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TECHNOLOGY ENHANCED LEARNING

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ADVANCE PROCESS CONTROL

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Lecture No. 1

Topic:
Development of Control Relevant
Linear Perturbation Models (Part 1)

Sub-Topic:
Linearization of Mechanistic Models'

Today what we are going to do is give you an overview, give you a motivation as to why do we need to look at this Advance Process Control. What is advanced what do we really mean by Advance Process Control, why are the different techniques that we need to use to develop an Advance Process Controller.

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And finally of course I will end up with what is the outline for the course. Well this course is going to be more of a control theory course. So I know that the classroom is mixed. We have students with different background, not just from Chemical Engineering. So we have students from Systems and Control, we have students from E and Mechanical Engineering and Chemical Engineering.

So most of my course is going to be generic in some sense and I try to pick up examples which are appealing to every branch does not matter in which, so I pick up some simple example to teach and use some theme example and this theme example will be used to teach concepts and in a simulance, you can pick up specific examples to a domain and do an assignment.

So the course will consist of, of course exams and quizzes but a measure component is going to be programming assignments or a budget. This is because this is an advanced course and everything that I teach cannot be done in an exam. You need to program and understand the concepts. I will be giving you programming assignments and I will also be giving you sample programs which I have developed.

So that you have some reference as to how to develop programs on these kinds of things and then the idea is that these, we will touch some tall problems and these tall problems we are going to use throughout the course to implement the concept that we learn in the course. So whatever you study on board, we will also solve some problems in the class but we also do simulations and you know try to understand.

The concepts through actually implementing it, actually doing it okay. So the course is going to be intense, its advanced process control, its advanced course and at the end of the course I expect you to know how to if you just land up in an industry, how will you do this advanced control, how will you.

Now my course is going to be having three models. I will explain them soon, what are these three models, why are they required, what is the relationship and so on. So these three models form three pillars of advance control and we will try to have a roughly two or three assignments in which we actually implement, we actually solve, you know, a toy advance control problem in simulation.

We are going to start from data. So the situation I am considering is we will end up in the industry where we have been asked to develop an Advanced Controller. You know, you open a control book they will say that well you can, to develop an Advanced Controller I have a mathematical module. In reality when you go to a company and if you ask them where the mathematical module is for this, they will just laugh at you.

There is no mathematical module developed by company people. They are too busy doing the stuff. For that you have to know how to do it. They have not attended our course. So you should start from scratch, you should start from where you have no information about a system given some system and said that now okay develop a new Advanced Controller from this system.

So we will start from data. We will develop models which I call is control relevant models. These will be developed either from data or from physics we will learn how to do both ways. So this will be about one, one and a half month I will spend on how to do module development which is control relevant.

Then I move to something called state estimation or a simple word for this would be soft sensing or software sensing or whatever you want to call it. Now we will look at it what it means today itself and then is not this soft sensing, how I develop Advanced Controller, how do I go ahead.

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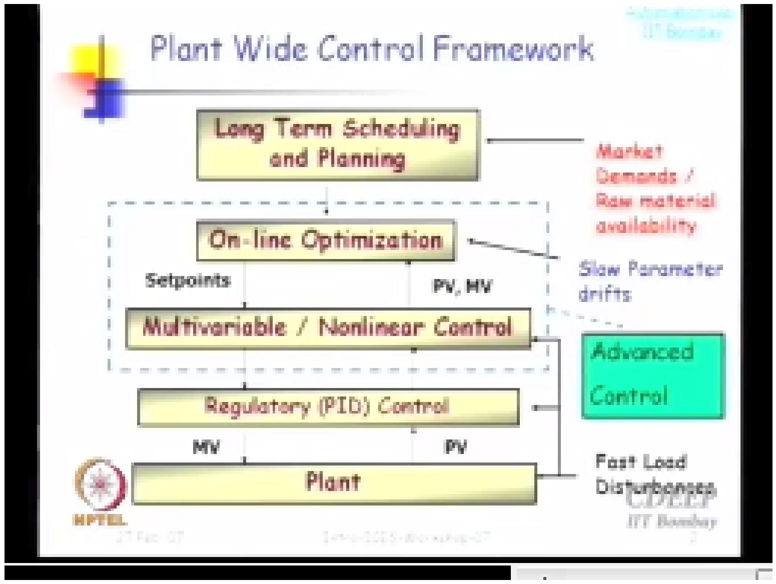

So let us begin this with a module plant, a chemical plant or a manufacturing plant or a power plant. It consists of controllers which are made this is the hierarchy which is shown here. You have variety of controllers. The simplest one which you studied in a first course is regulatory or PID controllers. So this PID controllers form the backbone of most of the control schemes and their majority, a large number of PID controllers.

How do you understand behavior PID controller, how do you come with its tooling parameters. All this is covered in your first course in control and I assume that most of you who are doing this advance control have atleast exposure to first course in control. So you know what a PID controller is. You have heard these names. The next level is what I am calling as Advance Control. Advance Control consists of two blocks.

First block is multi variable and non-linear control. What is multi variable? What is non-linear? I will go into that step by step .Then there are two layers here. One is called as Control Layer; the other is called as Online Optimization Layer. The Online Optimization Layer is, well you see a module based system that actually guides the multi variable controller.

So we have a Online Optimization scheme that keeps tell them what is the best way to operate the plant. Then there is one more layer which is said to be on the top of it which is called as Long Time scheduling and planning. This is also a control layer and control companies like Honeywell or richement but there are solutions in all four segments.

That is well of course the bed in bottom is regulatory control (PID controllers), they provide hardware and software for PID controllers. They also provide software and hardware required for implementing multi variable controllers. They have tie ups with specialized companies which can do Online Optimization and they also provide these companies today, advanced control also provide Long Time Scheduling and Planning solutions. Scheduling and Planning solutions deal with a range of issues like market demands. Let me tell you a specific example if you become easy even though it is from derive.

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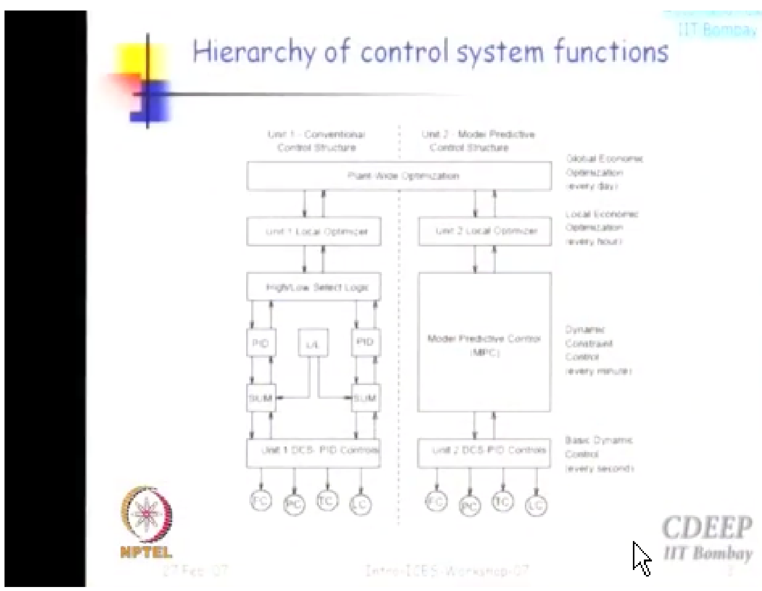

Which is from Chemical Engineering?

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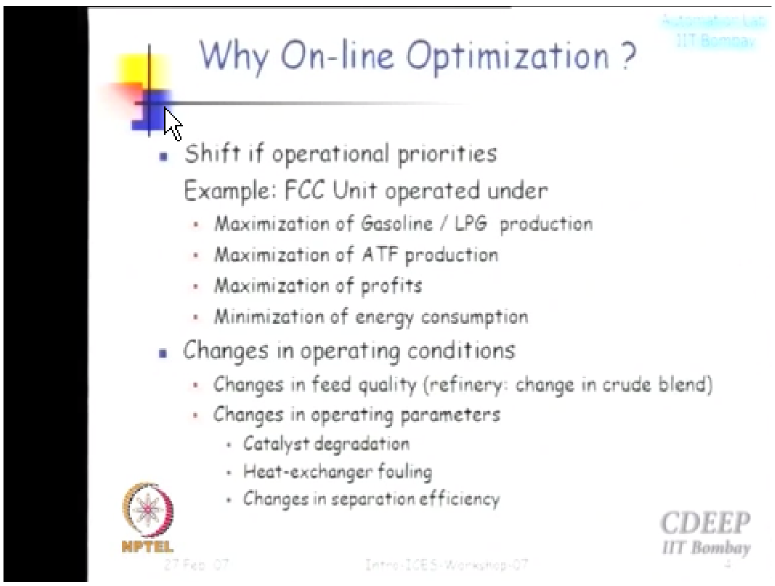

Let me consider an example of refinery. In a refinery what you do is you take coolant and get different products like gasoline and LPG and kerosene and so on. What happens is, in the first step you actually do distillation and separate these products and then you get heavy tar okay, which is not so much useful for running a vehicle, so what we do is, we have something called as of full ice catalytic cracking and we actually bed down.

These heavy materials into lighter products to create more gasoline, to create more petroleum, more radiation type of fuel and this process is called as full ice catalytic cracking. Now the question is, how do I run a four full ice catalytic cracker? When I am running this, there could be different operational goals, for example, operational goal could be I want to run catalytic cracker such that our fuel is maximum gasoline or I produce maximum.

It is month of December, there is lot of people travelling all over the country and I need to produce more aviation type of fuel. In let us say month of October, you have Diwali and you need more kerosene for political reasons or whatever. So some of the times I want to run the reactor such that I maximize the profit or someone might say well I want to run the reactors such that you minimize the energy consumption. So there are all kinds of operating goals.

To meet these operating goals you have to make decisions as to what should be the operating point. What should be the temperature, what should be pressure inside, what should be the cooling fortes all kinds of things. How will you decide this? You can decide this just based on experience. Once there is, you have a module for this reactor system it is a complex module consisting of differential algebraic partial differential equations.

This module is then used online periodically. Let us say every 8 hours or every 16 hours to decide what should be best operating point under that given conditions of operations and what should be under the given target. All company might receive a target but this month produce more aviation type of fuel okay. So how do I change the operating conditions is that I maximize elusion any production.

It also has to react too many of the things, for example, plant conditions keep changing. You have a catalyst doing this and a catalyst can degrade or it can start malfunctioning or you have heat exchangers and then heat exchangers have fouling problem and heat transfer reduces. So you have to keep, actually you have to be watchful and you have to keep moving the plant in such a way that you maximize or minimize whatever is your operating goal. So a modern plant will consist of multiple layers.

Those of you, who have distention control background will probably recognize some of the blocks that we have PLC stands for Programmable Logic Controllers. So these are distributed digital control systems which actually control a complex plant which are they use multiple PID controllers they use logic blocks like if-then-else, if this happens do, if that happens do that and all kinds of things.

Very adhoc with the practical way of handling problems. The modern way of doing it is through what is called as Modern Predictive Control so this Modern Predictive Control is a practical version of so-called classical optimal control and you have a optimizer sitting on the top of these modern predictive controller or on the top of the local PLCs and you have a plant wide operation based control which is either we can, entire plant, difference of units.

The overall optimizer looks at what is best way of operating the plant okay, Let us say over 1 month period or over 2 month period, what should be done. Should the first 15 days should it be perfect maximization, next 15 days could be energy minimization whatever.

So what is the best way to operate this plant is the high level task. What is that we are going to look at, advance control? So what I am going to say here is that advance control today actually is a multi level problem. It is a very complex problem and it requires expecting the different people. From hardware to control engineers to domain experts to optimization experts, scheduling planning, IUUR, It is no longer just some you know some managing some PID controllers.

It is very complex business. Whatever I am going to teach it is all implementable in the real systems, it is actually implemented and probably what they do is probably much more complex than what we teach. So it is not that something academic that I am going to be talk about. Whatever I am going to do in this class next 4 months, everything is going to be useful in industry when you go for a plant. This is just a cartoon for Online Optimization.

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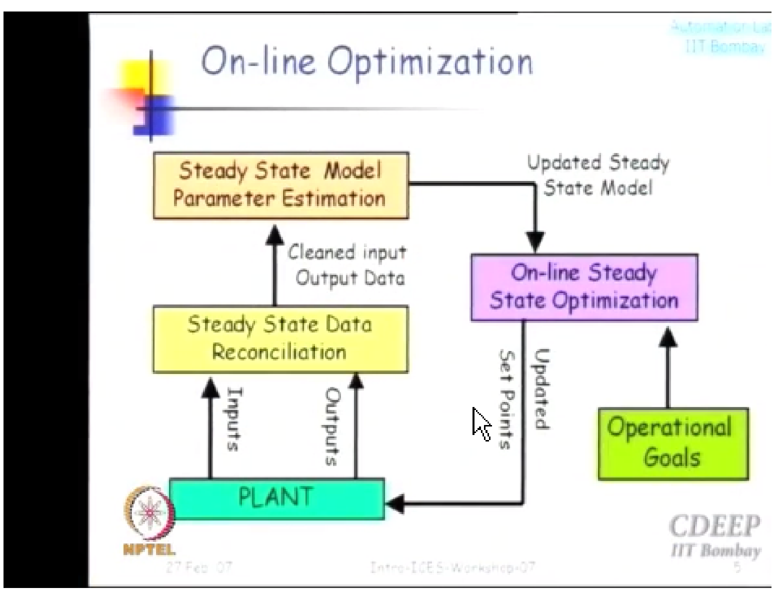

What you do is, you have a steady state optimization package and you have some operational goals. These operational goals are given to the plant, due set points as they are called. The plant keeps changing, so you have to keep updating the module online, it is a very difficult task. But this module which is used for Online Optimization is actually updated online every one day, every two days. Models parameters are tuned, adjusted and then it is used for Online Optimization.

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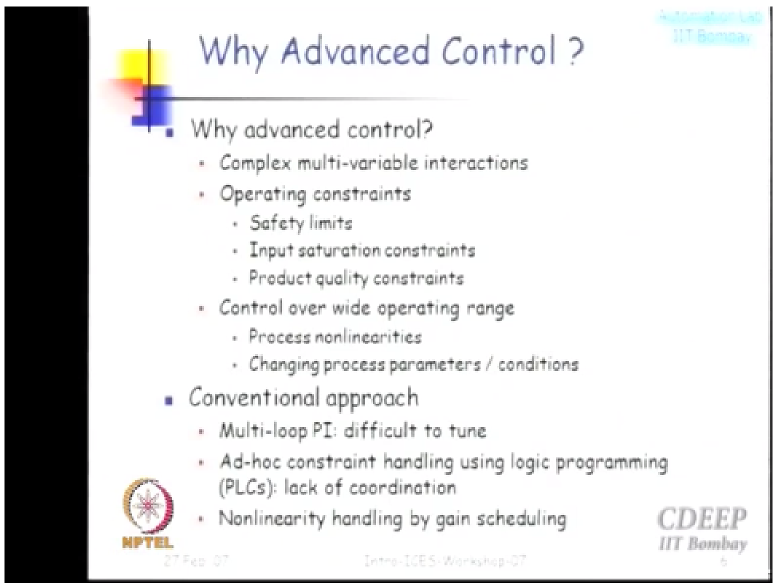

We are not really going to get into Online Optimization where this course will not permit us to get there. I will just talk about the modern predictive controller, multi variable control, and state feedback controllers. So in this entire hierarchy, I am just going to cover the layer just above the PID controllers. I do not have time to cover the entire hierarchy of advance control. But you should have a picture a global picture.

The global picture is that when you look at entire plant optimization optimal control in that we are going to look at let us say one unit control. We are not right now bothered about entire plant advance control. We are just looking at optimal control of one single unit and now why is unit control a difficult problem? One thing that makes it difficult is what are called as complex multi variable interactions.

Multi variable interactions are any real system that any engineering system that we encounter has many variables that need to be kept at desired levels. For example, let us take a boiler. In the boiler we are generating steam and it is in a drum, you have a boiler drum in which you have some way of heating the liquid, water and you generate a steam and the steam is supplied to variety of units. A very simple look, sealing simple system. Now, what is critical here is that I should get the steam of certain quality. I should get steam of certain temperature, pressure in order to operate certain things in my plant.

So it is important that temperature, pressure of the steam is very well maintained okay. Now, it depends on variety of factors. One thing that changes in the boiler is demand for steam. Suddenly, I have some three sub units operating right at forth falling operation, I need more steam. There is a sudden demand for the steam. When there is a sudden demand for the steam, the boiler has certain level of water inside in it.

The level starts dropping because you are drawing more steam. Okay, Level starts dropping the vapour space starts expanding and you know temperature and pressure and volume are related so all these variables start changing and they start changing in a coupled manner. The level change, pressure change, temperature change are coupled. You cannot say that one factor which is changing independently, everything changes together.

How do I control now? Well I can add, if the level is dropping I can add more water. If the temperature is dropping I can start hitting more, I can add more fuel, and I can start hitting more. Now if I start hitting more okay, more evaporation will occur and again the level will start dropping. So again temperature, pressure both of them and level are relevant on how do you heat the system.

So I just cannot say that this temperature and you know change the heating. If I start changing heating, to control temperature it will have effect on the level, it is not going to be separate. Same thing is there for let us say feed water. You will say that if the level is dropping add more feed water. You add feed water the level will change but the temperature will change. It is not going to happen that only edible will change.

Temperature will change, pressure will change, vapour liquid equilibrium will change, all complications will come up. So real problem has multi variable interactions. Everything affects everything and it is important that we understand these multi variable interactions and then develop the advance controller. Otherwise it is not possible to develop the advance controller. So understanding, modeling this multi variable interaction is a key to developing controllers. There are all kinds of operational constraints.

For example, you have safety limits, you have input saturation. You cannot heat more than certain amount of fuel you can inject is limited in a boiler. The least you can do is close the fuel you cannot have negative fuel slow. So there are product quality constraints I want a steam of certain quality. If it drops my dump stream processes will get affected. When you are operating a system over a wide range of operation, what becomes critical is the dynamics of the system.

Over a wide range and the dynamics of a system you over a wide range are typically highly non-linear and in order to do a good optimal control you have to worry about process non-linearity. Operating conditions change. I have a boiler and there is a heat transfer from the side valves to the atmosphere. The temperature of the atmosphere keeps changing by 15-20 degrees, the heat loss keeps changing. That has an effect on what happens inside.

So operating conditions keeps changing. Well, conventional way of handling such systems is using multiple PID controllers okay. I will give you another example which will tell you what the difficulty with using multiple PID controllers is. Let us say, this college students are attending good know this example. I had given the example of a motorcycle. I want to control a motorcycle or a car. In a car, what are the control outputs, speed and direction?

What are the manipulated variables available to you? Accelerator, brake and steering. Now you can tell this or that way. What are the safety limits, you cannot leave the road. You cannot go on right side or left side of the road depending upon which country you are driving. There are input constraints. You have maximum fuel injection. You cannot inject fuel infinitely and here minimum for injection of course. So you cannot go below certain values.

Now, let us say you have to control two things. One is speed and the direction. I decide that direction is to be controlled only using steering, speed is to be controlled only using accelerator. Now if I turn, that obviously has an effect on the speed. I am not just looking at velocity I am just looking at speed control and when I am accelerating, I can have speed attached to my accelerator, so there is a controller which matches speed and manipulates accelerator. There is one PID controller which looks at the direction, and then manipulates the steering. You have two PID controllers.

You can imagine, this will be a disaster because it is like two drivers who do not know about each other. One is only looking at steering manipulation and direction, the other person is only looking at acceleration. So this, having two drivers in a car when only looking at one aspect other looking at other aspect only and both having no coordination is a disaster. You cannot run the car like that.

You need one multi variable controller which simultaneously matches speed and direction and which simultaneously decides to change three things. Steering, brake and accelerator. This is what we want to do in this course. We want to have one controller which simultaneously changes multiple inputs to the plant by simultaneously considering multiple measurements. That is the key thing. I am just giving you an example of multi variable interactions.

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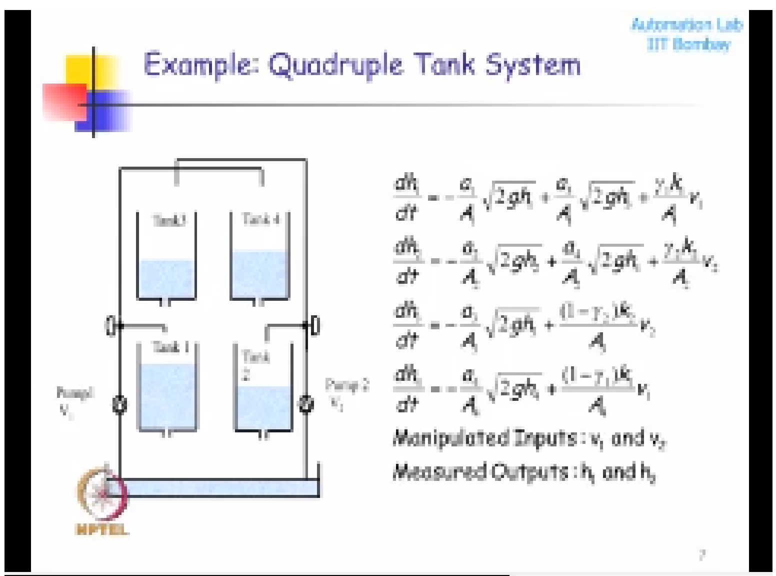

This is the simple system which we have in the lab. This demonstrates what is multi variable interaction is. This is a full tank system which is, this is the benchmark system which has appeared in one of the IEEE journal article and I will be sharing this article with you. So this is a simple system which demonstrates what multi variable interactions are. If you look at this, there are two control valves, one is here and the other one is here and in these two control valves if I change this control wall, the level in this tank will change because this flow will change but simultaneously the flow to tank 4 will also change.

So if I change this control wall, this level in tank 1 will change, the level in tank 4 will change and level in tank 4 will have effect on tank 2 level. So there is no way I can change wall 1without affecting level in tank 2 and tank 1 simultaneously. Same thing about the second control wall. This is a control wall, if I open or close this, the level in tank 2 will change but through this link tank 3 levels will change which will have effect on tank 1 level.

So effectively you know it is coupled. This is just a trial problem which we will use to understand missed most if the concepts. Very simple problem, two four tanks in series and the module you will understand very easily and you will use this to understand very complex things. Now just look here. The question is if I want to put two PI controllers, what I should measure and what I should manipulate.

Should I measure H1, level 1 in tank 1and manipulate wall 1 or wall 2 because everything affects everything. So how do I go about doing picking up two PI controllers, a difficult problem? In this way processes are much more complex.

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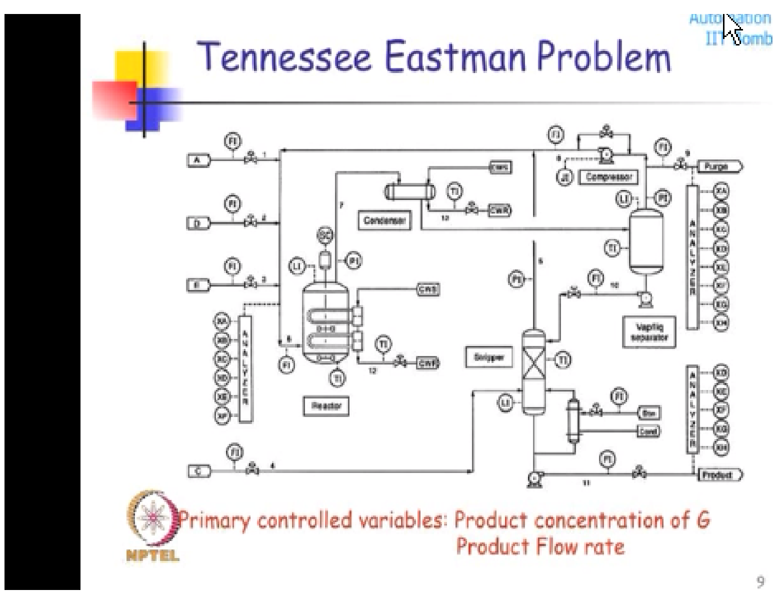

And then what happens is I will just show you a typical chemical plant typical chemical plant. There is a reactor here. Do not worry about if you do not understand chemical plants. Just understand them from a system's view point. There is a reactor here to be controlled, so some reactants are being pumped in you have .The product is being cooled here, then it is sent to vapour liquid separator. The liquid bit is a product which is being refined here and the product is drawn and some of the reactants which do not get used during the process are then again recycled into this.

This is a typical chemical plant, this is some process plant given by Tennessee Eastman Company. Well this particular system has about 54 measurements available and you can manipulate about 12 inputs to this plant, now I have 54 measurements and I have 12 inputs. So I can put 12 PID controllers. Now how do I pair? Which measurement should be used and which variable should be manipulated.

And without having to know anything about Chemical Engineering, you can just tell that well if you change one thing, it will have cascading effect on everything. Everything is connected. If you change one thing, other thing will get affected. So if I decide to change some cooling water here in the reactor, the temperature and pressure of the reactor will change but then that will change the dynamics of this condenser, of the vapour equilibrium here and then there is a recycle which is coming back to the reactor.

So whatever I am doing is again been fed back. So it is a complex business, how do you control this? What do you learn these ideas control these kinds of plants? Through some of our examples finally, you should get ideas how you will do it for this kind of a plant.

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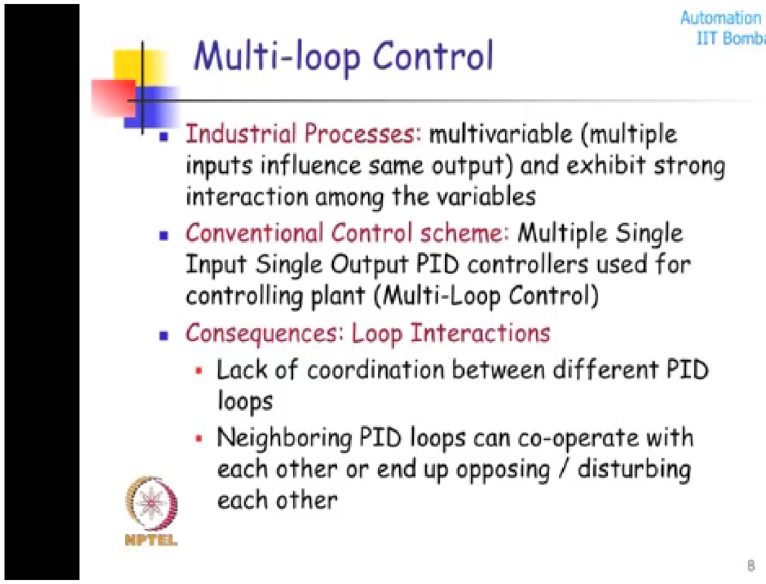

So when you put multiple PID controllers they can help each other, they can fight and they can stabilize the plant because how do you team them will control problem, I am not going to get into that and you do more about multi variable controllers and you can say that multiple PID controllers. But anyway difficult to do it. Even for a car, two drivers who do not like other, difficult to handle or difficult to handle or and so just show.

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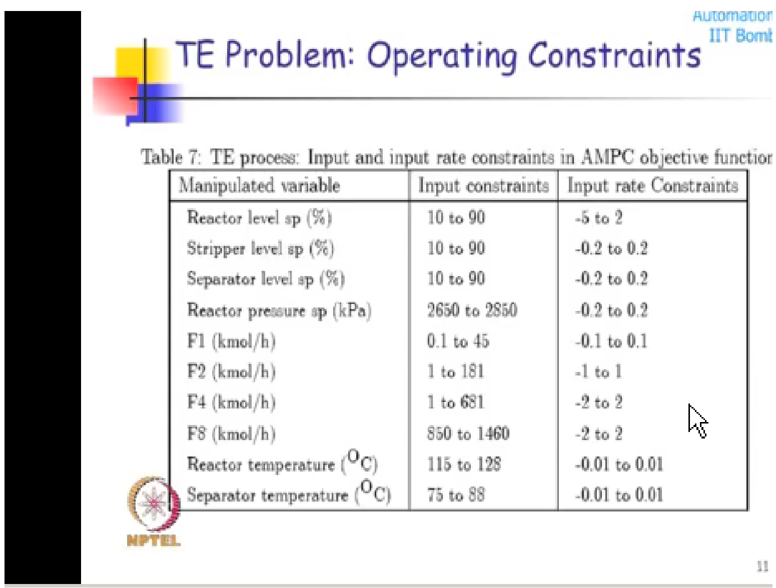

Manipulated variable	Input constraints	Input rate Constraints
Reactor level sp (%)	10 to 90	-5 to 2
Stripper level sp (%)	10 to 90	-0.2 to 0.2
Separator level sp (%)	10 to 90	-0.2 to 0.2
Reactor pressure sp (kPa)	2650 to 2850	-0.2 to 0.2
F1 (kmol/h)	0.1 to 45	-0.1 to 0.1
F2 (kmol/h)	1 to 181	-1 to 1
F4 (kmol/h)	1 to 681	-2 to 2
F8 (kmol/h)	850 to 1460	-2 to 2
Reactor temperature (^{O}C)	115 to 128	-0.01 to 0.01
Separator temperature (^{O}C)	75 to 88	-0.01 to 0.01

What is the control problem here? There are some six control outputs to be, six variables to be controlled and some ten inputs that can be manipulated simultaneously and there are constraints on how do you change this variables. You cannot, for example, reactor level cannot go beyond 90%, cannot drop below 10%. Certain 48 cannot be more than enough 45, cannot be less than 0.1.

At a time you cannot change, more than all kinds of consistent the reality. How do you have handled them? Well what we have to learn is not worry about putting multiple PI control this we are going to look at multivariable control us. So these are model based online model base control this, so I am going to use a dynamic model for this persist online all the time.

In the computer, this computer we have a model which has been simulated and this model will be used to decide how to control the plant okay. This all technologies which was developed in US and France back in 19 late 70s or starting from early 70s by two different companies one was a group form in US and other was a group from France and these controllers are now very much use multivariable controllers or very much used in all kinds of domains.

It started with chemical industry and by now it has spread to all engineering disciplines. This model based ready to controllers which use online dynamic model for controlling the plant it is a very material technology. It is use now in robotic applications since space applications in I recently in biomedical applications in out control of drives in. So those started from chemical these are how the computerize intensive, you need an online computing.

So it is started in a plant which was slow, chemical plants are very slow. You can make one change go for a T come back make another change, you all of further to control the dynamics of awareness is spread over one day okay, so your time to compute online and then computers say it 15, 20, 30 years back were pretty slow. The advance computer center which long you carry on your laptop would actually be entire room some big machine with fulfilling this entire room and then using that for control was very expensive, difficult and it happened only in the rich companies like Shell.

They could afford to do this. But now it is all over the latest when I heard is this has been used by Google to manage requests from server request. So this technology generic can be used anywhere. What is the basic idea? Basic idea is this is the body flight form of because you have done optimal control course, this is nothing but classical optimal control modified pursuit real industrial problem. It can handle multivariable interactions, because this particular controller is going to use a dynamic model for the plant online.

I am going to use online model. You can specified your constrains you can save a live on to operate this is remainder the so and so constrains. You got handle process what is the basic idea. Basic idea is what actually we keep doing everyday is given a model for the plant dynamics. The forecast you can do forecasting online forecasting. I have computer, I can do online forecasting what if I change feed water florid from this variable disvalue what will happen next one are in the boiler.

I can forecast I have a model. I have a computer, I can use method integrate and at similar to what is scenarios, what if I do this. And then I can decide to take an action which is optimal in some sense. So when I decide this action I will of course take to consideration the constraint and so on.

Let us go back to the car driving example. When you are driving the car whether you late I do not know it you actually have a dynamic model for your car in your mind. What is your dynamic model? You have develop this by doing some experience with the car, when you take the car or you take a motor cycle first you try to acetate little bit and then see how it shown. Then you have model if I press this much then you have another model that you develop is you press accelerator then you press your break and say whether it is stop.

How could use my break. And this model which you develop which is not quite quantitative it is probably more complex we do not know how calculations occur in our brain. So but variable to forecast we are able to forecast using this model and met decision based on what is going to happen next. If somebody is crossing the road and I am driving the car I am able to forecast whether he may cross before I reach that point or after I reach that point.

And I am not able to decide their action based on that. You can start pressing your break or even you start changing the direction depending upon your forecast okay. Something that we everyday every now and then keep doing. When you are driving when you are preparing for a course whatever any action when you are behaving with somebody, you have a model for this person, so whatever and then you forecast.

If I say this, this is going to happen and done, and he manipulate your actions inputs to decide what is going to happen. So this is what you have done, so you have a dynamic model for the plan which is running online in a computer which is use to do what are scenarios and then you make decisions based on this is scenario through optimization. So very complex, very computation intensive process, but now with so fast computer is possible to do it in just few seconds, few microseconds at times.

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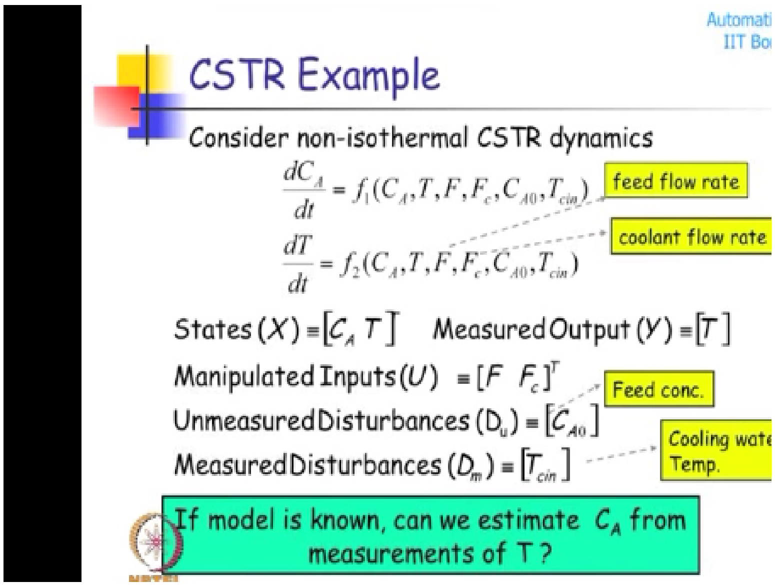

I just give you an example here, this is the reactor example do not worry look at to the system guy or system's person. In a reactor and simple reaction A goes to B okay some isolation and I have to two things to control concentration of A in the reactor and temperature of the reactor. It is a thermal reaction. Heat gets stimulated and measuring lets say temperature and concentration. And measuring the concentration of A and measuring temperature online.

I have two things which I have manipulate one is I can change the feed flow to the reactor of react in A, I can change the cooling water. I have a cooling water system which cools the reactor contains, so I can manipulate. I just want to show you visually without going to mathematics right now.

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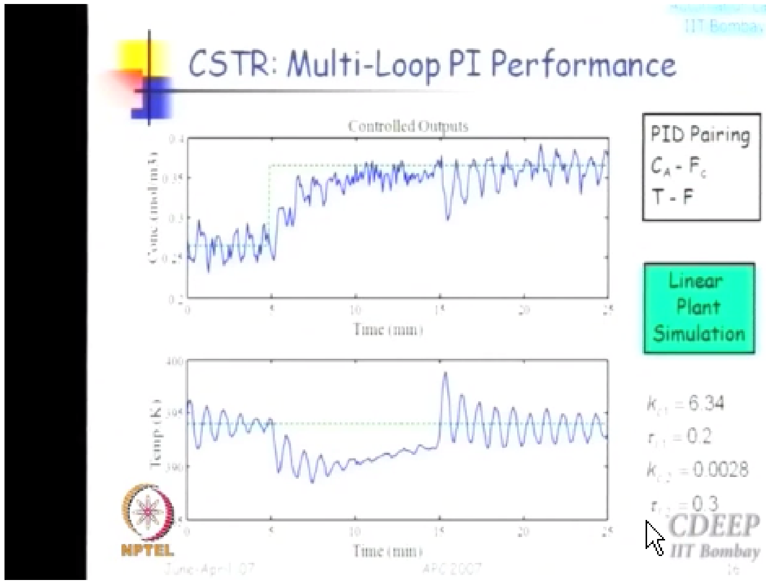

What happens if I put to controllers, If I put to drivers to drive this reactor as against I put one controller which is multivariable, what is the difference. Just look at it visually. I have put two controllers. I have taken concentration as a measurement and I am changing cooling water fluoride actually it should be concentration as a measurement and I am changing react and fluoride and take temperature as a measurement and FC that is cooling water has being changed.

So temperature to be maintained and changing cooling water okay. There is a jacket and in this jacket surrounding the reactor and I am pumping cooling water so that the contents are cooled. How does the reactor look like just imagine pressure cookers in which some reactors are coming out, some have been withdraw continuously? You have a surrounding jacket which is use for cooling the reaction okay.

I have put two drivers or two controllers, one only trying to control concentration inside the reactor, other fellow trying to control only the temperature. They do not want to know about each other. This is what coordination one only looks us its own object that is temperature control or concentration control. I have given here a step change in the concentration, I want to ramp up the concentration, you can see that.

I have changed the concentration point from 0.26 to 0.36 or something. But I want to maintain the temperature 2.395. I have tune the controllers these are believe me I am not created this example just to fool you. I have tune the controllers using best methods available. Each one of them separately works very fine human they start working together you can see what is happening okay There is lot of fluctuations, lot of you know .

This is what we call as interaction, because one action has effect on, if I change the cooling water temperature. It has effect on both, it has effect on temperature, it has effect on concentration. So one fellow is doing one thing is not enough you have to have a coordination, well deserve the manipulate variables and I have given a disturbance there in the concentration, so this is classic problem in which set point change followed by disturbance simulation.

And you can see the two controllers when they are trying to control you get this kind of profile and then what if use a multivariable controller.

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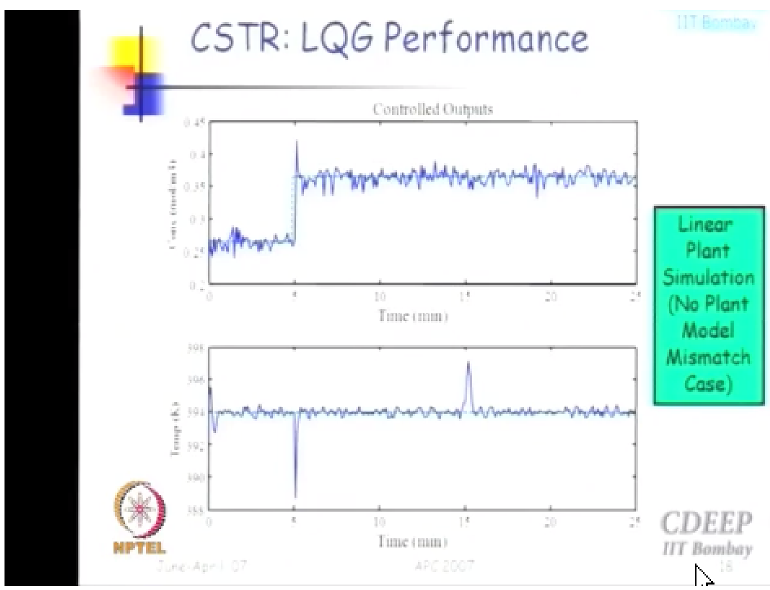

Just look at this, a multivariable controller will implement a step change just like a step change. The other variable temperature is not affected much, this one small blip which comes and then the temperature is steady. Why this is happening? Because this multi variable controller is simultaneously changing both the inputs by taking two measurements simultaneously. So just like when you are driving you will look at speed and directions simultaneously and manipulate three things simultaneously this is the controller which is the multi variable controller which will, so I just want to motivate to this diagrams.

That this is what this is the differences I mean go back and see here you know oscillations and not so great control whereas here when I introduce the disturbance.

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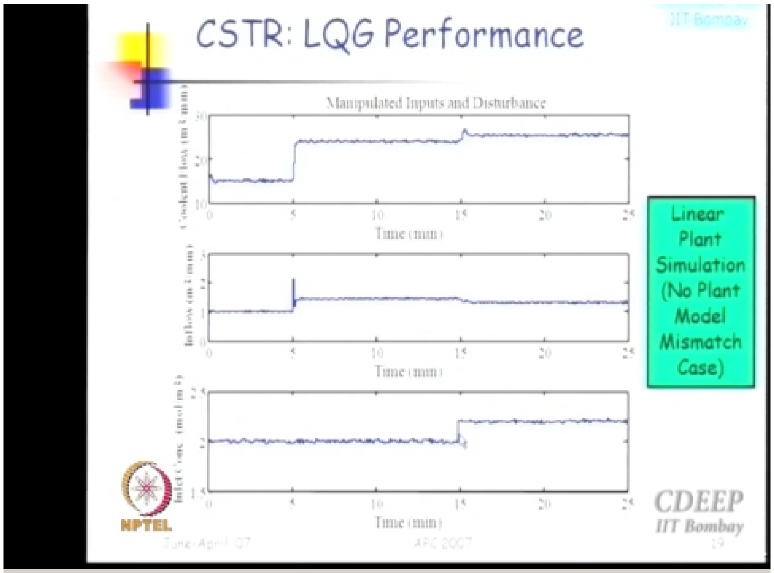

Introduce a disturbance It is just you know another blip here no effect on. Concentration which ever to control fanatics job I cannot do to this multiple PID controllers this a different even for two input output imagine for a chemical plant you know for a large power plant or unclear plant it is a very difficult.

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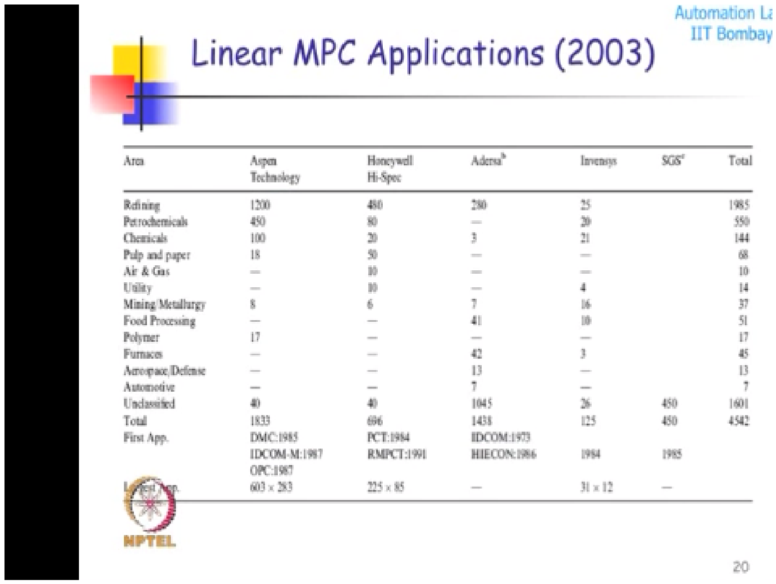

Area	Aspen Technology	Honeywell Hi-Spec	Adersa[b]	Invensys	SGS[c]	Total
Refining	1200	480	280	25		1985
Petrochemicals	450	80	—	20		550
Chemicals	100	20	3	21		144
Pulp and paper	18	50	—	—		68
Air & Gas	—	10	—	—		10
Utility	—	10	—	4		14
Mining/Metallurgy	8	6	7	16		37
Food Processing	—	—	41	10		51
Polymer	17	—	—	—		17
Furnaces	—	—	42	3		45
Aerospace/Defense	—	—	13	—		13
Automotive	—	—	7	—		7
Unclassified	40	40	1045	26	450	1601
Total	1833	696	1438	125	450	4542
First App.	DMC:1985 IDCOM-M:1987 OPC:1987	PCT:1984 RMPCT:1991	IDCOM:1973 HIECON:1986	1984	1985	
Largest App.	603 × 283	225 × 85	—	31 × 12	—	

So these multi variables are they something academic are they actually used. These multi variable controllers are actually used. There are companies which I have listed here companies which I have listed here applications in which these things have been used. Refining, petro chemicals, spull point papers, miming, food processing, polymer processing, furnishes, error space and defense.

This was 2003 survey of this multi variable control technology which we are going to studying in this course and what is the largest controller developed using this technology. No it is a refinery in Canada. Where they simultaneously monitored 603 measurements by manipulating 283 inputs simultaneously.

Using a model, mathematical model which is used in online. The mathematical model is like a book. If you have to go through the mathematical model. So these are different vendors who implement these controllers. And believe all this vendors are here in India. Implementing this controllers and daily if people who are trained how now what, what this complex businesses.

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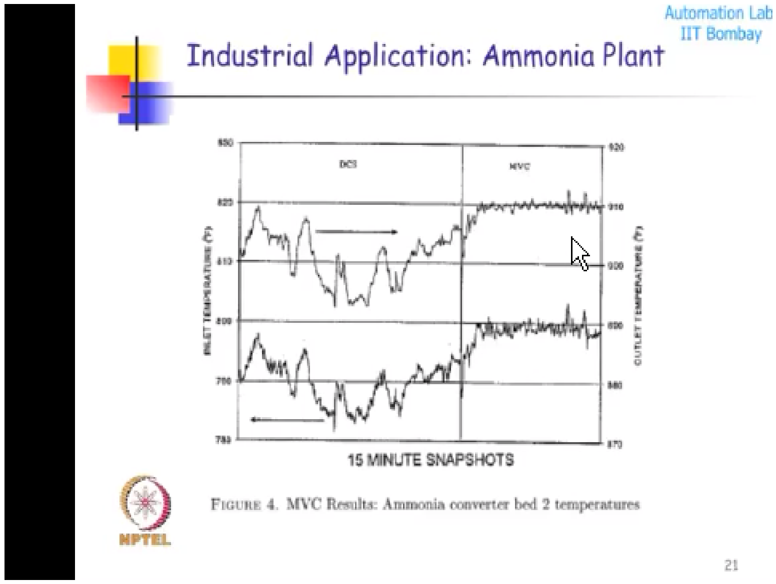

Just another visual motivation. This is slide for my industrial implementation. Before implementing, multi variable controller. I think I do not have to say much about. Do not worry about what, just look at the qualitative pictures of the graph. You want to control this variable and you want to this variable here. You can just see how the output is behaving. Before multi variable controller was implemented and after multi variable controller was implemented.

This huge difference, initially before a multi variable controller was implemented. There were two PID controllers. They were fighting it with each other and you can see lot of accusations. Who are controlled? Movement you have a multi variable controller. The control outputs are just added hacking the set points. It is very nice control.

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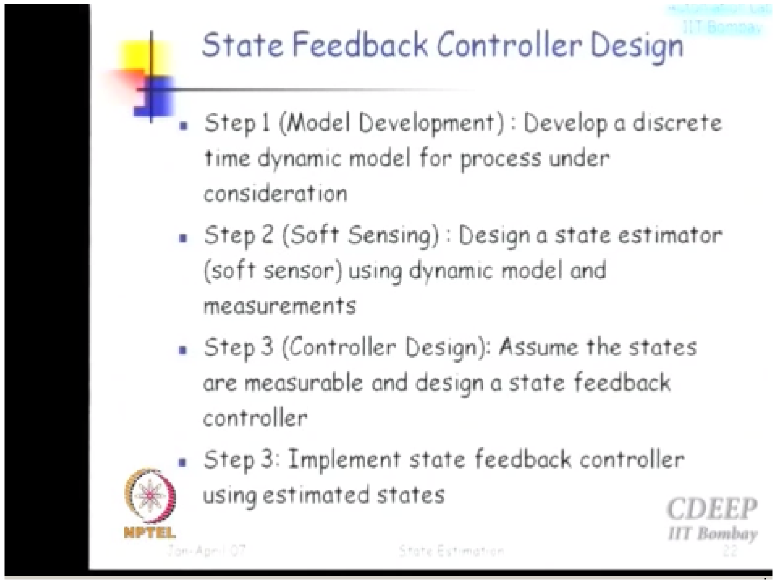

How do you design this controllers and a first thing that you need to do who design this controllers is to develop dynamic models okay. I should be able to credit that dynamic behavior of a plant of a system that I want to control online. So I need a model which can forecast and transient behavior not the study side behavior the transient behavior. It should be such that, it should be able to capture the dynamics and at the same time it should be simple enough so that online computation can be done very fast. You have all kinds of constraints. If you are controlling the robot.

You want to do these calculations in a fraction of a second. You cannot refer to wait for minutes to do calculations. So you need what I would call, control relevant models. So we will first how to develop this control development models. Then many times you want to control certain variables which have not directly measurable. A good example would be, while recent application of the soft sensing is surgical operation.

You want to actually maintain up the patient under the state of imposes. During the surgical procedure, you can have the mathematical model which estimates percentage of imposes. But there are no measurements of imposes. You measure blood pressure, you only measure blood sugar and you measure all kinds of other parameters. From that using a mathematical model you credit what the level is of imposes or you can credit what is the reaction to the pain. You can have, and people are talking now of online sensors for level of hypnosis during the surgical procedure.

I can think of, I want to you know in this room it is a temperature control problems and humidity control problem. The air injection are manipulating variables and there are distributed and let us say I want to major comfort level and I can define its in some comfort index which is some complex power of some humidity and temperature. There are disturbances peoples will keep coming and going out so warm way will come in suddenly and you have to react and one of you 60 watts bulb and you know you keep.

Disturbing the plant that is temperature. So it is a more complex problem for party where people are moving because they might be groups in some zones and now you are stationary it is easier problem to control. So you can actually have a mathematical module which estimates comfort index by measuring variety of parameters like temperatures distributed at different places and so on. Then you can have a state feedback control and the state is this variable which is probably not directly measurable but estimable through a module.

I have a reactor. I cannot measure concentration at each point inside the reactor. But I have a module which reconstructs what happens inside a reactor. So that is a state estimator. Using that estimated state I implement the feedback controller.

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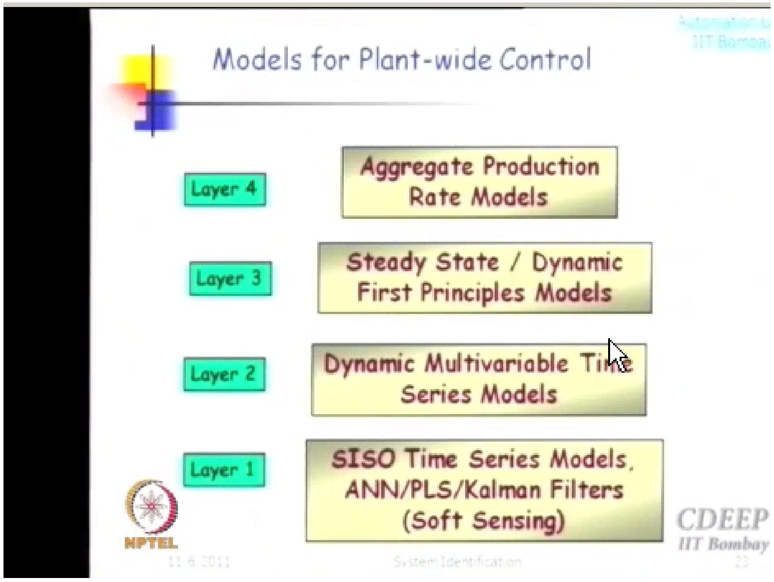

So you need models and you need different kinds of models. I talked about four layers of advance control. You need different models at different points. We are going to concentrate on layer 2, dynamic multi variable time series models. That is what we are going to look at. This is what is the core of our course, the modeling part. Aggregate Production Rate Models, Steady State Models, these are not really part of this course.

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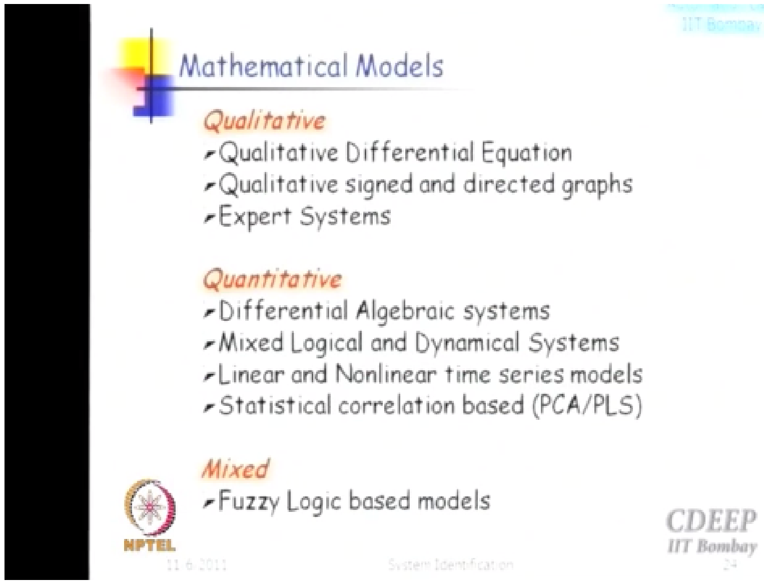

There are all kinds of models. You have qualitative models, you have quantitative models. You have mixed models like Fuzzy logic and we are not going to get into that too much. We will look at first principle models which are coming from Physics very briefly and what is their connection. How do you reduce those models to make them control relevant, how to simplify those models so that you can do calculations fast.

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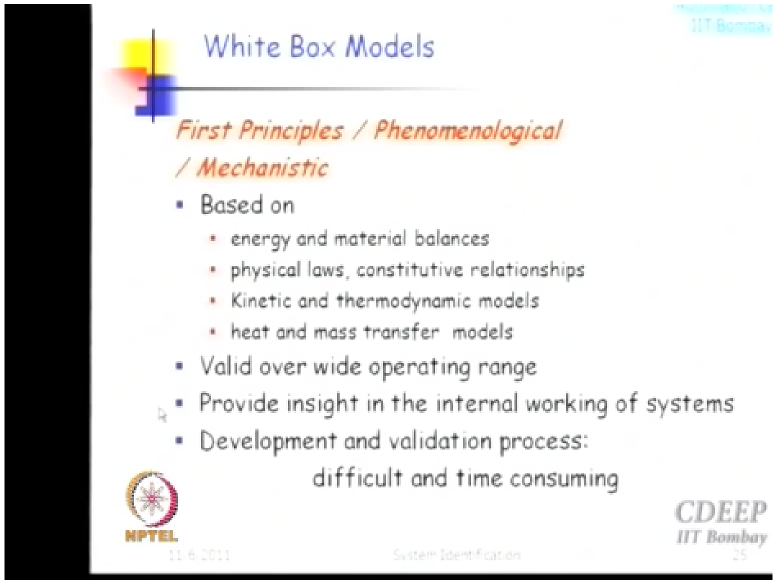

Other kind of models I am going to, so these first principle or thermological models. These models are great because if you can develop them, if you can develop a model from first principles writing a partial differential equation for temperature distribution in this room nothing like it. You can do accurate predictions of what is happening inside the room. But it is difficult to develop an expert and then to control them many times you do not need those kinds of models. Simplest example.

Qualitative models are models which we have simple example is that let us go back to the boiler. If I make a small change in the feed water fluoride, then the level will increase by a small amount. If I make a big change in the feed water fluoride, the level will change by a large amount. So I have a qualitative mapping between the cause and the effect. This kind of models actually uses everyday okay when we.

So these are not using some numerical values. These are qualitative labels or you can have more gradation, you can have, this medium change will have medium effect. Large change will have large effect. So this could be large decrease or large increase. So one can develop these kinds of models and then use them for control. It is not that it is not possible. But developing a model is a very difficult task. It is a time consuming affair.

First principle model for this full tank system would be differential equations which are coming from Physics, the flow from tank 1 to tank 2, how it occurs and you can write simple pressure balance equations and develop these models. I will give you these details but, you are familiar with these kinds of models. These kinds of models of course can be used for controlling the but many times they are difficult to develop.

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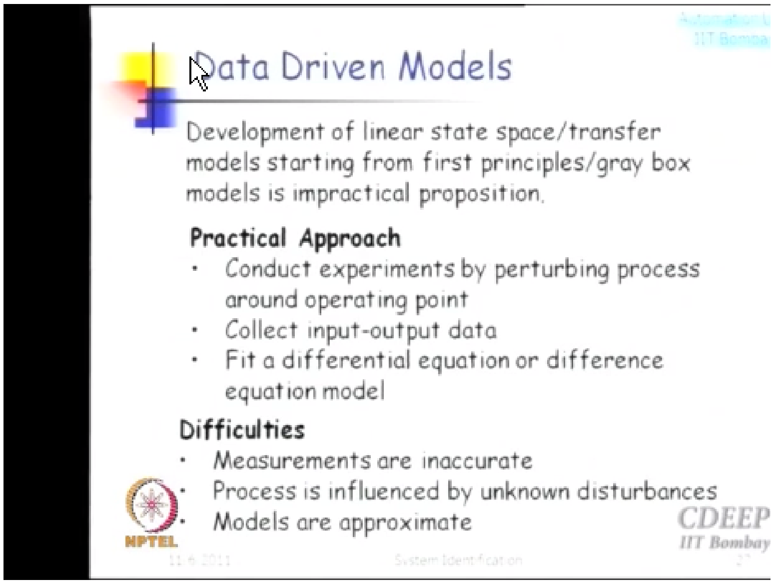

What we are going to do is to do something called data driven modeling. Data driven modeling is something in which a model which is polity similar to the model that you develop for car. You do some small experiment, you record in your mind how the car was behaving and you develop a model that links the cause and defect. This kind of models are good enough to conduct for containing the car, you do not have to be a mechanical engineer or an automobile engineer to drive a car.

Anyone can drive a car and heaters develop a model, he she does develop a model for driving that car. So we are going to develop these control relevant models only from data only from doing some poking experiments with the plant. I am going to inject some perturbation into the system. Observe how the output behaves. Then try to develop a correlation but not static correlation.

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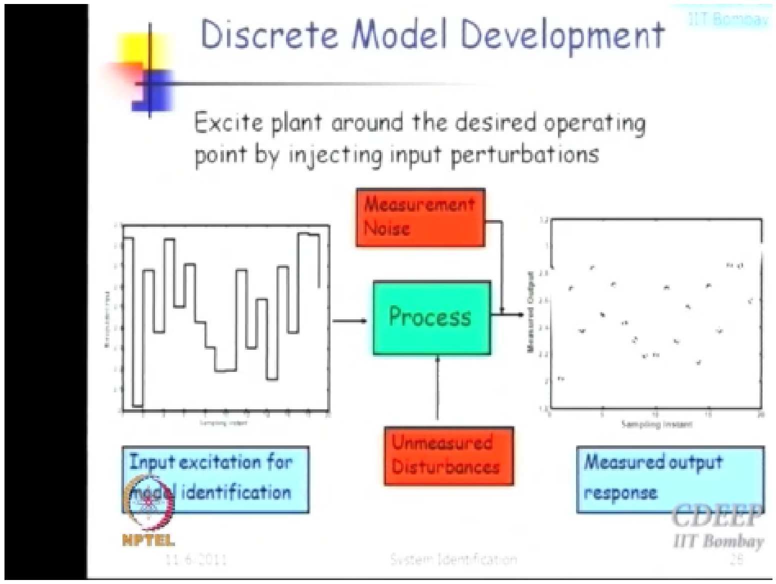

Either we want to develop a transfer function model or either you want to develop a differential equation that correlates inputs with the outputs. So I am fitting the differential equation into the data of output measurements and the inputs.

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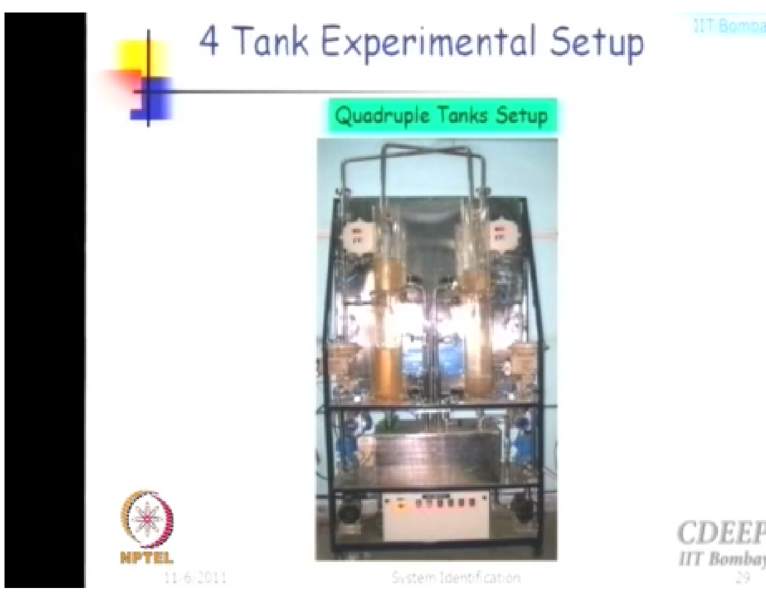

This full tank setup again. We have this in our lab, the same thing which I have been showing you just now.

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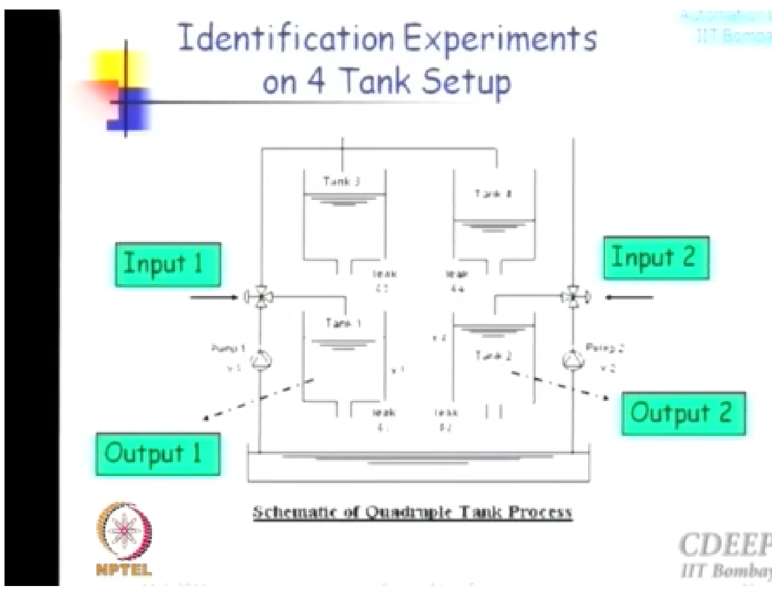

I want you to poking experiments, so what I have done is these two valves, there are two control valves here, if you can see, there is a control valve here, this is a control valve, there is another control valve and the flow from this is split. One part goes to this tank, other part goes to this tank. Same thing is here. This control valve, some flow goes here remaining part of the flow, actually goes to this tank. So this is the same interacting system. So whatever we actually do in simulations, we will be able to actually go and see in the lab.

Now I could come up and develop a model of this form for this particular system. Little bit complex task. Not so difficult for this simple system but it takes some time. The other way is you know.

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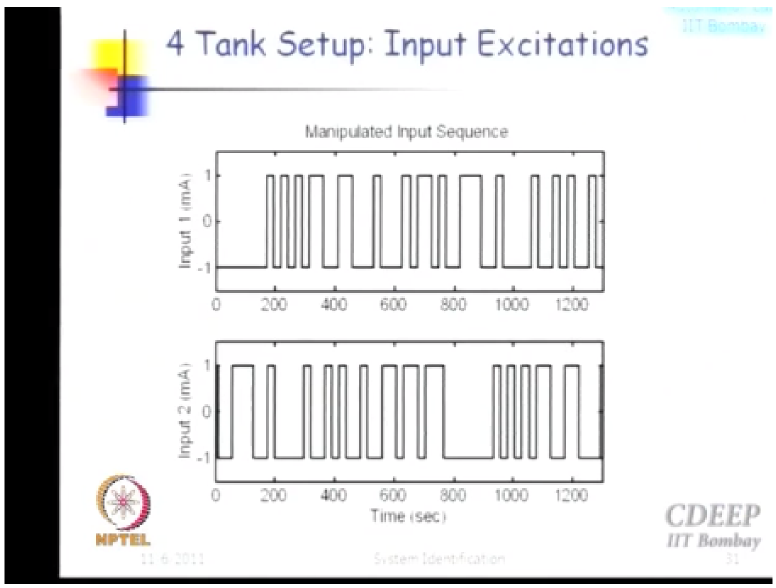

I just do poking. I just do perturb. I just change the valve positions and I record how the level changes as a function of time.

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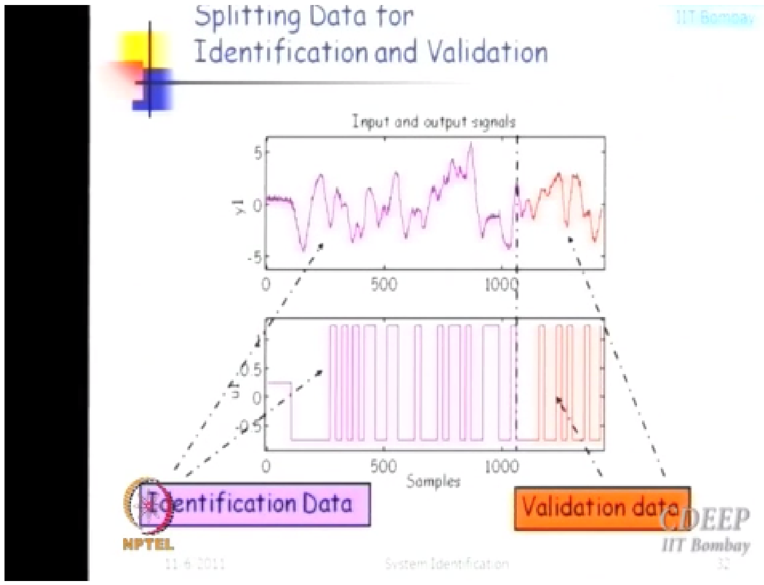

Here I have recorded how the level changes as a function of time and this data is been used to propose non linear or linear differential equation or a difference equation model and when you estimate the model parameters from the data. How do it, we will be doing in this as a part of this course.

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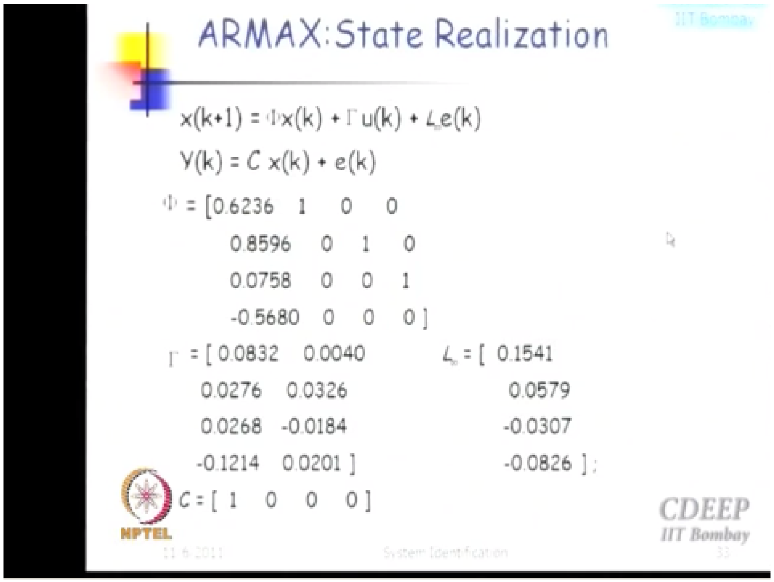

I will just show you the model that I have got from MATLAB toolbox. This is a model that is telling me that this is a discrete time model which tells me that the state x at time k+1is done at a regular interval. So that is a difference equation. At time k+1, is relevant to the state at time k, thriugh this matrix 5 and the inputs, valve 1, valve 2 position through this matrix γ and and why are the measured outputs. I am not going to measure all 4 levels. I am going to measure only level 1 and level 2 over tanks.

This is the mathematical model. This is the dynamic model, difference equation model. K is time here, discrete time okay, which I could develop only from this data. I do not have to know the Physics, I am just pertubing the plant, poking it, getting data and devloping the model.

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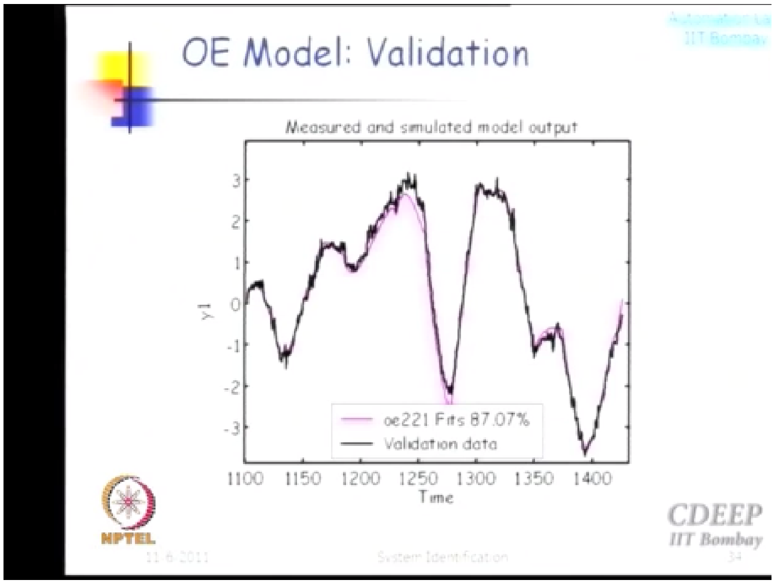

Model is pretty good. You can see it is able to predict the behaviour of level change as functuion of time. The black part is the actual data and this magenta line is actually the model predictions. This dynamic model developed from data predicts behaviour quite well. Then I am going to use it for control.

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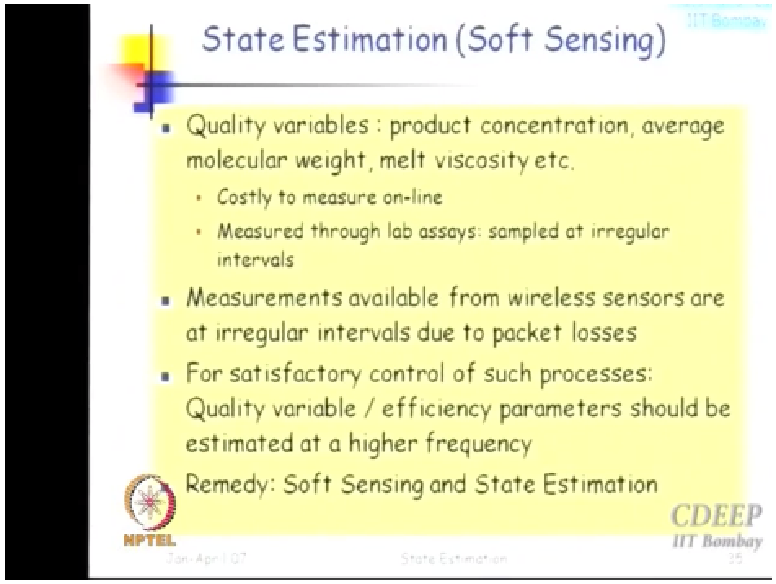

There is one more thing that I need to do. Once I have a model, I need to do what is called as soft sensing or state estimte.Well there are two ways. One approach is you go for Physics and so that you move that state from the system and then try to do a structured model, otherwise what is called as black box in which you just , the state may not have any meaning, physical meaning or input and output has physical meaning. The states are some mathematical constructs that help you to capture the dymanics. So there are two view points. We will cover both the view points.

Now let us say I have a model comimg from Physics and then I want to estimate some variables which are not directly major. I use whatis called as state estimation, what is the basic idea here.

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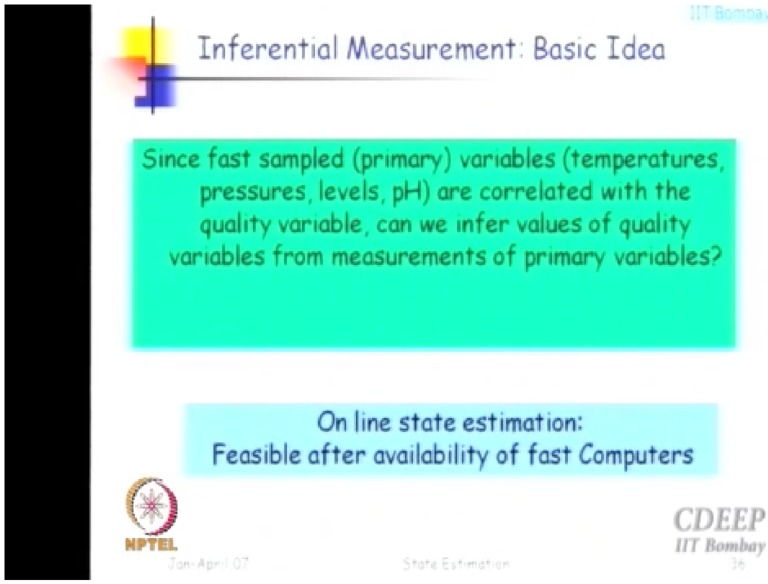

In many systems there are some fast primary measurements like temperature, pressure level, pH, this can be measured very fast using online sensors. These are related to some quality effect and then I can estimate this quality variable using a mathematical model.

So what I want to do is since I have fast computers, I want to use a mathematical model, take some measurements, fuse the data with the model predictions and construct estimate of a variable which cannot be directly measured. That is why I am calling it as soft sensing and then soft sensed variable is then used in my controller.

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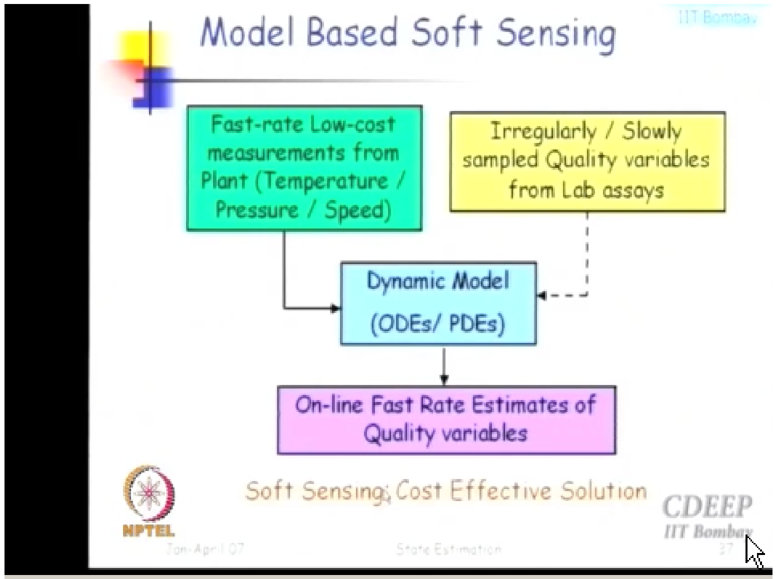

So I have fast rate data coming from simple measurements like temperature, pressure and I have some irregularly sample data coming from lab assays. I fuse this data with my dynamic model and then could be set of PDEs or ODEs and then I can estimate quality variables.

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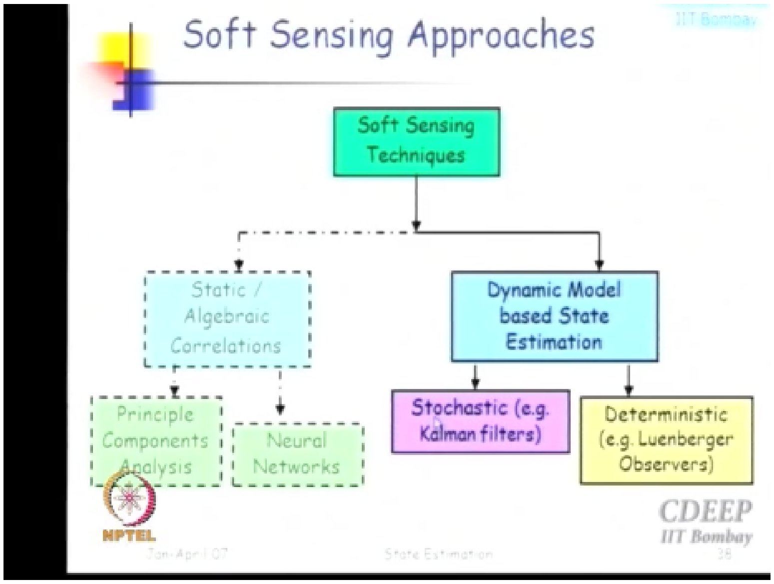

I will just skip this particular slide. There are various ways of doing this. We are going to do this using what is called as a dynamic model based estimation.We will be looking at this for about three weeks to four weeks. So the modeling coming from data, I will spend about four to five weeks. I will move onto state estimation, that is how do you estimate states. Given a dynamic model by fusuing data, so this would be about three to four weeks and then remaining part I will move to the advance control algorithms. So again the basic idea here is you have a online model.

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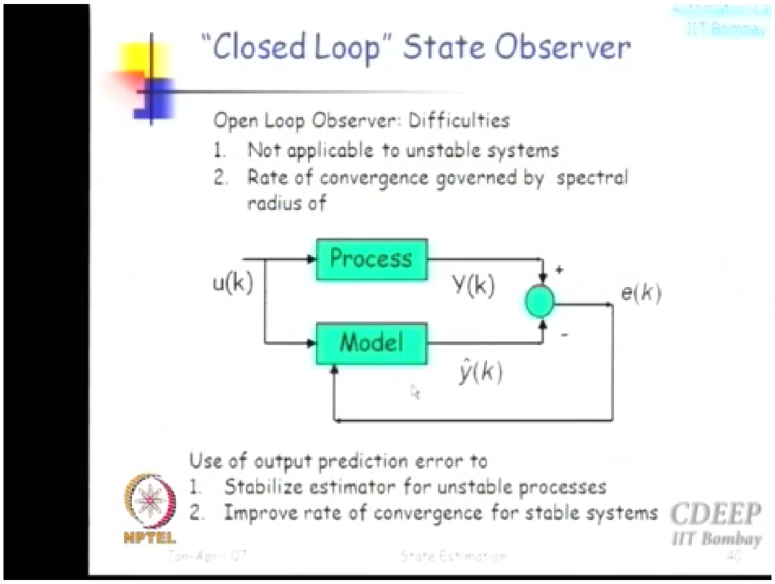

Running in your computer and you have process which is given some measurements. We actually use the mismatch between the model predictions and what is measured to correct the model online.

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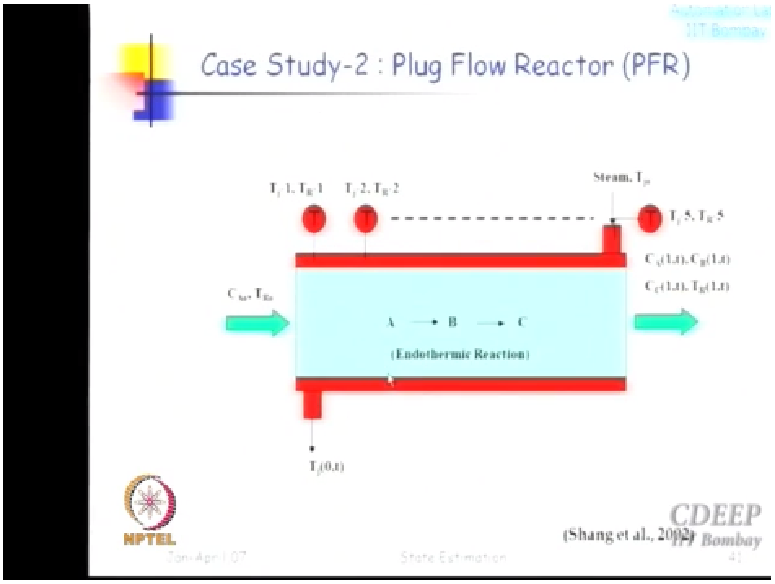

So we will look at this. So I will just give you an example of a reactor. This is a, for those who are not chemical engineers I will explain qualitatively. This is a qualitable reactor. There is a long tube and you start injecting the reactant here.

Again a very simple reaction. A goes from B, B goes to C. Do not worry about what is A and B and C, some reaction. Exothermic reaction, heat is generated during this reaction. So there is a cooling jacket, if you notice here, this red part is a cooling jacket. I want to actually know what is the concentration profile inside this reactor. Concentration measurements are extremely costly.

I mean just to give you a online concentration measurement, one sensor might cost about 20 lakhs whereas one temperature sensor might cost about 20,000. So putting 5 or ten temperatures sensors is I cannot afford to do that. I cannot afford to put concentration sensors, even 1 forget about putting multiple. But I would like to have concentration profiles inside because that is what matters to me when I am operating this system.

I can manipulate the cooling water flouride, I can manipulate the inlet flouride which is going. Here I can manipulate the cooling water.
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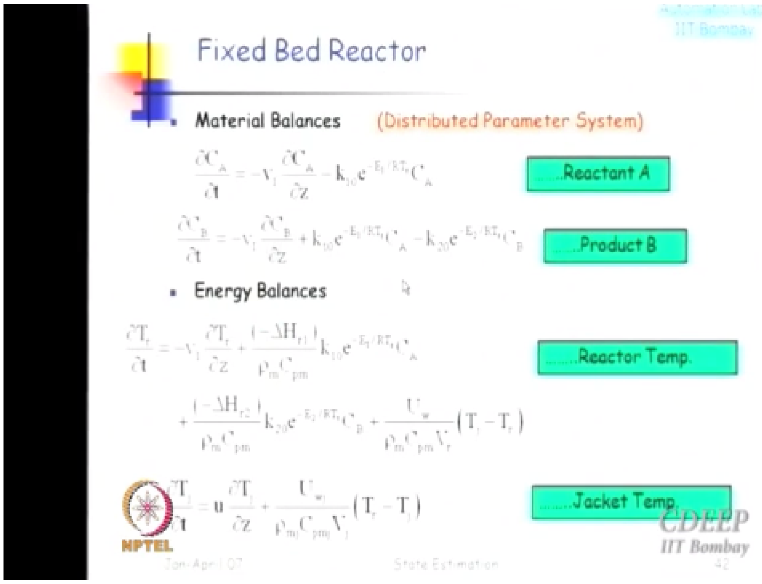

I am going to use this mathematical model which is actually coupled partial differential equations online and you do as this model online to construct concentration profiles inside. So this a software sensor.

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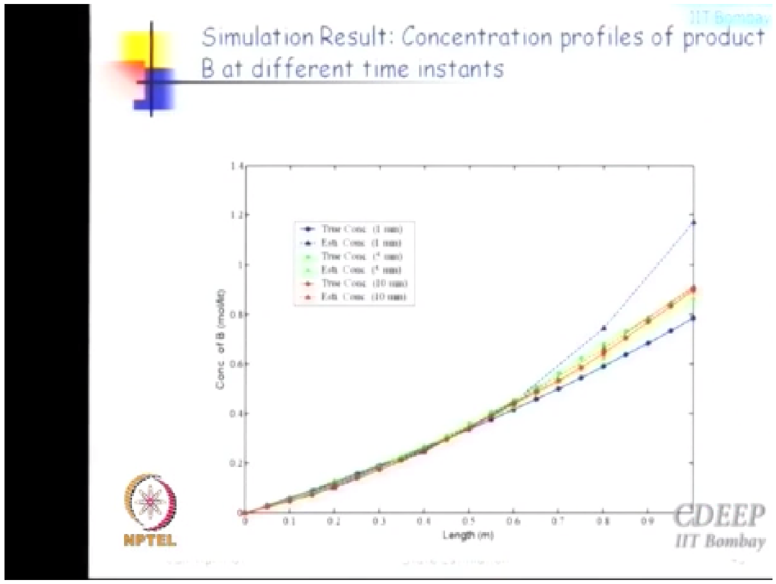

Just a demonstration of how concentration profiles change with time reactor.How concentration profile change about time inside the reactor.

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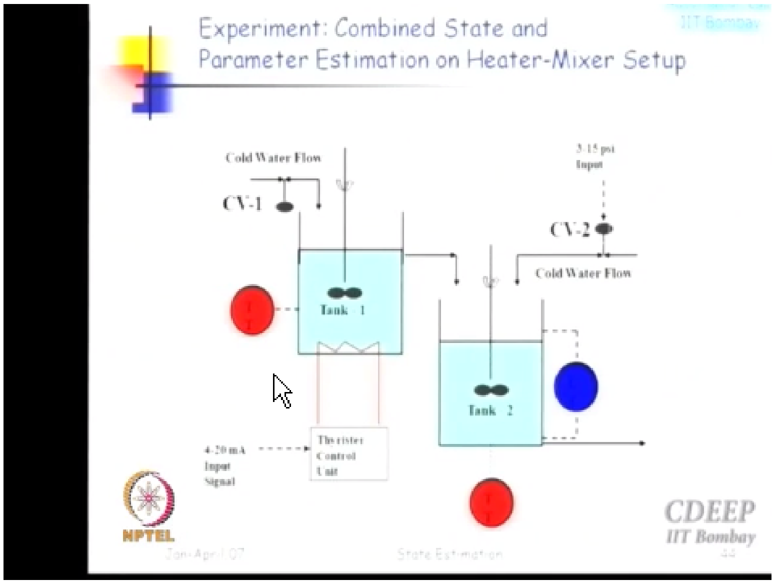

Practical example from my lab which is the software sensor again we have two tanks which are couple, there is heating element here and this hot water is then mixed with the cold water here. And then I am interested in the maintaining level of the water inside this tank. I am also interested in maintaining temperature inside this tank. I want to estimate some quantity which is not directly measurable online.

What is this quantity? I am doing this experiment in my lab and does the heat transfer from these walls to the atmosphere. Now I want to know what the efficiency of E-transfer is. I want to estimate some kind of effectiveness parameter, because this is model through you a ΔT those of you have done E-transfer course and done this you E-transfer course keep changing, because of the changes in the environmental condition.

It changes whether depending upon whether you are doing experiment in the night or in the day whether you are doing experiment with the fan, running out of the fan off and all kinds of things can change how you E-transfer occur to the atmosphere. That has significant effect on the dynamics. I want to estimate effectiveness of E-transfer.

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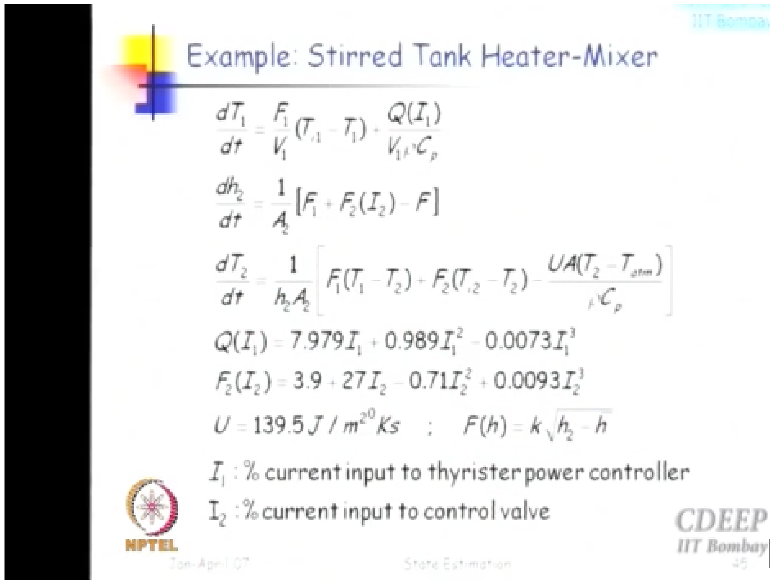

We have mathematical model and we have to use this mathematical model let us have get to the details. We have a dynamic model which talks about greater change of tank 1.greater change level of tank 2 ,greater change of tank 3 I want to use this model and then I want estimate a effectiveness of the heat transfer position u I have all three measurements two temperature .

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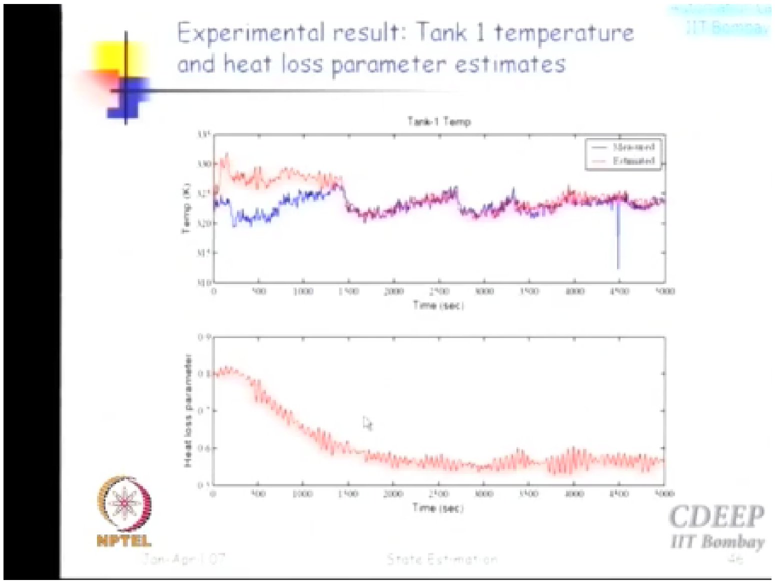

You can see that the estimated online using this temperature measurement Temperature in the heat loss parameter is estimated online using this temperature measurement. Well what we have done is we have taken one temperature measurement, one level measurement. We have tried to estimate other than temperature using our model online.

I am just comparing how the model based estimate for the temperature match with the measure temperature here. So temperature 1 in tank 1is being estimated through my observer and it is just being compared with the real measurements, you can see that it is a good observer or good soft sensor and you want to reconstruct a temperature in tank 1 using measurements of level and temperature in the tank 2 and I am also able to construct something which I cannot measure, effectiveness of heat transfer online. So I am measuring the parameter of interest, constructing it online.

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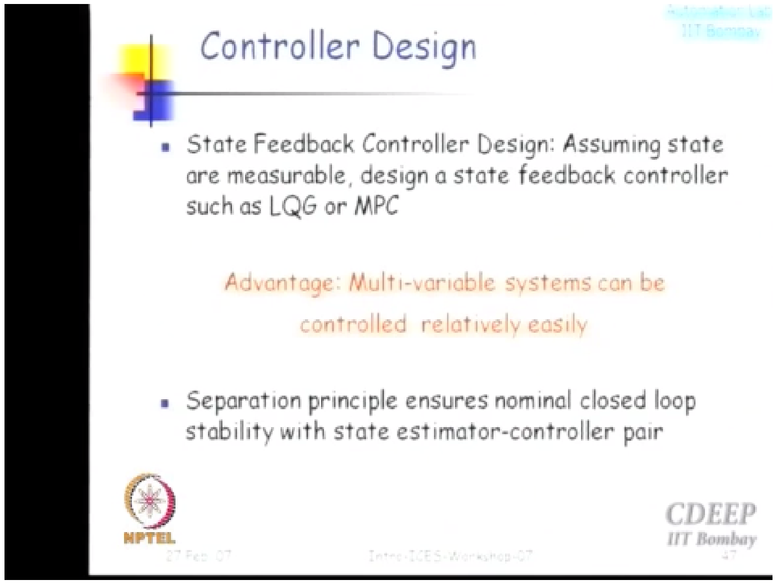

Use this state feedback controller, I can use this state estimators online and then do a state feedback controller and there are ways to design this, how to design this controllers will be the last part of my course. So we will end up by talking about, we have developed a model from data, then we talk about how to estimate unmeasured variables from this model and then we do controller based on these dynamic models.

So it is complete story starting from modeling to control. So you end up in a industry and somebody gives you and says that look this is my plant, this is my induction motor. Now develop an advance controller for this. You will say okay I know how to go about it. I will start with poking a developer model, validate my model, use it for controller esteem, observe a design, control a design and develop an advance controller which is a multi variable controller. That is what we want to do.

Well this entire field of advance control is an ocean and we will just touch tip of an iceberg. Just remember it is not possible to cover everything but idea is to sensitize you about things that are happening. Outline of the course is something like this.

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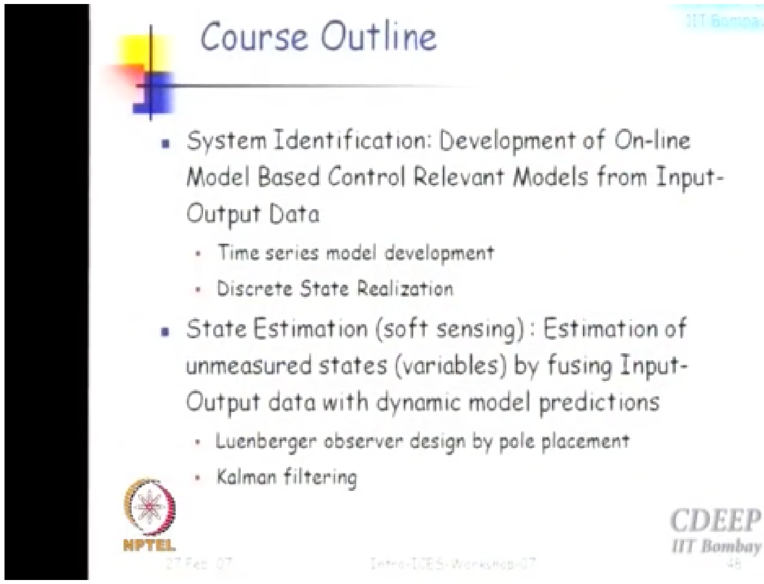

There are three modules. One is system identification, how do I develop online control relevant models purely from data or from Physics, I am fine with both. But I am going to emphasize more on how to develop it from data. From Physics you have been doing it in your engineering courses. I do not have to worry too much. Data driven modeling very important. State estimation, given a model how do I estimate internal variables which are not measurable.

State estimation will look at some popular techniques like Luenberger observer or Kalman filtering. We will move onto online model based control.

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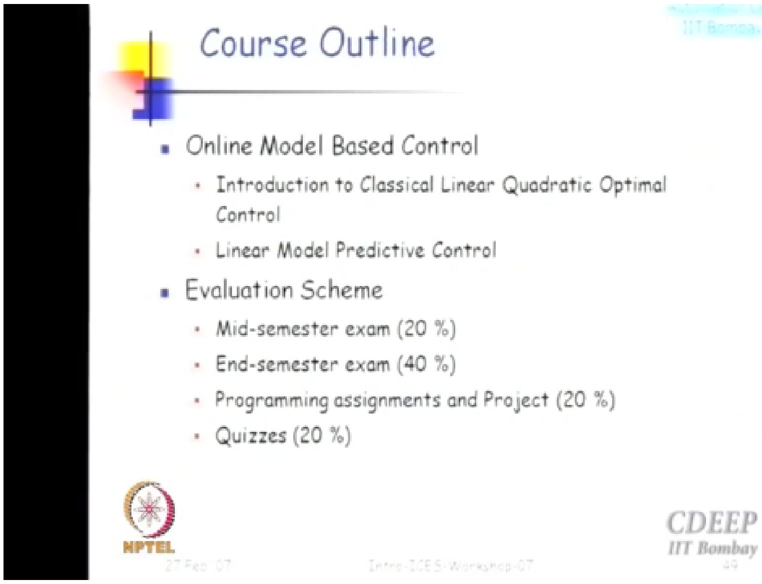

I will talk initially about classical quadratic linear optimal control theory which forms the foundation of linear model predictive control and then finally I will end with linear model predictive control. The evaluation scheme while I am quite decided about big semester examination will be 20% and end semester about 40%, I'm still debating how to split between the courses and the projects.

In this particular course, doing actually simulation experiments is very critical. You will not understand many concepts. It is like listening to lectures on swimming okay. Unless you jump into water you cannot understand how to swim. So unless you do this exercise of actually doing simulations of what is happening because the surround of things are so complex that you cannot ask an exam question on that.

You have to actually implement and see how it works and when you understand. So the project component could increase to from 20% to 30%. Quiz component could go back from 20% to 10% so that I will get a call after the population stabilizes and then how many projects you can generate because I have to go about doing it. So this last two parts are little fussy and we will take a call little later. So this is the breakup and this is how we are going to go about. So this is an intensive course on advance control starting from data to control, everything is covered. So welcome about and let us hope you may enjoy this journey together.

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