

NPTEL
NATIONAL PROGRAMME ON
TECHNOLOGY ENHANCED LEARNING

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ADVANCE
PROCESS CONTROL

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Lecture No. 10

Development of Control Relevant Linear
Perturbation Models (Part 2)

Sub-topics:

Development of ARMAX models (contd.) and
Issues in Model Development

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ARMAX: One Step Prediction

Consider 2nd order ARMAX model with $d=1$

$$y(k) = -a_1 y(k-1) - a_2 y(k-2) + b_1 u(k-2) + b_2 u(k-3) + e(k) + c_1 e(k-1) + c_2 e(k-2)$$

$$y(k) = \frac{b_1 q^{-2} + b_2 q^{-3}}{1 + a_1 q^{-1} + a_2 q^{-2}} u(k) + \frac{1 + c_1 q^{-1} + c_2 q^{-2}}{1 + a_1 q^{-1} + a_2 q^{-2}} e(k)$$

Difficulties:

- ✓ Sequences $\{y(k)\}$ and $\{u(k)\}$ are known but $\{e(k)\}$ is unknown
- ✓ Non-Linear in parameter model - optimum can't be computed analytically

Solution Strategy

Problem solved numerically using nonlinear optimization procedures

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Okay, so let us start looking at this ARMAX model. One thing I want to emphasize before I proceed is you have to solve problems which I have given you okay, start solving them yourself or with help of your friends, come for the divergence efficiency, if you do not solve problems there is no point in attending to these lectures, you will not understand anything okay. So you all become blink and uttering beyond a certain point okay.

It is like without solving problem, attending this lectures is like learning, swimming by theory, we have to jump into water, you have to solve problems otherwise the concept will not become clear. Extremely important that you solve problems, I will wait actually for this course, other than just the hand problems it is important to do simulations and programming. So this is the advanced course and everything cannot be done by hand, very, very simple things can be by hand okay.

So I am just waiting to cover up to certain points, so that I can start giving you programming assignments okay. And to be very frank, even though I might decide to give 20 or 25% witness to the programming, real learning will happen if you do programming parts seriously okay. So that is more important than, you exams in which I cannot ask more than two by two matrices or three by three, you know some simple systems which you can work with in three hours or in one hour or whatever is said for the exam.

But if you do the project seriously, what I would tend to do is try to pick up several eight different systems and ask you to simulate these systems, I will give you differential equations for

the systems with all the parameters with the sample program as to how to simulate stochastic process, how to simulate noise. So that you can look at by program and develop your programs okay.

And then when you start working with MATLAB programs in your data you will get much better understanding than what you can get just by the simpler lectures. So this is only one part, the simpler lectures look notes will be one part that is one thing. The second thing is that please upload my, or please download my letters notes, I have revised them, then I have rearrange them, revise them so.

Some definitions I have changed, these are literature various, you know different peoples will use, different definitions for covariance, auto covariance, some books prefer $1/n-1$ some books $1/n$ and so on. So it is important that we follow one strict to one particular temptation and use that okay. So we were looking at this model which is ARMAX model, ARMAX model and then I said the trouble here is that, I did not know E, I only know Y and U okay.

So this C_1 C_2 and T sequence E is not known and that is the trouble when you want to estimate the model parameters. So my aim in the next two minutes or next two slides is to show you that how can I do some algebraic manipulation, so that I can do calculations only with Y and U, I somehow try to eliminate these variables here $E(K)-1$ and $E(K)-2$, these two variables I want to manipulate okay.

Doing some algebra and that algebra I am going to do okay. Why, because we have developed ARX model, in ARX model we had this term $E(K)$ appearing, if only $E(K)$ appears in my equation, I do not have so much problems okay. I am able to manage doing calculations, but yeah, it is a colored noises. Yeah, so we have seen yesterday in the exercises that W_K+W_{K-1} to get that gives us a colored noise.

Because auto covariance 1 is not 0 okay, so for this particular moving average process, you know auto covariance will be, I would actually there is a exercise problem if you check for this kind of a process C_1 C_2 okay. I think problem number 8 or something, I do not remember now. You were asking yesterday, problem number 5, just look at the problem okay. So this is a colored noise.

But so, I wanted to do an algebraic manipulation, so algebraic manipulations just keep this global picture in mind, right, somehow I would do an algebraic manipulation and I want to transform this equation such that it has only Y U at only E(K), I do not write E(K)-1 E(K)-2 okay. So I am going to do this algebraic manipulation and that is why I am doing some preparation for that. So how do I estimate the model parameters, I still have to do optimization okay.

I do not know a1, a2, b1, b2 and c1, c2 six parameters, I still would not do the optimization, but I somehow do eliminate right now for purpose of calculations to setup the optimization problem. I need a transformed equation which only has, you know which will have all six parameters, parameters will not vanish. But only Y and U will be there in my equation, so that you know my computations become.

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Invertability of Noise Model

Crucial Property of Noise Model

Noise model and its inverse have to be stable i.e. all its poles and zeros should be inside the unit circle
(follows from spectral factorization theorem)

$$e(k) = H^{-1}(q)v(k) = \sum_{i=0}^{\infty} \bar{h}_i v(k-i) \qquad v(k) = H(q)e(k) = \sum_{i=0}^{\infty} h_i e(k-i)$$

$$H^{-1}(q) \text{ is stable i.e. } \sum_{i=0}^{\infty} |\bar{h}_i| < \infty \qquad H(q) \text{ is stable i.e. } \sum_{i=0}^{\infty} |h_i| < \infty$$

Note : $H(q)$ is always 'monic' polynomial i.e. $h_0 = 1$

Key problem in identification: Find stable and inversely stable such $H(q)$ and a white noise sequence $\{e(k)\}$



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Because only what I do U is the non signal, E(K) it is not measured real signal okay. So the fourth, it is pertained in Y(K), why it is, yeah, yeah, but I want to separate the effects of deterministic contribution to Y okay, and disturbance contribution to Y. So this is written to Y coming from known inputs, U is the known input, manipulated variable okay. This is modeled for contribution to Y which is coming from unknown sources okay.

I want to separate that okay, I want to separate them, because it will help me afterwards the designer controller which can reject the disturbances. See what is the aim of controller design? Aim of controller design A is to take the system from one state to other state, I want to know my temperature inside a reactor is some 300 value taken into 320 set point change okay, called tracking.

Or as Y net you know, some altitude of 20,000 feet, I wanted to take in 25,000 feet okay. So that is my tracking problem. Other problem is disturbances rejection okay, this disturbance rejection. So H^{-1} when you inverse okay, zeros will become poles and poles will become zeros right, you understand. That is why we need invertability of the – okay.

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Example: an ARMA Process

Consider a first order ARMA process

$$v(k) = 0.8v(k-1) - e(k) + 0.5e(k-1)$$

where $\{e(k)\}$ is a white noise sequence

i.e. $H(q) = \frac{1 + 0.5q^{-1}}{1 - 0.8q^{-1}} = \frac{q + 0.5}{q - 0.8}$ has a pole at $q = 0.8$ and zero at $q = -0.5$

Then, $H^{-1}(q) = \frac{1 - 0.8q^{-1}}{1 + 0.5q^{-1}} = 1 - 0.13q^{-1} + 0.067q^{-2} - 0.0325q^{-3} + \dots$

and $e(k)$ can be recovered from measurements of $v(k)$

$$e(k) = v(k) - 0.13v(k-1) + 0.067v(k-2) - 0.0325v(k-3) + \dots$$

Note: When noise model is stable and inversely stable

$\hat{e}_k \rightarrow 0$ as k increases

Thus, terms after some $k = n$ (depending on decay rate) can be neglected

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I just give you an example here, this is an example of ARMA process okay, for this particular process the pole and the zero, there is one pole and one zero, both of them are inside unit circle okay. And if you do H^{-1} , yesterday I showed you how to do long division and actually there is an

exercise in the exercise which I have given you, there is an exercise in which you should do long division by add, and actually check how do you express okay.

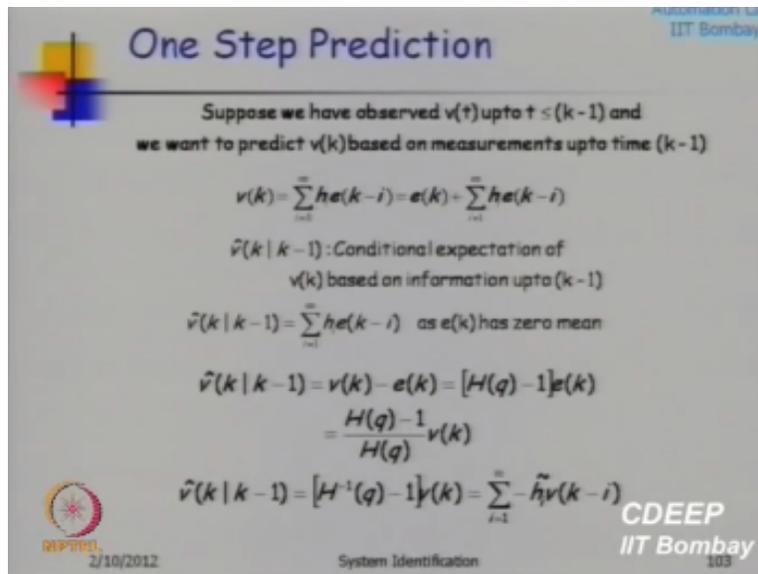
So I talked about FIR model then going from, you know AR to moving average and so on. So you should do the exercises the new realization. So what you can see here is that if the poles are inside the unit circle and zeros are inside the unit circle this coefficients here will go on diminishing and, you know as K increases okay. So which means in this series actually you can trunk it, because after sometime the coefficient will become negligible, they will become close to zero.

And then you can take a finite approximation okay, but you will lead large number of terms depending upon how the poles are zeros are, you will need large number of terms. So actually this inverse okay, see I had told you somebody had asked me why for ARMA model why not use AR or MA model? The reason is somewhat hidden here okay, you will need less number of parameters for an ARMA model than either one of them ARMA or AR.

Because if you expand this as a series and then trunk it okay, then you will need more number of coefficients to get the same effect which this is giving okay. That is why we normally use, this is a highly parameterized form than the series expansion okay. It is more convenient to work with this parameterize form as well as number of parameters is concerned, it is easier to work with this form then okay.

And then this will happen that you can trunk it only if the poles and zeros both are inside the unit circle okay. Inverse this truncation either way okay, it is possible only poles and zeros are inside the unit circle. If they are not inside the unit circle then in one direction it might grow and then you have problems okay.

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One Step Prediction

Suppose we have observed $v(t)$ upto $t \leq (k-1)$ and we want to predict $v(k)$ based on measurements upto time $(k-1)$

$$v(k) = \sum_{i=1}^{\infty} h e(k-i) = e(k) + \sum_{i=1}^{\infty} h e(k-i)$$

$\hat{v}(k | k-1)$: Conditional expectation of $v(k)$ based on information upto $(k-1)$

$$\hat{v}(k | k-1) = \sum_{i=1}^{\infty} h e(k-i) \text{ as } e(k) \text{ has zero mean}$$

$$\hat{v}(k | k-1) = v(k) - e(k) = [H(q) - 1]e(k)$$

$$= \frac{H(q) - 1}{H(q)} v(k)$$

$$\hat{v}(k | k-1) = [H^{-1}(q) - 1]v(k) = \sum_{i=1}^{\infty} \tilde{h}_i v(k-i)$$

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Okay, so now let us go to what is called as one step prediction. This is the critical thing when you come to identifying model from data. Let us keep the global aim into the mind, I want to somehow eliminate $E(K-1)$, $E(K)_2$, $E(K-3)$ whatever appears, I am only comfortable with $E(K)$, $Y(K)$ and $U(K)$, past $Y(K)$ appears in my predictions no problem, past $U(K)$ appears in my prediction no problem, only just $E(K)$ appears not a problem.

I have a trouble with all $E(K)$ in the past, because I do not know them okay. So what we are going to do is – okay, so suppose you have observed $V(K)$ up to time T which is equal to $K-1$, and then you want to predict $V(K)$ based on measurements of $V(K)$ up to time $K-1$ okay. So let us write $V(K)$ as, let us say I have done this long division, and then I have expressed this as, you know summation of I have just explained this in the previous slide.

If you have the slide which you can check that. So see I am going to split this into two component, this summation $E(K)$ and everything that is in the past, I do not write $E(K-1)$, $E(K-2)$ so I have summed up here 1 to ∞ okay, in practice there will not be ∞ 1 to some N into the past okay. So this component I am going to call as the conditional expectation of $V(K)$ based on, see there are two components at instant K there are two components, something coming from the past.

This is coming from the past okay, and this is see always remember one thing time K is the current time instant $K+1$ is the next one, $K-1$ is the past okay. So $V(K)$ is a random variable okay, it has some part which is coming from the past history okay, and something is going to happen

now instantaneously okay. Now before this $E(K)$ happens can you give me a guess of what is the best guess for $V(K)$, how will you find out.

See suppose you happen to know all these past $E(K)$ suppose for the time being you happened in the hole past $E(K)$ okay, but you do not know the current detail, what is the best guess for $E(K)$? $E(K)$ is the 0 mean random variable, what is the best guess mean 0 okay. So I am going to call this part as the conditional mean that is conditional expectation, what is the best that you can expect okay, value of $V(K)$ that you know the next $E(K)$ that is going to come now is 0 okay.

And see this part is coming from the past it is not going to change now, whatever has happened in the past has happened okay the random variable which is going to occur now okay I assume that the best that is for it is 0 okay so in that case we split this $v(k)$ into 2 parts you know this v^k k v^k given $k - 1$ this notion we are going to use from now on throughout k given $k - k$ given $k - 3$.

And so on so this means estimate of the way should read this is that estimate \hat{v} is an estimate of v stochastic process v at instant k using measurements up to instant $k - 1$ using measurements up to the pervious instruct okay that is what is so now I can just do an algebra and show that this is nothing but $H_q - 1$ because what is v is H_q into e okay and this is doing the algebra here okay I am writing this as a just see whether you are comfortable with this algebra.

I am just doing this algebra okay is everyone with me on this what is e_k is you know you can write e_k as $H \frac{1}{H} \times v(k)$ okay that is what I have done knowing from here to here I have written e_k as $v(k)/H_q$ okay $v(k)/H_q$ yeah it is conditional expectation oh it is not an estimate so \hat{v} should not be there oh this is of settled difference I agree with you \hat{v} will appear when you start doing computations right now it is just the conditional expectation we have a point okay.

Get what I am saying you have a point right now we are so right now this \hat{v} should not be here so with slide if I start correcting now it will take some time read it without \hat{v} mentally remove \hat{v} here this is true if you know the truth then this is the true \hat{v} will come when you start doing computations using y and u that time \hat{v} will appear then you take expectation now you get expectation v now what is the expectation of v expectation of v is expectation of $e +$ expectation of this term right.

So what is the expectation of e_0 what will be the expectation of this see now you have to be very careful with your expectation because this is something in the past which has already happened it is not going to change now okay so you cannot get expectation of that inside and say expectation will go to 0 okay yeah condition expectation as gone 0 well okay so given something as happened up to or you take conditional expectation on both sides yeah. You will take condition expectations on both sides.

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One Step Output Prediction

Suppose we have observed $y(t)$ and $u(t)$ upto $t \leq (k-1)$ and
 We have $y(k) = G(q)u(k) + v(k)$
 and we want to predict $y(k)$ based on information upto time $(k-1)$
 $y(k | k-1) = G(q)u(k) + v(k | k-1)$


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Okay so now let us go back to our model I want to eliminate $v(k)$ I want to eliminate $v(k)$ which is in the past so I am going to write a expectation of y_k is condition expectation of so ia m talking your you see this I am taking conditional expectation of y_k now for conditional expectation of y_k is gq into qk times v kd1 $k-1$ that is condition expectation of v_k now with algebra which we have done earlier we know that this can be do you see this what I am doing now.

Yeah now we are using up to $k - 1$ typically there is always a unit delay between in any digital system where there is always a unit delay between q and y so we are using u in the past we are not using current in the real digital systems it really would you will have situation where u give an input and instantaneously y will get affected okay if a physical system I am talking about physical system okay.

Now do you see the algebra here see v is $y - gu$ okay I am just substituting that here so I get this expression here just see the algebra now okay so this conditional expectation of y okay does not involve e right now I have removed e effectively using H inverse I have removed e okay using h inverse I have removed e the right hand side only contains u and y but uk is multiplied by this operator and now Gq as always a dealing of unit deal okay see for a real system the delay between the input and output is always minimum delay of 1 is there okay so current y_k is affected by u_{k-1} it is not affected by u_k okay so that thing that u comes on the passes hidden in q Gq okay.

Yeah no those have to be estimate so it is a chicken and egg problem just wait know just wait to hear the full story okay just wait so I am just arranging this and I am see what I have done here as this rearrange this equation and I have put it like this just do the algebra if you are not comfortable you can do it I can wait from some time you do it hand just see whether it you get the same expression which I got here okay.

Just start from this point and see whether you get this expression is the derivation correct okay it is not why should be expectation the predication with this conditional expectation the prediction is actually conditional expectation in stochastic term how do you what is prediction there is something unknown component or which you have to make a guess then only you can prediction right.

Oh no $\hat{}$ we have been using for estimate of the prediction okay so the true conditional expectation will not have $\hat{}$ okay so very settled differences no matter of two much is everyone okay with this derivation is this clear okay see now I have to do a.

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ARX: One Step Predictor

Consider 2nd order ARX model with $d = 1$

$$y(k) = \left[\frac{b_1 q^{-2} + b_2 q^{-3}}{1 + a_1 q^{-1} + a_2 q^{-2}} \right] u(k) + \left[\frac{1}{1 + a_1 q^{-1} + a_2 q^{-2}} \right] e(k)$$

One step ahead predictor for this model is

$$\hat{y}(k | k-1) = \left[\frac{b_1 q^{-2} + b_2 q^{-3}}{1} \right] u(k) + \left[\frac{-a_1 q^{-1} - a_2 q^{-2}}{1} \right] y(k)$$



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Let us look at one set a head prediction here let us go back to our let us go back to arx model I am going back to arx model this is my arx model okay let us look at what is Gq here this is my G q okay this my yeah you just see here even though $u(k)$ is written here because of q^{-2} , $2q^{-3}$ you are never going to get qk you will get $u(k)$ you ilel get $u(k-2)$ $u(k-3)$ okay. So now what is H inverse just go back and see what is H inverse what is what is this term.

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One Step Output Prediction

Suppose we have observed $y(t)$ and $u(t)$ upto $t \leq (k-1)$ and
 We have $y(k) = G(q)u(k) + v(k)$
 and we want to predict $y(k)$ based on information upto time $(k-1)$
 $y(k | k-1) = G(q)u(k) + v(k | k-1)$
 $= G(q)u(k) + [1 - H^{-1}(q)]y(k)$
 However, $v(k) = y(k) - G(q)u(k)$
 $\hat{y}(k | k-1) = G(q)u(k) + [1 - H^{-1}(q)][y(k) - G(q)u(k)]$
 Rearranging we have
 $\hat{y}(k | k-1) = H^{-1}(q)G(q)u(k) + [1 - H^{-1}(q)]y(k)$
 or
 $H(q)\hat{y}(k | k-1) = G(q)u(k) + [H(q) - 1]y(k)$

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1-H invests okay.

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ARX: One Step Predictor

Consider 2nd order ARX model with $d = 1$

$$y(k) = \left[\frac{b_1 q^{-2} + b_2 q^{-3}}{1 + a_1 q^{-1} + a_2 q^{-2}} \right] u(k) + \left[\frac{1}{1 + a_1 q^{-1} + a_2 q^{-2}} \right] e(k)$$

One step ahead predictor for this model is

$$\hat{y}(k | k-1) = \left[\frac{b_1 q^{-2} + b_2 q^{-3}}{1} \right] u(k) + \left[\frac{-a_1 q^{-1} - a_2 q^{-2}}{1} \right] y(k)$$

which is equivalent to difference equation

$$\hat{y}(k | k-1) = -a_1 y(k-1) - a_2 y(k-2) + b_1 u(k-2) + b_2 u(k-3)$$

Advantage : All terms in RHS are known
Residual at k 'th instant can be estimated as

$$e(k) = y(k) - \hat{y}(k | k-1)$$

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So what is H here $1/(1 + a_1 q^{-1} + a_2 q^{-2})$ okay so this is my H inverse -1 this is H inverse -1 okay so for ARX model one step ahead predictor okay turns out to have only past u and past y is that alright just be comfortable with this first is this okay because read carefully yeah you heard out 11 so it one step ahead no see from $k-1$ to k I am predicting value of k given information up to $k-1$.

So it is one step ahead prediction one step with reference to $k-1$ it is one step right see without knowing the measurement $y(k)$ I am trying to guess what will be $y(k)$ okay so what is the best estimate see your going to get a measurement at instant k which is $y(k)$ before that before it happens if I ask to give me guess what is the best guess and you have this model how will you create a guess this is how you create that guess which one this one this one.

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One Step Output Prediction

Suppose we have observed $y(t)$ and $u(t)$ upto $t \leq (k-1)$ and
 We have $y(k) = G(q)u(k) + v(k)$
 and we want to predict $y(k)$ based on information upto time $(k-1)$
 $y(k | k-1) = G(q)u(k) + v(k | k-1)$
 $= G(q)u(k) + [1 - H^{-1}(q)]y(k)$
 However, $v(k) = y(k) - G(q)u(k)$
 $\hat{y}(k | k-1) = G(q)u(k) + [1 - H^{-1}(q)][y(k) - G(q)u(k)]$
 Rearranging we have
 $\hat{y}(k | k-1) = H^{-1}(q)G(q)u(k) + [1 - H^{-1}(q)]y(k)$
 or
 $H(q)\hat{y}(k | k-1) = G(q)u(k) + [H(q) - 1]y(k)$

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Look at this equation $H^{-1}G$ what is H see okay.

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Consider 2nd order ARX model with $d = 1$

$$y(k) = \left[\frac{b_1 q^{-2} + b_2 q^{-3}}{1 + a_1 q^{-1} + a_2 q^{-2}} \right] u(k) + \left[\frac{1}{1 + a_1 q^{-1} + a_2 q^{-2}} \right] e(k)$$

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Let me just go move here.

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$$y(k) = \underbrace{\frac{B}{A}}_G u(k) + \underbrace{\frac{1}{A}}_H e(k)$$

$$H^{-1}G = \frac{A}{1} \times \frac{B}{A} = B$$

$$(1 - H^{-1}) = (-A + 1)$$

See this my model is yk everyone agree with me yeah so this is my G and this is my H okay what is H inverse G is A/1 x B/A AA cancel so this is = B okay what is 1- H inverse A- 1 oh sorry 1- A 1- A right so that is what I have done just go back and check.

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ARX: One Step Predictor

Consider 2nd order ARX model with $d = 1$

$$y(k) = \left[\frac{b_1 q^{-2} + b_2 q^{-3}}{1 + a_1 q^{-1} + a_2 q^{-2}} \right] u(k) + \left[\frac{1}{1 + a_1 q^{-1} + a_2 q^{-2}} \right] a(k)$$

One step ahead predictor for this model is

$$\hat{y}(k | k-1) = \left[\frac{b_1 q^{-2} + b_2 q^{-3}}{1} \right] u(k) + \left[\frac{-a_1 q^{-1} - a_2 q^{-2}}{1} \right] y(k)$$

which is equivalent to difference equation

$$\hat{y}(k | k-1) = -a_1 y(k-1) - a_2 y(k-2) - b_1 u(k-2) - b_2 u(k-3)$$

Advantage : All terms in RHS are known
Residual at k 'th instant can be estimated as

$$e(k) = y(k) - \hat{y}(k | k-1)$$

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So this is G okay so this is nothing but H inverse G okay AA cancels in this case okay this is $1 - H$ inverse okay so my what is my best estimate of y_k using information available only up to $k-1$ that is this in this case you get y_{k-1} which is in the past which is happen you have the data okay H instant okay you are giving a prediction okay now the trick is to defined e_k as difference between y_k and prediction of y_k okay.

So the nice thing about the ARX model is that the right hand side as only y and u and it is simple function of a_1, a_2, b_1, b_2 movement I move to R max you will have a very complex function of $a_1, a_2, b_1, b_2, c_1, c_2$ okay there are 2 extra parameters c_1, c_2 there and you will have trouble yeah instead the best estimate this is the condition made now see what is the best estimate weather the more is the best estimate or the mine is the best estimate or there are so many questions are there.

You know but if you assume Gaussian distribution okay mean and mole are everything collapses to only one value and mean is the best estimate conditional mean is the best estimate.

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ARMAX: One Step Predictor

Consider 2nd order ARMAX model with $d=1$

$$y(k) = \frac{b_1 q^{-2} + b_2 q^{-3}}{1 + a_1 q^{-1} + a_2 q^{-2}} u(k) + \frac{1 + c_1 q^{-1} + c_2 q^{-2}}{1 + a_1 q^{-1} + a_2 q^{-2}} e(k)$$

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We always assume Gaussian process we work with mostly for simple modeling we assume Gaussian process non-Gaussian process is we will assume or some very complex problems. Yeah, Gauss has created universe that is unmatched and you know many of us get hidden because of great work by Gauss okay, so let us look at this equation law ARMAX model okay, can you do it, can you do this business yourself and let us see whether what I have written here you get the same thing so you are doing do $H^{-1}G$ and 1- and tell me what you get, okay. So I will move to this, okay.

(Refer Slide Time: 32:04)

$$y(k) = \underbrace{\frac{B}{A}}_G u(k) + \underbrace{\frac{C}{A}}_H e(k)$$

$$\left. \begin{aligned} H^{-1}G &= \frac{A}{1} \times \frac{B}{A} = B & \text{ARX} \\ (1-H^{-1}) &= -(A+1) \end{aligned} \right\}$$

$$\rightarrow H^{-1}G = \frac{A}{C} \times \frac{B}{A} = \frac{B}{C}$$

$$1-H^{-1} = \frac{C-A}{C}$$

Now the only difference that you have is that you have a C here okay, so when so this id for ARX okay, now when you have a C here for this case you have to talk about $H^{-1}G$ that will be $A/C \times B/A$ so A, A cancels you will get B/C you get B/C right. what will you get for $1-H^{-1}$ $C-A$ so $1-H^{-1}$ is $C-A/C$ sorry by C you will get this right.

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Automation Lab
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ARMAX: One Step Predictor

Consider 2nd order ARMAX model with $d = 1$

$$y(k) = \left[\frac{b_1 q^{-2} + b_2 q^{-3}}{1 + a_1 q^{-1} + a_2 q^{-2}} \right] u(k) + \left[\frac{1 + c_1 q^{-1} + c_2 q^{-2}}{1 + a_1 q^{-1} + a_2 q^{-2}} \right] e(k)$$

One step ahead predictor for this model is

$$\hat{y}(k|k-1) = \left[\frac{b_1 q^{-2} + b_2 q^{-3}}{1 + c_1 q^{-1} + c_2 q^{-2}} \right] u(k) + \left[\frac{(c_1 - a_1) q^{-1} + (c_2 - a_2) q^{-2}}{1 + c_1 q^{-1} + c_2 q^{-2}} \right] y(k)$$

which is equivalent to difference equation

$$\begin{aligned} \hat{y}(k|k-1) = & -c_1 \hat{y}(k-1|k-2) - c_2 \hat{y}(k-2|k-3) \\ & + b_1 u(k-2) + b_2 u(k-3) \\ & + (c_1 - a_1) y(k-1) + (c_2 - a_2) y(k-2) \end{aligned}$$

Residual at kth instant can be estimated as

$$e(k) = y(k) - \hat{y}(k|k-1)$$



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System Identification

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So what is the one step by a predictor here, the step my predictor here so this is my $H^{-1}G$ okay, this $1-H^{-1} C-A/C$ okay is this okay what is nice about this equation, in this equation on the right hand side you only have Y and U okay. No, no we are using a lower order model with less number of parameters, less number of parameters means you need excitation for a smaller period of time which means you are wasting product for a smaller period of time so your experimentation period to get the model smaller is cost effective.

Correct, no, no see I am giving you toy examples in really let us tell systems I have worked with some, I can show you some industrial data where you know you need between one input and one output okay, you need 40 parameters or 50 parameters okay, which compresses to 4 or 6 parameters when you go to ARMAX okay, where is 40 and where is 4 or 6 you know it is that kind of a difference okay, in some sense yeah.

It is a compressed form yes, yeah exactly if the current disturbance was 0 perfectly a very nice interpretation, if current disturbance was 0 then the best estimate of yeah would have been this that is another looking at it, if the current does it might happens to be 0 and why do we choose 0 because it is we are, I should modeling there is a 0 mean white noise, okay. Okay, so I can convert this into a difference equation okay, I have transform the problem of unknown e_k to this \hat{Y} okay. Now how I am going to deal with so my error here, well my error here is I have call it ϵ because it an estimate of e_k it is not equal to e_k so estimate of e_k .

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Automation Lab
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ARMAX: One Step Predictor

Given : $\{u(k) : k = 0, 1, 2, \dots\}$ and guess for model parameters
 Assume : $\hat{y}(0|-1) = y(0)$, $\hat{y}(1|0) = y(1)$, $\hat{y}(2|1) = y(2)$

$$\hat{y}(3|2) = -c_1 \hat{y}(2|1) - c_2 \hat{y}(1|0) + b_1 u(1) + b_2 u(0) + (c_1 - a_1) y(2) + (c_2 - a_2) y(1)$$

$$\epsilon(3) = y(3) - \hat{y}(3|2)$$

$$\hat{y}(4|3) = -c_1 \hat{y}(3|2) - c_2 \hat{y}(2|1) + b_1 u(2) + b_2 u(1) + (c_1 - a_1) y(3) + (c_2 - a_2) y(2)$$

$$\epsilon(4) = y(4) - \hat{y}(4|3)$$

$$\hat{y}(5|4) = -c_1 \hat{y}(4|3) - c_2 \hat{y}(3|2) + b_1 u(3) + b_2 u(2) + (c_1 - a_1) y(4) + (c_2 - a_2) y(3)$$

$$\epsilon(5) = y(5) - \hat{y}(5|4)$$

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Okay, so now I have this one step predictor I can start using it in time okay, I have this data which is u_k given from $k=0,1,2,3,4$ I have this data okay. Then to kick off my estimator I need these values of \hat{Y} initially I can guess then equal to Y_0 okay, and then I will start using this difference equation, so what is y_3 given to I will use a difference equation and find out see I have made a guess that this value is nothing but equal to y_0 , this value is nothing but equal to y_0 this is my guess okay.

Now but how do you parameter estimation you are given a guess okay, of $C_1 C_2, A_1 A_2, B_1 B_2$ okay, and then you actually predict y find out the difference and minimize the sum of the square of errors that is what you want to do finally, right minimize the sum of the square of errors. So I am started using the difference equation in time I am starting from time 0 so $y_3 \in 3$ is given by this okay. Next I find out y_4 given 3, notice one thing here I have generated y_3 given 2 it is used here, okay.

Now y_5 given 4 I am using this estimate and this estimate here okay, so given a guess of $C_1 C_2 A_1 A_2$ and $B_1 B_2$ and I have this data of U and Y I can go on estimating these numbers \hat{Y}_3 to 4354 and so on right, I can do this up to N my data is some 100 data points so I can do this.

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Automation Lab
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ARMAX: One Step Predictor

Given : $\{u(k) : k = 0, 1, 2, \dots\}$ and guess for model parameters

Assume : $\hat{y}(0|-1) = y(0)$, $\hat{y}(1|0) = y(1)$, $\hat{y}(2|1) = y(2)$

$$\hat{y}(3|2) = -c\hat{y}(2|1) - c\hat{y}(1|0) + b_1u(1) + b_2u(0) + (c_1 - a_1)y(2) + (c_2 - a_2)y(1)$$

$$\alpha(3) = y(3) - \hat{y}(3|2)$$

↓

$$\hat{y}(4|3) = -c\hat{y}(3|2) - c\hat{y}(2|1) + b_1u(2) + b_2u(1) + (c_1 - a_1)y(3) + (c_2 - a_2)y(2)$$

$$\alpha(4) = y(4) - \hat{y}(4|3)$$

↓

$$\hat{y}(5|4) = -c\hat{y}(4|3) - c\hat{y}(3|2) + b_1u(3) + b_2u(2) + (c_1 - a_1)y(4) + (c_2 - a_2)y(3)$$

$$\alpha(5) = y(5) - \hat{y}(5|4)$$

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Yeah, only here because Y appears no in my question see there are two things here \hat{Y} appears and Y appears. In this equation consist of Y, \hat{Y} \hat{Y} is different from Y, Y is the true measurement \hat{Y} is the estimate so in this difference equation \hat{Y} is appearing Y is appearing okay, so that is what in my equation here Y2Y1 is appearing Y3Y2 is appearing but there is no problem Y is measured only trouble is, only trouble with this guy so this has to be estimated here and then put here, okay.

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ARMAX: One Step Predictor

Given : $\{u(k) : k = 0, 1, 2, \dots\}$ and guess for model parameters

Assume : $\varepsilon(0) = \varepsilon(1) = \varepsilon(2) = 0$

↓

$$\hat{y}(3|2) = -a_1 y(2) - a_2 y(1) - b_1 u(1) - b_2 u(0) - c_1 \varepsilon(2) + c_2 \varepsilon(1)$$

$$\varepsilon(3) = y(3) - \hat{y}(3|2)$$

↓

$$\hat{y}(4|3) = -a_1 y(3) - a_2 y(2) - b_1 u(2) - b_2 u(1) - c_1 \varepsilon(3) + c_2 \varepsilon(2)$$

$$\varepsilon(4) = y(4) - \hat{y}(4|3)$$

↓

$$\hat{y}(5|4) = -a_1 y(4) - a_2 y(3) - b_1 u(3) - b_2 u(2) - c_1 \varepsilon(4) + c_2 \varepsilon(3)$$

$$\varepsilon(5) = y(5) - \hat{y}(5|4)$$



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So I can actually okay this we can skip, I have given a alternate way of predictions okay, you can see this in the notes where is there are two different ways of predictions I have explained you one way of doing predictions this is another way of doing predictions.

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Parameter Estimation

Parameter Estimation by Optimization
Find θ that minimizes objective function

$$(\hat{a}_1, \hat{a}_2, \hat{b}_1, \hat{b}_2, \hat{c}_1, \hat{c}_2) = \underset{(a_1, a_2, b_1, b_2, c_1, c_2)}{\text{Min}} \frac{1}{N} \sum_{k=3}^N \varepsilon(k, \theta)^2$$

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Okay, so now how do I estimate the parameters I estimate the parameter such that some of the square of errors is minimized over you know there p to n some over p to n with respect to the 6 parameters a_1 a_2 b_1 b_2 so I have to solve this problem using non linear optimization. I have to solve this problem using non linear optimization tools there is no other go why the problem comes the problem comes because of this the problem comes because y_3 is estimated.

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ARMAX: One Step Predictor

Given : $\{u(k) : k = 0, 1, 2, \dots\}$ and guess for model parameters

Assume : $\hat{y}(0|-1) = y(0)$, $\hat{y}(1|0) = y(1)$, $\hat{y}(2|1) = y(2)$

$$\hat{y}(3|2) = -c_1 \hat{y}(2|1) - c_2 \hat{y}(1|0) + b_1 u(1) + b_2 u(0) + (c_1 - a_1) y(2) + (c_2 - a_2) y(1)$$

$$e(3) = y(3) - \hat{y}(3|2)$$

↓

$$\hat{y}(4|3) = -c_1 \hat{y}(3|2) - c_2 \hat{y}(2|1) + b_1 u(2) + b_2 u(1) + (c_1 - a_1) y(3) + (c_2 - a_2) y(2)$$

$$e(4) = y(4) - \hat{y}(4|3)$$

↓

$$\hat{y}(5|4) = -c_1 \hat{y}(4|3) - c_2 \hat{y}(3|2) + b_1 u(3) + b_2 u(2) + (c_1 - a_1) y(4) + (c_2 - a_2) y(3)$$

$$e(5) = y(5) - \hat{y}(5|4)$$

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Which is it depends upon the guess c_1 c_2 then this estimate gets multiplied by c_1 again you see that or here these two are estimates linear estimates they get multiplied by c_1 c_2 so non linear in parameters problem okay, typically very difficult to solve not so easy to solve this problem. Subject to this model equations you have to solve this problem, so I have to solve this constrain of optimization problem that is ϵ k is computed using this equation and you know it is very important to give a good initial guess and so on.

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ARMAX: One Step Predictor

Consider 2nd order ARMAX model with $d=1$

$$y(k) = \left[\frac{b_1 q^{-2} + b_2 q^{-3}}{1 + a_1 q^{-1} + a_2 q^{-2}} \right] u(k) + \left[\frac{1 + c_1 q^{-1} + c_2 q^{-2}}{1 + a_1 q^{-1} + a_2 q^{-2}} \right] e(k)$$

One step ahead predictor for this model is

$$\hat{y}(k|k-1) = \left[\frac{b_1 q^{-2} + b_2 q^{-3}}{1 + c_1 q^{-1} + c_2 q^{-2}} \right] u(k) + \left[\frac{(c_1 - a_1) q^{-1} + (c_2 - a_2) q^{-2}}{1 + c_1 q^{-1} + c_2 q^{-2}} \right] y(k)$$

which is equivalent to difference equation

$$\begin{aligned} \hat{y}(k|k-1) = & -c_2 \hat{y}(k-1|k-2) - c_1 \hat{y}(k-2|k-3) \\ & + b_1 u(k-2) + b_2 u(k-3) \\ & + (c_1 - a_1) y(k-1) + (c_2 - a_2) y(k-2) \end{aligned}$$

Residual at k 'th instant can be estimated as

$$e(k) = y(k) - \hat{y}(k|k-1)$$



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So it is not a trivial solution to fortunately there are tool box is now available and you can vacuole of the tool box as well as control engineers develop models and, so I would just generalize what have said is something called prediction error method I have this model $y_k = g I$ am just saying that g has some parameters θ , okay and h has some parameters entire parameter vector $a_1 a_2 b_1 b_2 c_1 c_2$ I am calling it as θ .

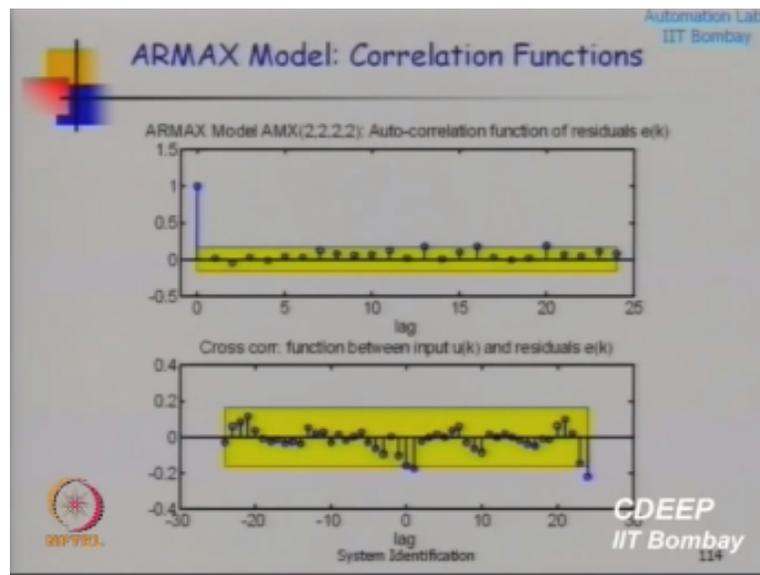
And I have this data of $y_k u_k$ then what is the optimal prediction we just derive this optimal prediction optimal prediction of y hat given $k-1$ is given by h inverse $g \times 1 - h$ reverse y okay then you find out this error okay and then you minimize some of the square of errors okay this way of identifying models v^2 estimation of the models okay this is called as prediction error method why there is an error method because v expressly construct predictions and then use that minimize that okay. This is called a prediction error method or in system identification literature this is popularly known as pem okay.

So you are predicting note one thing the predictor here what is main thing about the predictor/predictor does not have e in the past but it has only had y and u y and u Are measured value known values, so you can actually construct the some of the problems in the tutorial sheet are given a second order model construct a predictor or given a first order model construct a predictor, so you should actually workout those predictors and check how the predictors workout okay.

So predictor equation becomes more complex for box Jenkins model for ARMAX is easier than box Jenkins okay and it is even more difficult to identify box Jenkins than ARMAX. So let us come back to our old problem we have to minimize this some of the square of errors and if I do this using mat lap tool box I get this and the data that we have been looking at one time data okay I get this model parameters and well as I told you this models consist of two things one is a b c they are the polynomials that you get and then e is the white noise whose mean is almost equals to 0 okay.

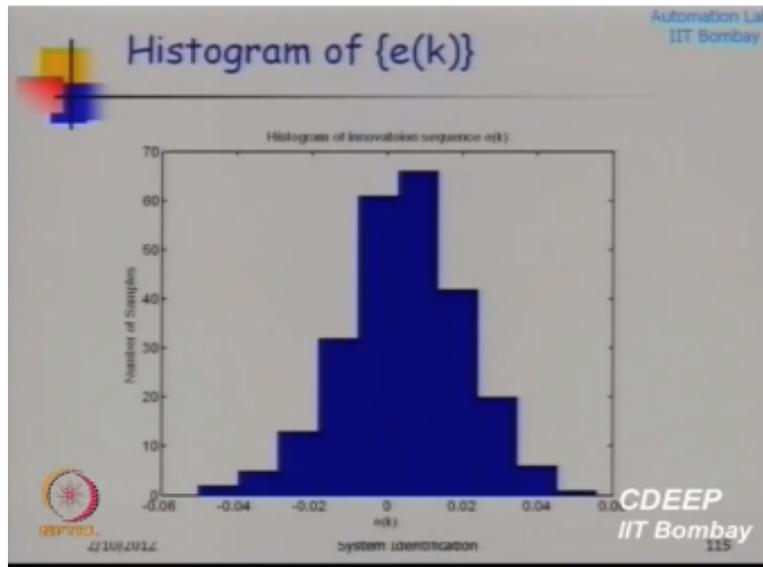
Why it is not equal to 0 because this is an estimate okay and yesterday I was telling you that you know the estimate of a random number might which has two mean 0 the estimate might come very close to 0 see here it is coming 10^{-3} very close to 0 okay. And it is variants is this λ^2 this is my model second order this is convention of mat lap that means there is a time delay of 2 order of a polynomial is 2 order of b polynomial is 2 order of c polynomial is 2 that is what is 222 okay.

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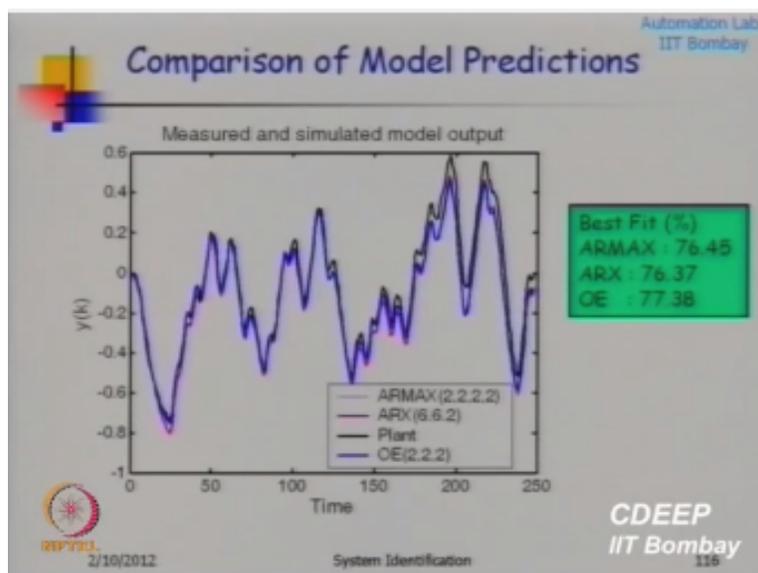
And then I get this ARMAX model and you know I should check auto correlations cross correlations all that business we should do you can see that this is almost a white noise e_k is a white noise you do not have well higher order here ARX model we have to go to sixth order here only using second order model and going to get reasonably good model okay.

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So e_k if I put histogram of e_k looks like it is a Gaussian noise the way it is distributed the way the errors are distributed if I compare different models.

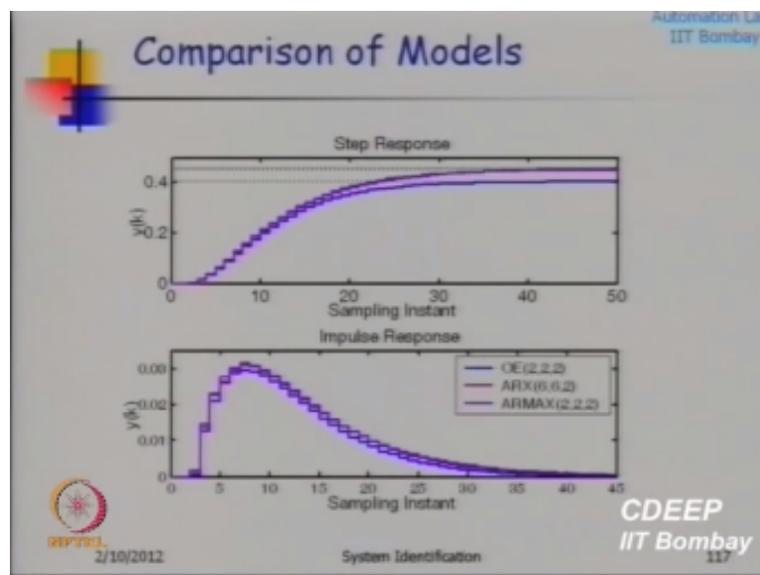
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Now there is something this is simulation which is noise free I have remove the noise component and compared how good are the three models I developed oe model ARX model ARMAX model all of them are giving almost similar predictions okay, this is these predictions are using the noise models that is why it is just fitting okay these predictions are without the noise model that is why there is difference because this gap is because of the noise okay.

So what is typically done in real exercise is that you take one data set okay you identify a model using the data set you take another data set and see whether these models predict that data okay that is what I have done here okay. So you can usually see here that most of the variation in data is explained by this model so model is a good model okay that is called prediction see you are removing uncertainty and saying that what is the best prediction so I talked about one step prediction you can talk about two step prediction 3 step predictions 5 step prediction you can talk about infinite polarization predictions.

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Actually technically speaking what I have plotted here infinite polarization prediction not taking in to account y at all if I just know u okay see go back here to this model, if I were to assume that only this part is there okay and I do not know anything about this, what is the best prediction see this prediction problem is always there no see want to know what is the best prediction of

temperature of the 15 days if I develop this model for temperature variation in Bombay I would try to predict okay and the models are bad that is why you curse you news papers are whatever the weather department for but the problem is you know you have to develop $G(q)$ and $H(q)$ okay.

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Prediction Error Method

Given data set $Z_N = \{y(k), u(k) : k = 1, 2, \dots, N\}$

Model : $y(k) = G(q, \theta)u(k) + H(q, \theta)e(k)$

Optimal one - step predictor

$$\hat{y}(k | k-1) = H^{-1}(q, \theta)G(q, \theta)u(k) + [1 - H^{-1}(q, \theta)]y(k)$$

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System Identification

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If your $G(q)$ is not so good your prediction for next 15 days are not going to be good or this one more thing which we do not realize that there are always unknown disturbances okay, in a weather prediction we always unknown disturbances so those can upset your predictions no you said at day after tomorrow is going to be sun shine but there is some disturbance somewhere and you know the clouds come in so you have problem.

So best estimate of day after tomorrows weather okay given you know given this is 0 you can make using this model okay, so just like a develop one step higher predictions in the books on this thing you talk about multi step predictions multi step prediction we are going to use for

control after sometime I will talk about predictive control I will do p step higher predictions and k step higher predictions and all.

Then you know I have once have this model I am using it for doing all kinds of I want to see step is for there I want to see emesis point so I can do all that I want to see Nyquist plots of these models.

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Steps in Model Development

- Selection of model structure
- Planning of experiments for estimation of unknown model parameters
 - Design of input perturbation sequences
 - Open loop / closed loop experimentation
- Estimation of model parameters from experimental data using optimization techniques
- Model validation
 - Prediction capabilities
 - Steady state behavior

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So let me just summarize what are the steps in the model development given data you have to first select the model structure or model ARMAX model or Zinkins model whatever ARX model okay then you have to plan the experiments now planning of the experiments and selection of model structure are couple you must have realize that if I am using ARX model let me collect data for a longer time if I intend develop you know ARMAX model I can do a shorter experiment and so on.

So you are math's understanding of math's is declare to where you are plan your work you know where your plan the experiments very important there are so many issues I mean we are just touching tip of the ice - burg this is very huge area we do these excitations when the plot does not close look in to the open look I mean there are lot of debits people are still working on close look and excitation this time so on.

So moment you move to this close loop experimentation there are lot of issues there noise and the input become correlated because the controller output is function of measurements but measurement have noise so the controller output become a function of noise and then you have mess, you cannot estimate model parameters correctly I have given one problem in the just check what is the problem the identifying the parameters.

If the plan is in close look okay there are problems and then you have to worried at the model is that model good or bad you have to take some independent data and see whether this model predicts that data okay all those things are required without that you cannot really you know do a good job. I think before I go to that let me see the demonstrate to you the still walks at least some probably we visit it again so these mat lob has tool box develop a professional and it has a very nice interface I think was a burbiar showed you how do you commenced this re the nice interface which looks measure more nice symptom okay.

So you probably would say that if it is all this symptoms of five minutes of job why did you give so many lectures know that is a good question and this is the data which I have been shown you this is the data which is so this is the quadraptions data for the tank two tanks in series okay level variation in the lower tank with respect to voltage given to the valve in the control valve okay.

This is the data we have been looking t this is the level variation these are the inputs this kind of inputs is called as random binary two state input by only two states why not multiple tests 12 this is come this is the historical package you know earlier probably through you know limited digital hardware it is possible to introduce quadraptions which are only the two levels okay.

So there is nothing wrong in multi level signal we can always introduce but these two keep using this so PRBS is called PRBS is Sudo random binary input okay why do not give step into why do not give you know there is a problem in a exercise sheet this tells you why you should not just step into you will have difficulties in this matrix Ω transpose Ω will have you know column dependency in this matrix Ω transpose Ω .

So rank of the matrix Ω transpose Ω is deeply where you plan this experiments okay so remember that now how do I tell this model here well I have taken this data I just go here and set

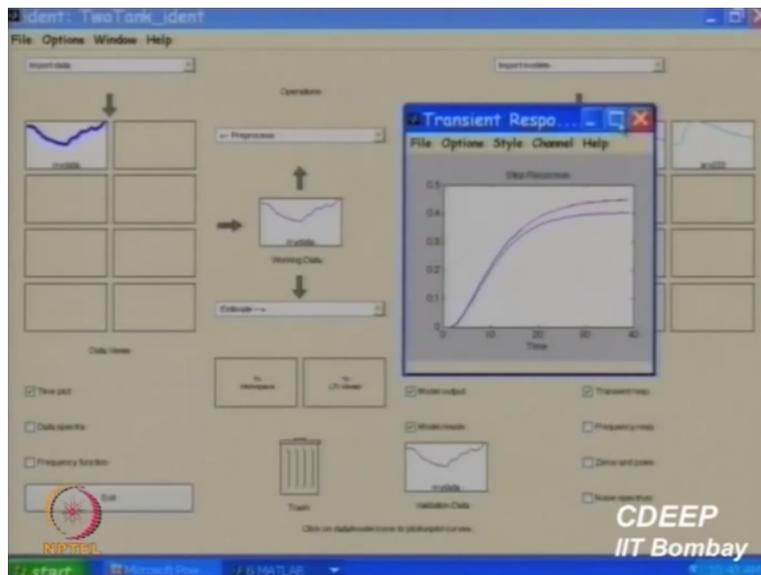
parametric model what model 1 ARX model or I will choose boxen model okay I will chose bonjent models and just say estimate okay.

And it has done that okay this is my bj model this is my bj model okay I want to see how good is the model predictions so this model is good oaky I want to compare this with other models that I have developed okay I have developed here ARX model is 4, 4, 2 ARX mode is 6, 6, 2 I want to compare with this and I want to compare with this okay.

All this optimization business which have been totally used is solved like this in fraction of second like this in fraction of second inside two boxes and then you can see all times of law you can see how good is the model prediction you can say well I want to see whether there is auto correlation of the residuals model residuals.

So this is for box and sign other models this is for the ARX 2,2 models this is OE model so OE model that nice is colored for boxen things and noise is white so the auto correlation is within the band except at lag 0, lag 0 is 1 they are probably high lag 0 this is cross correlation in the cross correlation.

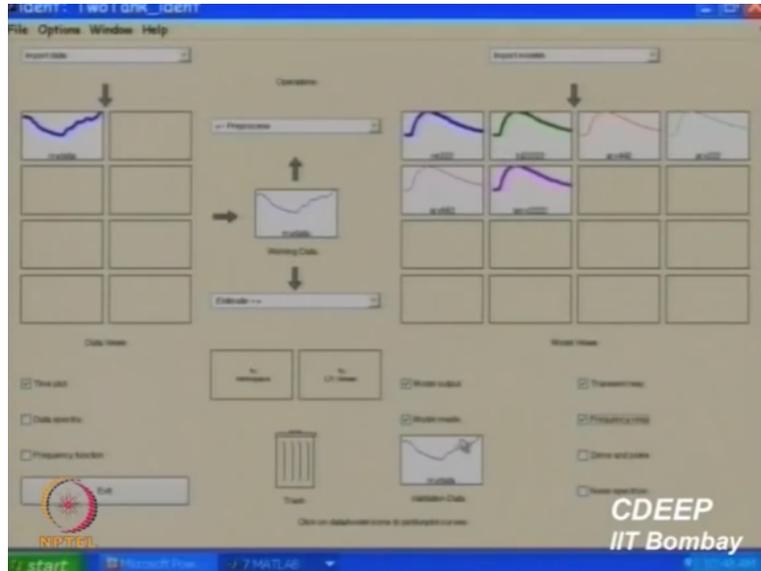
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So you can get all these plots this you know you want to see transept is forms at the two models are the three models are compared okay so it just click of things provided you know you want to compared both all the three models okay so doing it is known not problem it should not theory N

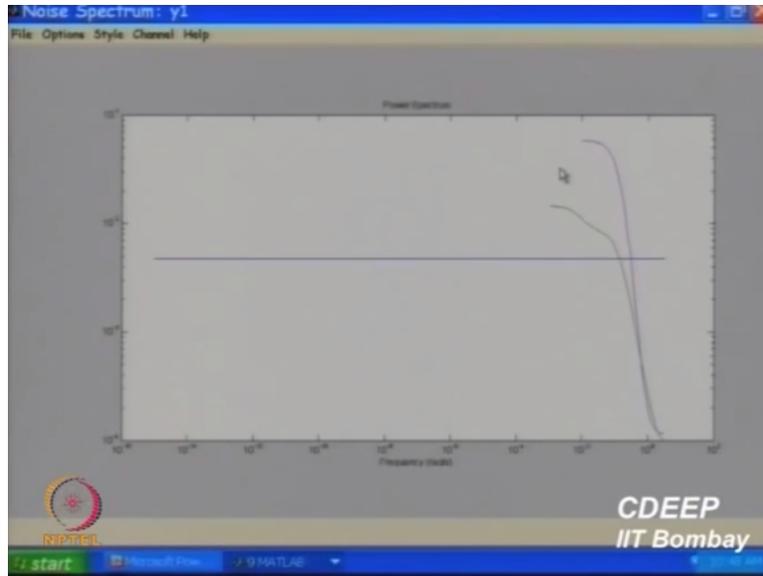
why you are doing it okay so for that will have to keep dealing my notes go back to the reference that I have given.

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And slowly it will come in not, not I can see what are the models I can check what is the noise spectrum you know what the power spectrum is?

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So these are just clicks away you know you can just develop all types of model then you want to see the model parameters' you know what was the boxenging model parameters so I just take this and drag it to box space I go mat lab that space and see who this is my bj 2,2,2,2,2.

(Refer Slide Time: 58:54)

```

MATLAB
File Edit Debug Desktop Window Help
Current Desktop | Current Command Window | Command Window
Your variables are:
ans  bj22222  goto_ws

>> bj22222
Discrete-time IDPOLY model:  $y(t) = [B(q)/F(q)]u(t) + [C(q)/D(q)]e(t)$ 
B(q) = 0.001404 q-2 + 0.01161 q-3

C(q) = 1 - 1.16 q-1 + 0.1695 q-2

D(q) = 1 - 1.865 q-1 + 0.8639 q-2

F(q) = 1 - 1.655 q-1 + 0.6842 q-2

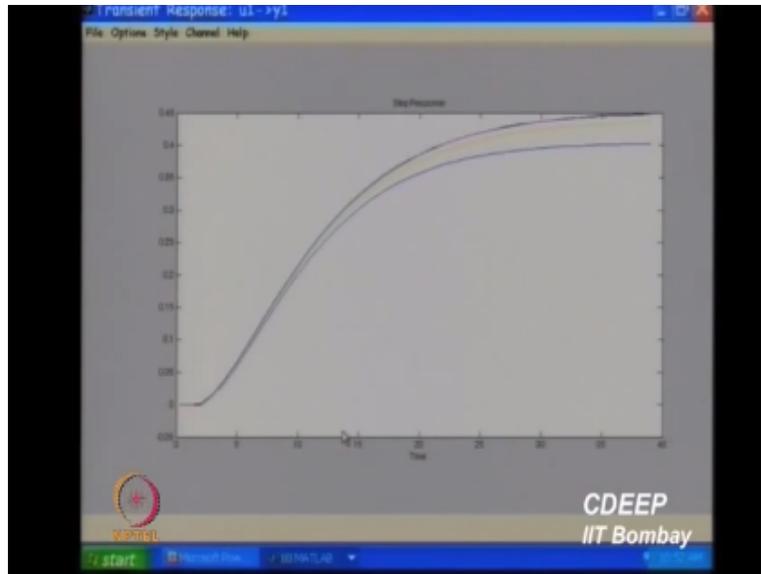
Estimated using PEM from data set mydata
Loss function 0.000251098 and FPE 0.000268566
Sampling interval: 1
>>
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This is our model okay it give me a/b, c/d tabular square been everything calculated okay what is this look at this model this is B/F and C/D notation is different, I am calling B/A and c/d they are calling what B/F and C/D. last function of the square of errors F B is a I will come to that, session is clear to you can create it in multiple ways you can load data directly. So there are way loading data input data, you can import existing models you can import, you can save data from a file, you can data from.

You have to prepare data outside, I will give you a program which will take the 4 time model okay crates simulation and create data files for identity then you loaded into identity and then you run your own sessions, so do that actually you can have session in the you know computer lab we have. Actually computer labs is now split we are undergoing renovation.

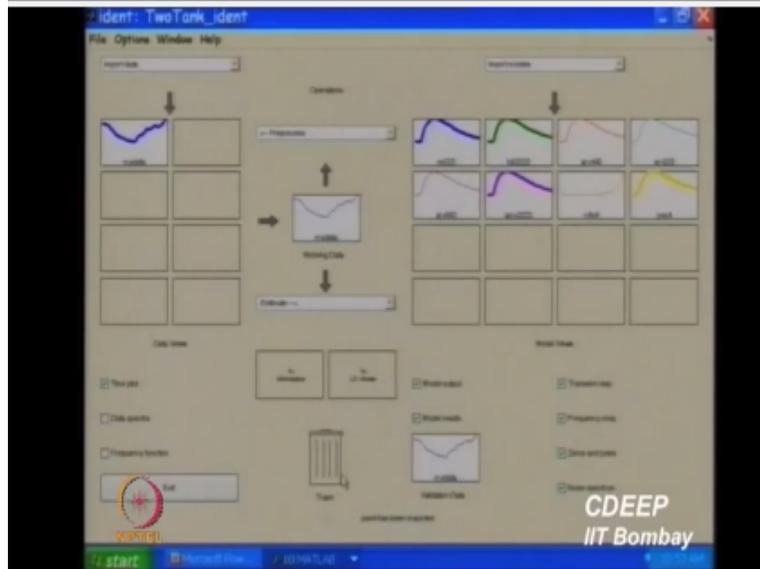
So let me see if I can do a session next week so that you have real data and you can play with the data, you can see all this models been developed and actually I have talked about only bear minimum essential there are many model which you can develop using this, you can develop ARX output error model ARMAX model you know BG you know, you can also develop directly okay. So you can decide to develop a forth or third space model.
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This model is good prediction error method is good okay there is one more method of identifying models called as suspect identification method, sometimes it will give trouble this is also a good method, I should did not bad things about but it sometimes give you not so great models, and then we can do other things like go to identity phase, I want to see okay you want to see how this develop. You just go to work space and ask to say I have pss4 this is 4 state models.

C matrix is that B matrix is this for what we are calling in our notes as $5 \gamma c$ they are calling ABC so you have data you can directly get state space model in fact the next think I am going to talk about, is that If you identify these transfer function models how to convert this into space that is called state realization. So you can directly get a model and then you can work develop control based on this model.

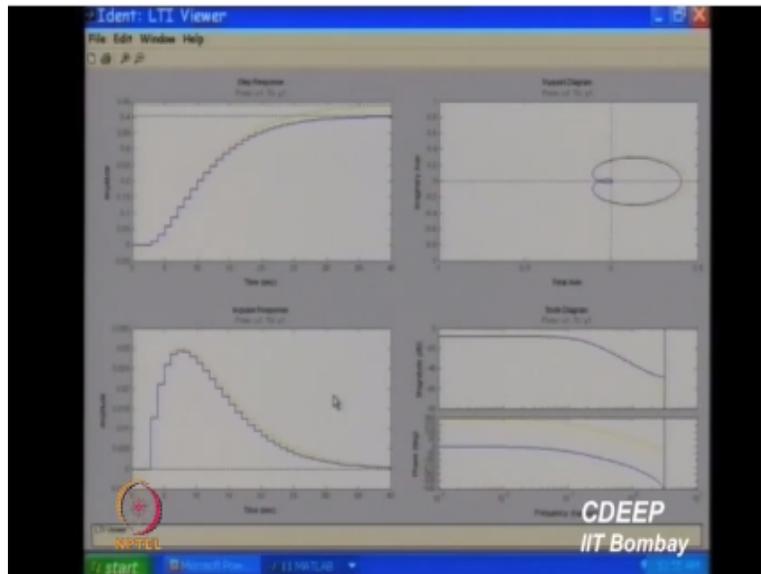
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There is one more thing here which probably you should know I want to look at comparing all kinds of properties of these models I take them to something called LTIU is the linear time memory system property viewer okay, so let me take two different models go back LTIU. Is the wonderful tool you can lot configuration I want to have a plug configuration of this type and I want to look comparison and take response from there on.

This is the comparison of two models which I have estimated and comparison of step responses typically you want to look at frequency responses that work. So well you can create all kinds of things here you can go say plug consideration 4 you like emphasis plans also you also like plate let say, you can see all four.

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Phase angle they will also come into the picture and then so it is possible to, the tools are available, you should know what it means otherwise you will generate garbage okay. you should know what is the stochastic process, what is the colored noise? What is the white noise? What will really happen when you develop these models? And why I should make choices and how do I make choices, you know those things.

You can develop models very quickly okay and so you should know how I should inject a perturbation and all these things become a piece of art beyond the point they are not really, you have know your math, you have to understand it very well.

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Model Structure Selection

Issues in Model Selection

- Process application (batch / continuous)
- Time scale of operation

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System Identification

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Now whether process is running in continuous mode or it is running in a batch mode what is the time scale operation so you cannot do this completely as a control engineer okay you have to have your you know, mechanical engineering chemical engineering what it is whatever is your basic background that you have to use because to plant you should know what that plant is okay this is what I have heard is that some of the earlier failures this night combat air craft there.

Because the control system where not designed by aeronautical engineering that designed by mechanical engineers who were control engineers but you have to how the help of live I have to control the chemical plant I should know how the chemical reactor works I cannot just say you know I will develop this type to this model I will control you can do it for some extend but you should also know the physics so the complex study so what kind of application it is

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Automation Lab
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Model Structure Selection

Issues in Model Selection

- Process application (batch / continuous)
- Time scale of operation
- Type of application (scheduling/optimization/MPC/Fault Diagnosis)
- Availability of physical knowledge / historical data

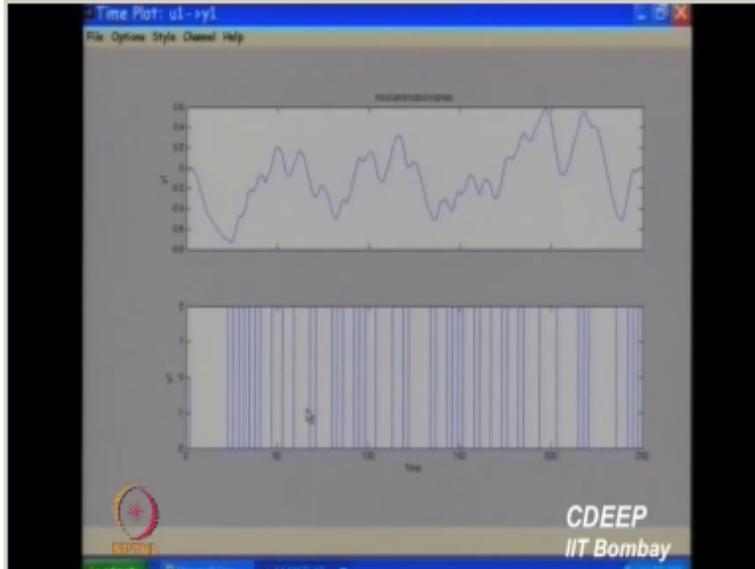
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You have to know to this system but it is not completed you actually see how do you what is the frequency range in you should know what is the relevant frequency range okay.

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See here I showed you this data right earlier I have showed to certain for this if I go here and if I look at this time box okay I have chosen a certain frequency of extension right I have done that low in the process physics see if I have given two fast then y would not have you know change so much it has no time to change okay.

Then we call it that input is not sufficiently excited the input is not sufficiently exciting okay then you cannot do the identification you will get a bad model okay so actually this is not through the black box in that sense when you choose this okay what should be the switching time between any two jumps I chose it carefully but do not chose carefully doing the physics I land up into call okay so black box is inputs with the pinch of salt okay so okay.

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