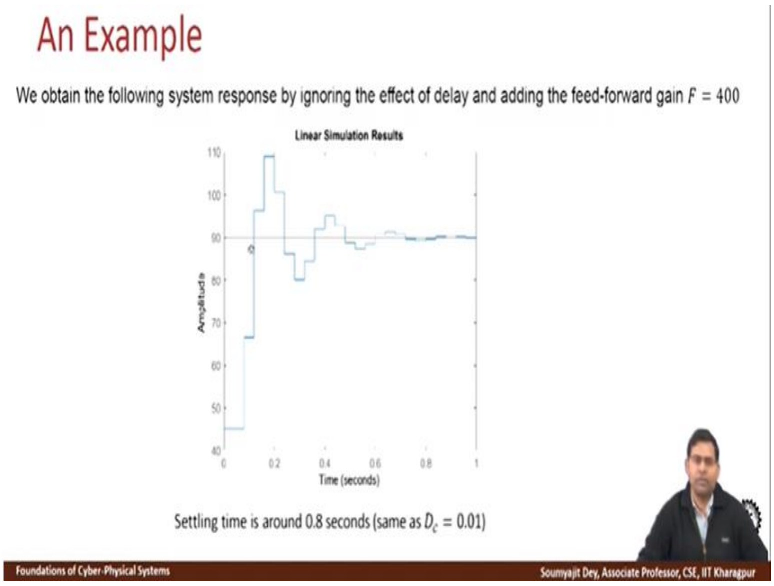

So now let us simulate the whole system with respect to the reference value and this is the plot. So with respect to this reference value we are again plotting it here we have the same settling time that we saw for of course the unit step response. But now we are saying that the systems tracking this reference of 90 and the controller design does not the plant model the controller design does not take care of modeling the delay. But still when I apply the control on in my matlab simulation with this delay still is working fine.

And the next part like I already said that well now if I go for a different thing that is I increase the sampling period and there is also a value of the delay in the loop. And we see that as long as we are modeling it as part of my control as part of my plant model. So this is my augmented system model that I have created. And I have created the controller and the feed forward gain and as long as I am modeling I mean my control design process step account of the delay then when I apply the control updates with the delay in the loop we see down the system response is setting down here.

But again for this higher sampling period if I am assuming that where the delay is not there but when I will simulate delay is not there but when I will simulate delay is not there that I am assuming for the design process. But when I am going to stimulate, I am going to stimulate it with this delay actually that means the controller update is calculated. But it is actually injected into the loop after this sensor to actuator delay when the system is running when the plant is running with the sampling period.

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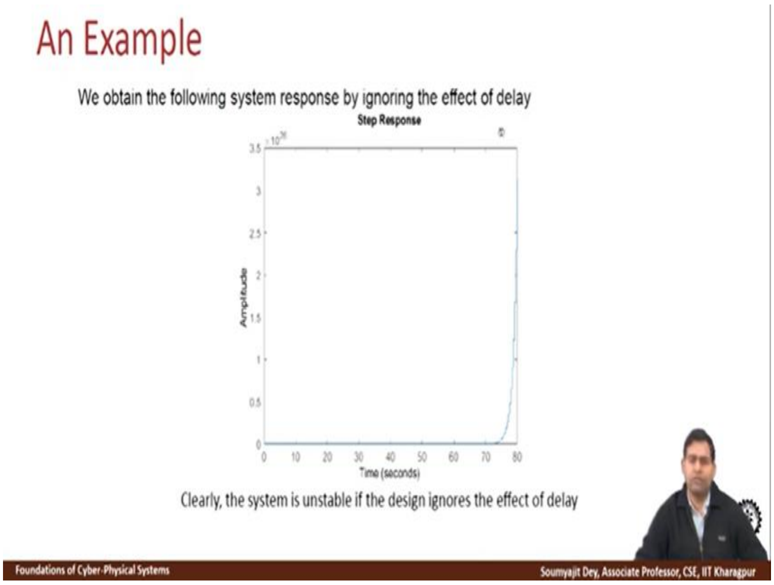

In that case in this modified case when I am doing the step response calculation, we see that the output goes unbounded then that means there is no point in going for really applying the feed forward gain and applying the value of y and trying to come up with a controller which is tracking the value of y which is 90 here so we can see that well here the system is unstable. But when we designed it earlier with respect to the augmented system model, we saw that clearly it was stable.

So that was about it and we found that the system is stable in my step response and accordingly I applied y and F and created the tracking model and I saw that it is working. But when we came here it is I mean when I am applying the control design process with the delay again for the higher sampling period. And till it is working but when I am applying the control design process with the higher sampling period without modeling the delay but actually simulating the system with the delay, then it is not working.

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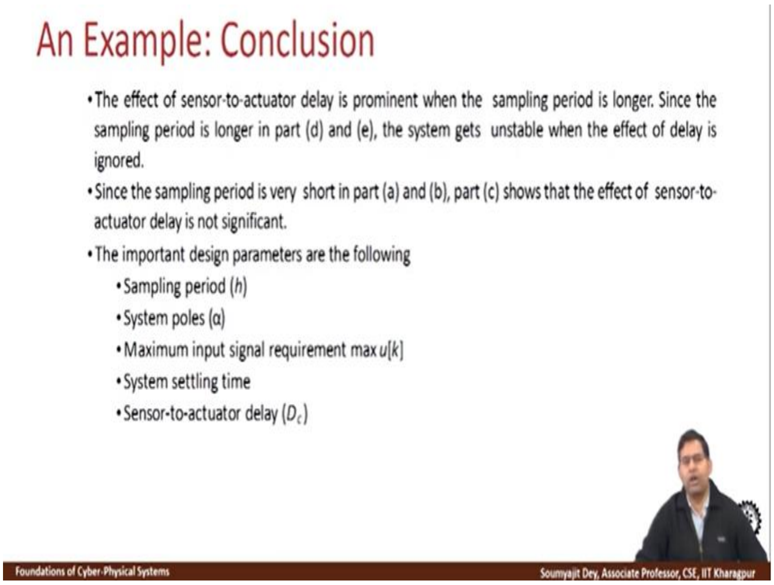

So, that is the point we are trying to make that suppose you have created a controller and that controller programs are scheduled along with some other controllers or some other programs. And there is really a delay due to the scheduling and your control design process is not accounting for the delay. Then you can have this kind of situation happening when you are actually implementing it but in Matlab if you are not simulating the delay you will not see any problem. But when you actually implement it you will see that the problem you will see the problem in Matlab when you actually model the delay without accounting for the delay in the control design.

But if you are trying to create the system with suitable augmented model then you will get nice results even with your implementation. So and similarly if you are having a you if you do not have many other tasks so your professor is quite free. And then you are able to run the controller at a higher rate in that case like we saw that even if you are not modeling the delay while doing the controller design then even when you implement if you can get an acceptable step response and an acceptable output. But this is purely happening because although your design is flawed but your processor does not have much load so there is no delay when you are actually implementing it. So these are the few things we wanted to point out here and may be with this we will end of this session, thank you.