Process Control -Design, Analysis and Assessment
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Introductory Concepts

Let us continue with the second lecture of the course, still an introductory lecture. In the last lecture I talked about singular input singular output control, talked about what Servo control means, what regulatory control means and so on. And I made the point that most of the time we study singular inputs singular output control.

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However real processes are really multiple input multiple output this is actually a picture that I had shown at the end of the class last time where I said if you have a plant like this there are likely to be multiple inputs that you could manipulated to control multiple outputs which are of interest from a profitability or safety or any other point of view that you might have.

So the question is if we learn CSO control quite a bit how does that (())(1:07) to this MIMO control is an interesting question that we would like to answer.

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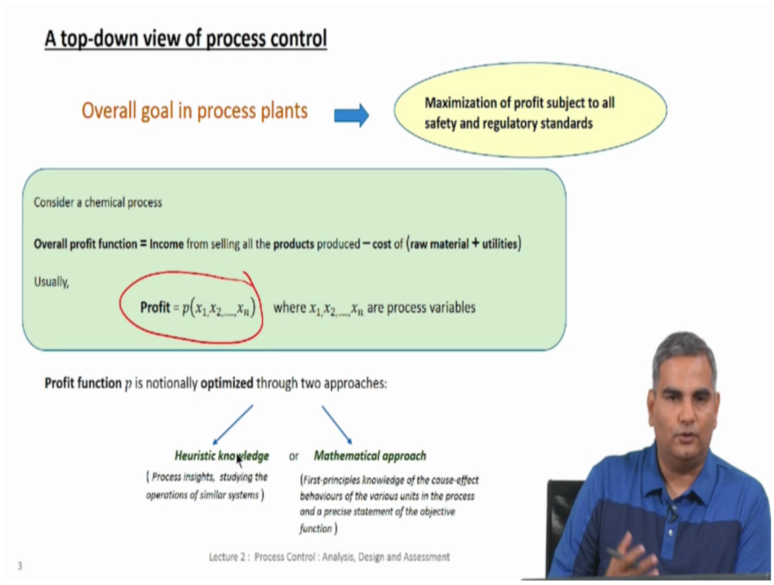

So let's take a top-down view of process control. As I mentioned in the previous picture the overall goal typically in running a process plant is maximization of profit. Obviously subject to all safety and regulatory standards let's consider a chemical process such as the one I showed in the previous picture just for mental image of what we are talking about here. It could be any other plant.

If you want to compute the overall profit that you are likely to make from this plant, so you can write it is following, it is income from selling all the products produced minus the cost of raw materials that are used to produce these products and also the utilities that we use. So for example we might need electricity to run the plant, we might need heating, cooling and so on. So if you subtract all of those cost out then that will give you the profit that you are going to make.

Mathematically you could write this profit as a function p which is a function of several process variables that might participate in this profit function. Now the idea is really to figure out how to maintain these values at certain values and of course what those values are supposed to be, so that I maximize my profit. There are 2 approaches to doing this; one is to actually mathematically formulate this profit function as a function of several process variables.

And then say if these process variables were to take certain values than this profit function is maximized. However because most processes are rather complex and the first principles modeling of. And the process is themselves become very complex. Usefully this is not how people identify the values for these process variables. In general what you do is you might have done subsystem testing.

So for example if reactor is a part of a big process you might know that the optimal temperature at which I should run this reactor is this, so you would use that value instead of doing a composite profit function and so on. So from small subsystem testing on lap resting you have decent idea of what values you want these variables to take and of course you will use your process inside to come up with these values.

And also look at similar systems and what ranges of these variable values to they operate and so on. To get you an idea of what numbers makes sense. So this is what I have written here as heuristic knowledge this is what is done in most process plans to come up with values for this variables that will maximize the profit.

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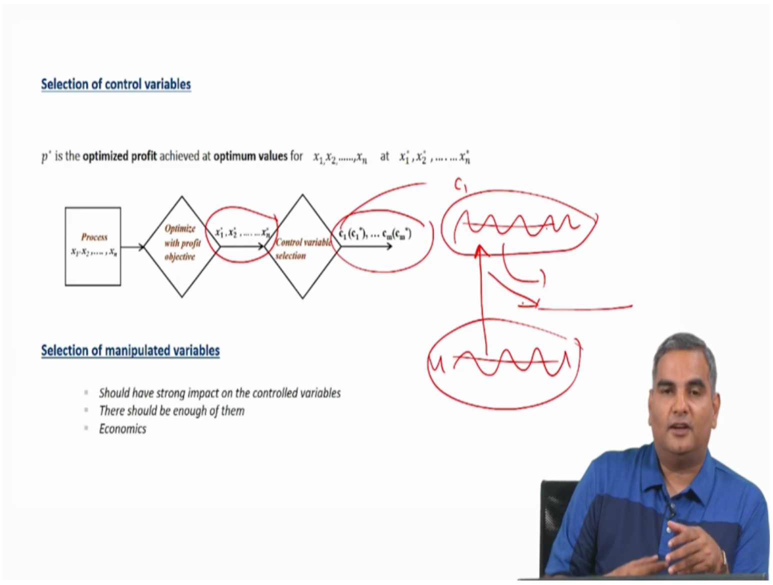

Now once you have this profit optimized at these values, so that basically means that you have to maintain these variables at its values. So in some sense you have to control these variables to take these values the problem of control variable selection it is the one where you have a process, you’re going to say how many control loops do I need? Do I need 10 control loops, 15 control loops, 20 control loops?

That’s a question that we are trying to answer. So the logic is that I need to keep all of these variables at some set values, so out of those I might pick the ones that are most sensitive and then say okay those are the ones that am going to control at those values. So that’s one simple idea that you could use or you could say I'm going to find a linear combination of these variables.

And then maintain them at certain values and so on. So there are several heuristic ideas that one could use to figure out what variables that you want to control. Of course outside of this there are certain variables that are related to safety which you will surely want to control. For example temperatures and pressures when temperature and pressures go high in a process you really want to control those.

Because the reactor vessel will have metallurgical limits beyond a certain temperature it might crack, melt and so on and beyond a certain pressure this research might burst. So those are standard safety critical variables that you need to control. What we are talking about here is outside of those the variables that are things that you want to control, so that you run your process optimally.

So you would pick in some senses subset of this variables as control variables. So when you think about the process picture that I showed you and you are trying to think about how to control this process, the first step of what are the variables that I need to control, is done is this manner. You could do all of this very mathematically in very sophisticated fashion but in most cases in real industrial practice it is done more from prior knowledge and insight about the process.

Okay, so at this point let's say I have figured out how many variables that I want to control. Now as we talked about in the face of control then we have variables that we want to control we need to figure out variables that we should manipulated. So I have to find out what variables can I manipulate in the process. So manipulation automatically means I should have some mechanism of changing the values of these variables.

So for example if I have a pipe and there is a flow-through a pipe and I want to manipulated the flow to take any value I want then basically what I need to do is I have to put in a valve what we call as a controller and actuator which I manipulated make the flow be anything that I want. So I have to figure out variables such as this, do I want to have manipulated flows? Do I want to manipulate some pressure so that I control something else and so on?

So I need to find enough of these manipulated variables, so that I control the variables of interest. So in general heuristically the notion of selection of these manipulated variables goes like this. Of course these variables should have a strong impact on the control variables. So if

I have manipulated variable which I change and nothing happens to any other control variables that this manipulated variable is not useful.

So I want to find manipulated variable which have very large impact on the control variables. Now the 2nd thing is there should be enough of them, so if I have 10 variables that I want to control at certain values and if I use just one manipulated variable it's not going to work most of the times. So I need to have enough of them and really if you think about control there is a notion of a moving variability from one variable to another. What I mean by this is the following.

Supposing you take these control variables C1, we wanted to maintain value here but because of disturbances let's say it is varying like this. So basically what we want to do is, we want to go from here to situation where it's flat. That means I want to reduce the amount of variability in this control variable and as they say there is no free lunch. If you want to reduce the variability here that variability has to be moved to somewhere else.

So the essence of control is basically moving this variability to a manipulated variable. So that manipulated variable moves but it keeps this to be a consistent value. So in some sense I'm moving the variability from a control variable to a manipulated variable. Clearly I'm trying to move the variability because this is not good for me from an economic point of view.

So if I find an equivalent variable where if there is variability it is not really good for me then there is no point in doing control. So the idea is to move variability from variables of serious interest from of a profitability viewpoint to variables which can change will not have a big economic impact but these changes will make sure that the control variable is tightly controlled.

So the economics also plays an important part. So to summarize when we look at a process plant such as the one I showed then you have to do a careful selection of controlled variables and a careful selection of manipulated variables in much more advanced control classes are advanced control techniques one can talk about how to do this very systematically, mathematically.

But in general you might understand this more heuristically and then say the control variables are the important ones from the profitability viewpoint and the manipulated variables are the ones that are enough for me to manipulate, so that the control variables stay at their desired value.

And in fact most industrial processes the choice is usually through some heuristic like this.

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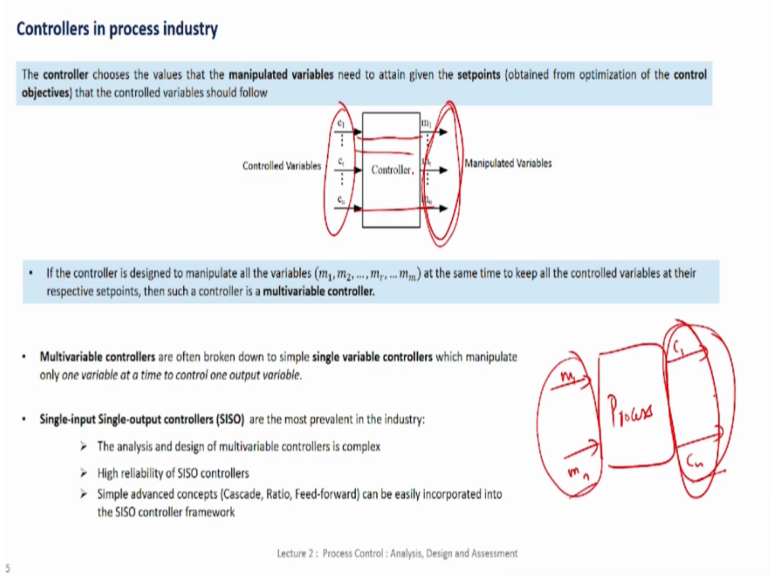

Now that we have let’s assume chosen the control variables and manipulated variables and notice in the blog diagram that we have been showing. So if I have a process block, okay. So what we say is that if there are let’s say several manipulated variables in this case I’m calling them m1 to mn and let’s say there are several control variables, if I draw a blog diagram like this.

What this means is that if I manipulated all of these variables, so the process whatever the connections are, the physical connections the control variables are going to take certain values, so this is a process model where by manipulating these variables I can change the control variable values and only because by manipulating this variables I can change this control variables values.

I actually control these variables to whatever desired values that I want them to take. However from a controller viewpoint the idea is to say, okay if these are certain variables and they have to take certain values, how should I choose the manipulated variables, so in some sense the controller is the inverse of the process? In the process the manipulated variables dictate what output is.

And in the controller the outputs dictate what the manipulated variable values are. So if I have so many control variables then controller in some mathematical calculation which will see the values of this control variables, check them against a desired value for them the set points and then decide the manipulated variables have to be set at these values and once these manipulated variables are set at those values because they are physically connected through this process they are going to change the control variable values.

And then again you will check whether these control variable values are close to their desired values if yes then no need for any more manipulated, if not you keep manipulating till the control variables go close to the desired value. So that is the basic idea of control. So if you think about a truly multivariable control then what we will say is there is a controller which gets (())(12:49) all the control variable values and the controller has to decide all the manipulated variables at the same time, right?

So if you truly think of this as a multivariate problem you should solve this at one shot. However in the previous lecture you would have seen that we have single input single output, right? So one manipulated variable for one control variable, so one might ask this question and then say look I want to do this multivariable control. However I want to only implement single input single output control, okay.

How do I do that? So immediately you will notice that if I have to break this down into multiple single input single output controllers then I have to pair the control variable to manipulated variable. So I might say C1 is parity with m1, C2 is bad with m2 and Cn is paired with mn, right? So I might have to figure out for every control variable what is the corresponding manipulated variable, so that I pair those and then break them into single input single output controllers.

Now in real industrial practice as I said before many of the processes used this kind of pairing to come up with multiple single input single output controllers, so that the process can actually be control very effectively. If you ask why would someone want to do this? The reasons of the following.

Number one as you might imagine if I have let's say hundred control variables hundred manipulated variables thinking about all of them and looking at a control which has multiple control variables and multiple manipulated variables might become very complex and it might not be easy to understand, how to design this controller? So the analysis and design of multivariable controllers might become too complex for standard application in many industries.

The 2nd and more important reason is supposing I were to do this multi-variable controller that is multiple variables are being controlled by multiple and inflated variables, let’s say the controller fails all engineering systems have certain reliability all of them are prone to failures. So if the control system fails then at one chart you lose control of hundreds of variables.

So that is something that people worry about, so you don’t want to do that. Instead if I had broken this problem into let’s say 50 or hundred single input single output control systems even if one of this SISO controllers fail all the others are working. So from reliability view point it makes a lot more sense to think about the problems like this.

Though breaking a multivariate controller into single input single output control is could give you are suboptimal solution. And the 3rd reason is whatever is optimality that is lost because I’m breaking down a multivariate problem into single input single output problem those can be somehow compensated for by using very simple advanced concepts such as cascade control, ratio control, feed forward control and so on.

These are what are called as traditional advance control ideas and this can easily incorporated into SISO controller framework. So it’s a very simple block that you can add to existing control is. So we avoid complexity, we maintain reliability and we compensate for sub optimality through very simple techniques. So multiple single input single output controllers are actually very effective even for real multi-variable processes.

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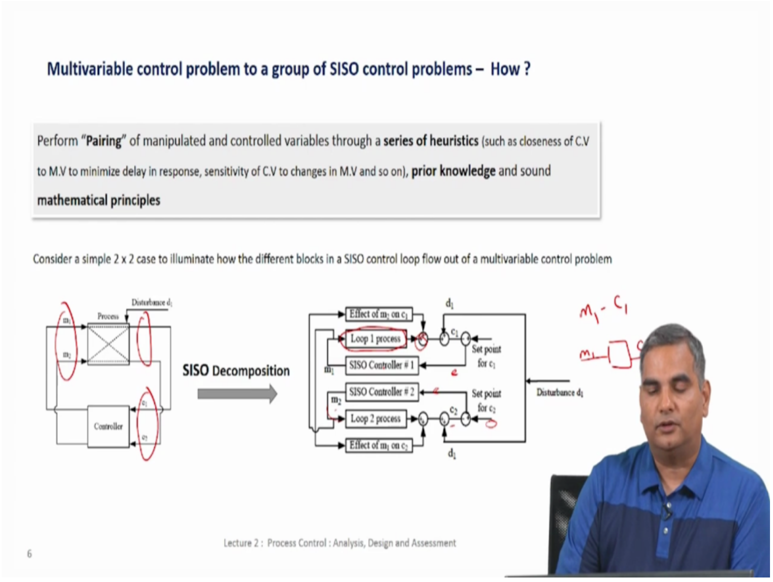

So let's kind of think about how that large problem is broken down into smaller problems, the reason why am showing this year is to give you an idea of how for realistic, for real industrial problems we start from an overall concept of control which is inherently multivariable and then we break that down into single input single output controllers and think about single input single output controllers for the next 15 to 20 lectures.

So I just want you to understand that while we are doing the SISO controller it's not as if you're not solving the original problem, we are still solving the original problem through clever means is something that you can think about. So let's take this process for example, so here much like how I have shown in the previous pictures, so this process has let's say 2 manipulated variables and the output 2 control variables.

So this is a process where the manipulated variables are the input and the control variables are the output and as I mentioned before a controller is an inverse of the process. So here I have the controller values as the input and this gives me the manipulated variables as the output. Now if I were to do this truly in a multivariate fashion I should get these values and then do some computation.

So that m1 and m2 are calculated together for these 2 values but as we have been saying what we are going to do is we are going to break this down into single input single output controllers. So when we do that the blog diagram may look like this. Let me this one thing here to give you an idea of what is happening. So let's say I pair m1 and C1 then this loop one of this process.

This blog basically says whenever there is a change in m1 how does C1 change, okay. So this blog has m1 as input and C1 as output. So this C1 goes here and because this process is multivariate the changes in m1 is not the only thing that is affecting C1, the changes and the other manipulated variable m2 could also affect C1. So this is what we have and because of linearity here we can say.

The total change in C1 is because of changes in m1 which is acting to actually control C1 and also changes in m2 which is acting to control C2 but because it's multivariate whenever that changes there is going to be effect on C1 also. Now this combined effect shown as C1 here and that is compared against the set point to generate an error. So remember this is an error only for C1.

And that error goes through the SISO controller which has only one single input which is the error between C1 and its desired value and it decides what m1 is. Now a similar situation occurs for the other loop. I have loop 2 you can see that m2 effects C2 and any change in m1 which is because I want to control C1 it will also have an effect on C2. So these 2 are added and then I have C2 value here which is compared against its set point and that error goes into the 2nd controller which decides what m2 will be.

So when I go from here to here I have not lost anything at all because though I'm thinking about these SISO controllers the effect of the other manipulated variable and still showing in this picture. And the effect of the other manipulated variable comes in as a disturbance to the individual SISO loops, so that is how you want to think about the SISO control.

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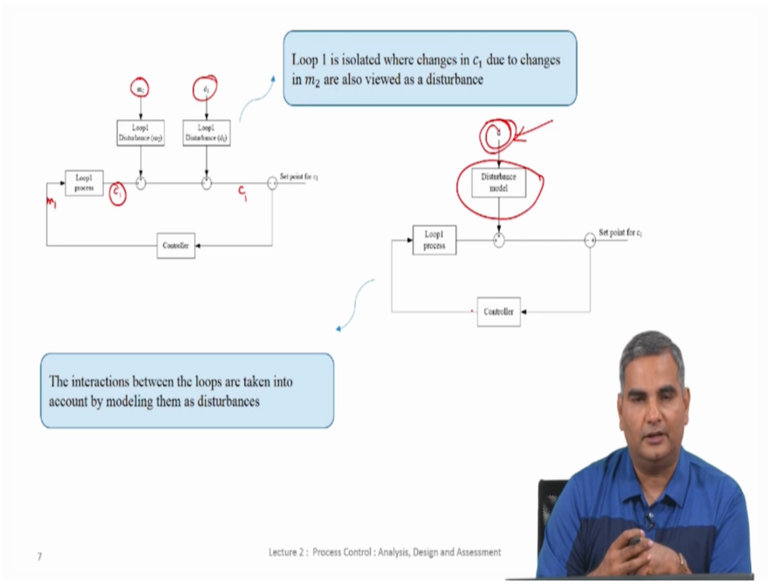

So when we finally look at this what happens is you can simplify this into this blog diagram where you have loop for process one, so which is basically m1 coming in and the effect of m1, c1 because of the effect of m1 here and now I have broken down that pitcher into 2 different pictures. So I'm going to say the effect of m2 which is the other manipulated variable you might want to think of that as a disturbance that changes the value of the control variable C1.

And there might be other disturbances in the process which also change the value of C1. Nonetheless this C here, C1 here is a combined effect of what m1 has on C1 which is directly the manipulated variable that used to control this. And the unavoidable effects of m2 which is trying to control C2 on C1 and the unavoidable effects of disturbances which anyway we have no control over.

So you could see that I have now got a single input single output loop for C1 and m1 where the effect of m2 is counted as disturbances. Now further simplification is because it is linear I add all of this and say this is one disturbance and then I have disturbance model. Now this looks like you have standard single input single output controller. There will be a corresponding single input single output feedback block for C2m2 pair also.

Now how do I analyze control look like this for a multivariate process? What you typically do is this disturbance is something that is known, so once you design the controller which you will study or learn as we go through this course, you will check how well this control loop works for all kinds of disturbances? And you will check how well this control loop works for all kind of disturbances.

Because you know that there are natural disturbances that come from the environment and also the disturbances that come out because the other loop is trying to control for C2, right? So by looking at various disturbance models here and then ensuring that this loop works even when there are several different types of disturbances, we convince ourselves that the single input single output loops will do quite well for the multivariate process.

So that is a basic idea of how we break down a multi-variable scheme into multiple single input single output schemes. The critical idea here is that you should test these schemes quite well by looking at several disturbance models to see that whatever interaction effects we have lost, we still analyze them and then see whether the loop is going to perform well even in the presence of such interaction effects.

So I hope this gives you an idea how a multivariable control problem is broken down into several SISO control problems though we lose optimality I hope I've convinced you by looking at it in this fashion when we test the single input single output control loops we do have a notion of the fact that this testing is being done for an inherently multivariate process and the last optimality could be made up by simple very traditional advance control as I call it.

And all that you learn in SISO control is really in some sense very useful for real process control also and in fact this is borne out by the fact that about 90% of all control loops in industrial processes are really SISO loops and they still perform very well. So with this I will stop this lecture and I will see you again in the next lecture with more concepts in terms of feedback control in nomenclatures, different control structures and so on, thank you.