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Process Control

Compulsory exercise 5

1. **Parameter estimation of a DC motor with least squares (LS) method**: [This web page](http://techteach.no/tekdok/dcmotor/) presents a DC motor. The web page includes some experimental data. Estimate K, T and L using the ordinary least squares method. As known data for the estimation, use control signal u [V] and speed S [krpm]. Do not use any special function in Matlab for the LS estimation, i.e., program from scratch the formulas that calculate the estimate. Finally, check, qualitatively, with a simulation if the model is good.

Mathematical model of DC motor

where S [krpm] is the speed. C [V] is the control signal. L [V] is an equivalent voltage representing the load torque. L is in the range of ± 10 V.

The known parameters are and . Estimate parameters are K,T and L.

Then

where .

Least squares estimation of model parameters

where known parameters are

and unknown parameters are

Estimate parameters are:

Comparation between real data and simulation with estimate parameters.

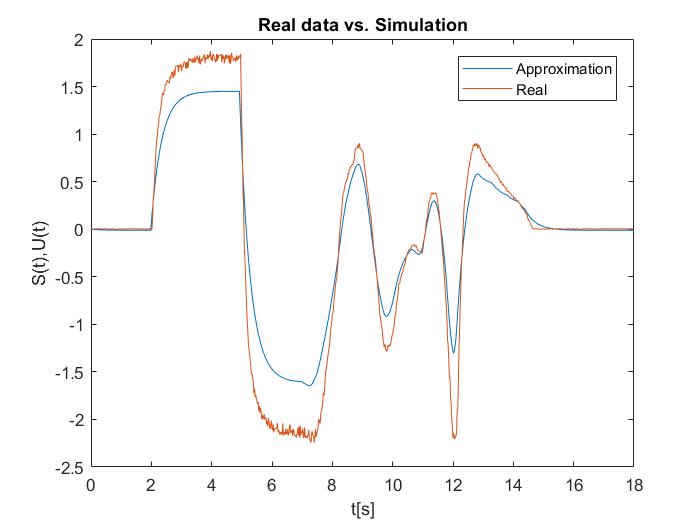


Figure 1 - Comparison with real data and simulation

**2.Parameter estimation of an air heater using the grid optimization method:** [This web page](https://home.usn.no/finnh/air_heater/) presents an air heater. The web page includes some experimental data. Make a Matlab program which estimates the heater gain K\_h, the time constant theta\_t, the time-delay theta\_d, and the environmental temperature T\_env with the grid optimization method. Finally, run a simulation that (hopefully) demonstrates that the adapted model represents the real air heater well.

Mathematical model of Air Heater

Where is outlet temperature, is environment temperature, is additive temperature of the heater, which is describe

Where u is delay control signal, is time constant [s], is heater gain [K/V], is time delay.

Known parameters are .

Substitution of :

Than

Discrete model:

Matlab solution of Grid method:

%T - enviroment

if(u(1)==0)

T\_env= y(1);

end

%Time delay calculation

count=0;

c =1;

min = y(1)+1;

while (min>y(c))

count = count+1;

c = c+1;

end;

Td = count\*Ts;

%estimation of ?\_t(T) and Kh

e=100;

Ni=20;

V=zeros(Ni,Ni); %grid matrix with error

for i=0:Ni

K=0.5+i\*0.1;

for j=0:Ni

T=0.1+j\*0.01;

% run simulation

sim('simulation\_t2\_a.mdl')

%error y\_real - y\_pred

V(i+1,j+1)= sum(N); %min value of the function with error

if (sum(N)< e)

e = sum(N);

K\_opt = K;

T\_opt = T;

end;

end;

end;

Estimated parameters: , = 0.1 s, s, K/V

**3. Parameter estimation of the air heater using the nonlinear least squares (NLS) method**: As Problem 2, but now use nonlinear least squares method implemented with fmincon() in Matlab.

Matlab solution with fmincon method

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%21.2 2018

%----------------------------------------------------------

disp('-------------------')

disp('Using fmincon() in Matlab solve an optimization')

disp('(Nonlinear Programming, NLP) problem:')

disp('min\_x f(x)')

disp('s.t.')

%----------------------------------------------------------

format compact

clear all

close all

global y\_m\_prev y\_m u\_m N

%--------------------------------------------------

%Loads data from file into workspace.

load airheater\_logfile.txt;

Ts=0.1; %Sampling interval

L=length(airheater\_logfile);%(Matrix name becomes same as logfile name.)

N=L;

t=Ts\*[1:N]';

%loading data from the file

u\_m=airheater\_logfile(1:N,2);

y\_m=airheater\_logfile(1:N,3); %T\_out is y\_m

y\_m\_prev=airheater\_logfile(1:N,3);

% Tout\_est= ones([N,1]);

% u= ones([N,1]);

%y\_prew

for i=1:N

if(i==1)

y\_m\_prev(i)=0;

else

y\_m\_prev(i)=y\_m(i-1);

end;

end;

% if(u(1)==0)

% T\_env= y\_m(1);

% end

%

% %time delay estimation

% count=0;

% c =1;

% min = y\_m(1)+1;

% while (min>y\_m(c))

% count = count+1;

% c = c+1;

% end;

% Td = count\*Ts;

%---------------------------------------------------

%Contraints:

K\_min=0.1;K\_max=2;

Theta\_min=0.1;Theta\_max=2;

Theta\_d\_min=1;Theta\_d\_max=10;

Tenv\_min=20;Tenv\_max=30;

x\_lb=[K\_min,Theta\_min,Theta\_d\_min,Tenv\_min];

x\_ub=[K\_max,Theta\_max,Theta\_d\_max,Tenv\_max];

%--------------------------------------------------

%fmincon:

x\_guess=[0.5,0.2,3,25];

Aineq=[]; Bineq=[]; Aeq=[]; Beq=[];

fun\_objective\_handle = @(x)fun\_objective(x);%Local function

fun\_constraints\_handle = @(x)fun\_constraints(x);%Local function

optim\_options=optimset('Display','on');

% optim\_options=optimset('Algorithm','sqp','Display','on');

[x\_opt,fval,exitflag,output,lambda,grad,hessian] =...

fmincon(fun\_objective\_handle,x\_guess,Aineq,Bineq,Aeq,Beq,x\_lb,x\_ub,...

fun\_constraints\_handle,optim\_options);

%--------------------------------------------------

%Displaying the optimal solution:

disp('-------------------')

disp('Optimal solution:')

output

fval

x1\_opt=x\_opt(1) %Kh optimal

x2\_opt=x\_opt(2) %Theta optimal

x3\_opt=x\_opt(3) %Theta\_d

x4\_opt=x\_opt(4) %T\_env

%--------------------------------------------------

%Applying the optimal solution:

f\_min = e'\*e;

%--------------------------------------------------

%Defining local functions:

%x1 is K, x2 is T, y is Tout\_pred

function f = fun\_objective(x)

global y\_m\_prev y\_m u\_m N

Ts=0.1;

Kh=x(1);

Theta=x(2);

Theta\_d = round(x(3)/Ts)+1;

u = u\_m(1:N);

u = [u(1)\*ones(Theta\_d,1); u(1:N-Theta\_d)];

Tout\_prev = y\_m\_prev(1:N);

Tout\_meas= y\_m(1:N);

T\_env = (x(4).\*ones(length(u),1));

Tout\_est =((1-Ts/Theta)\*Tout\_prev+((Kh\*Ts)/Theta).\*u)+(Ts/(Theta.\*T\_env));

e = Tout\_meas-Tout\_est;

f = e'\*e;

end

% Defining constraints

function [cineq,ceq]=fun\_constraints(x)

cineq = []; % Compute nonlinear inequalities.

ceq = []; % Compute nonlinear equalities.

end

I couldn’t solved the error which is:

*Error using fmincon (line 609)*

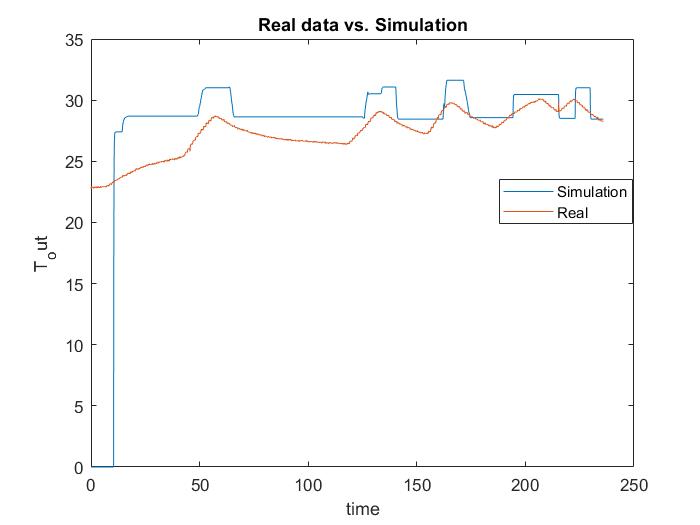
*Supplied objective function must return a scalar value.*

*Error in optim\_fmincon\_estim3 (line 70)*

*fmincon(fun\_objective\_handle,x\_guess,Aineq,Bineq,Aeq,Beq,x\_lb,x\_ub,...*

**4.Comparison of estimation results**: Which of the grid method and the NLS method gives the best parameter estimates for the air heater? (Design the comparison yourself.)

The results is only for grid method:



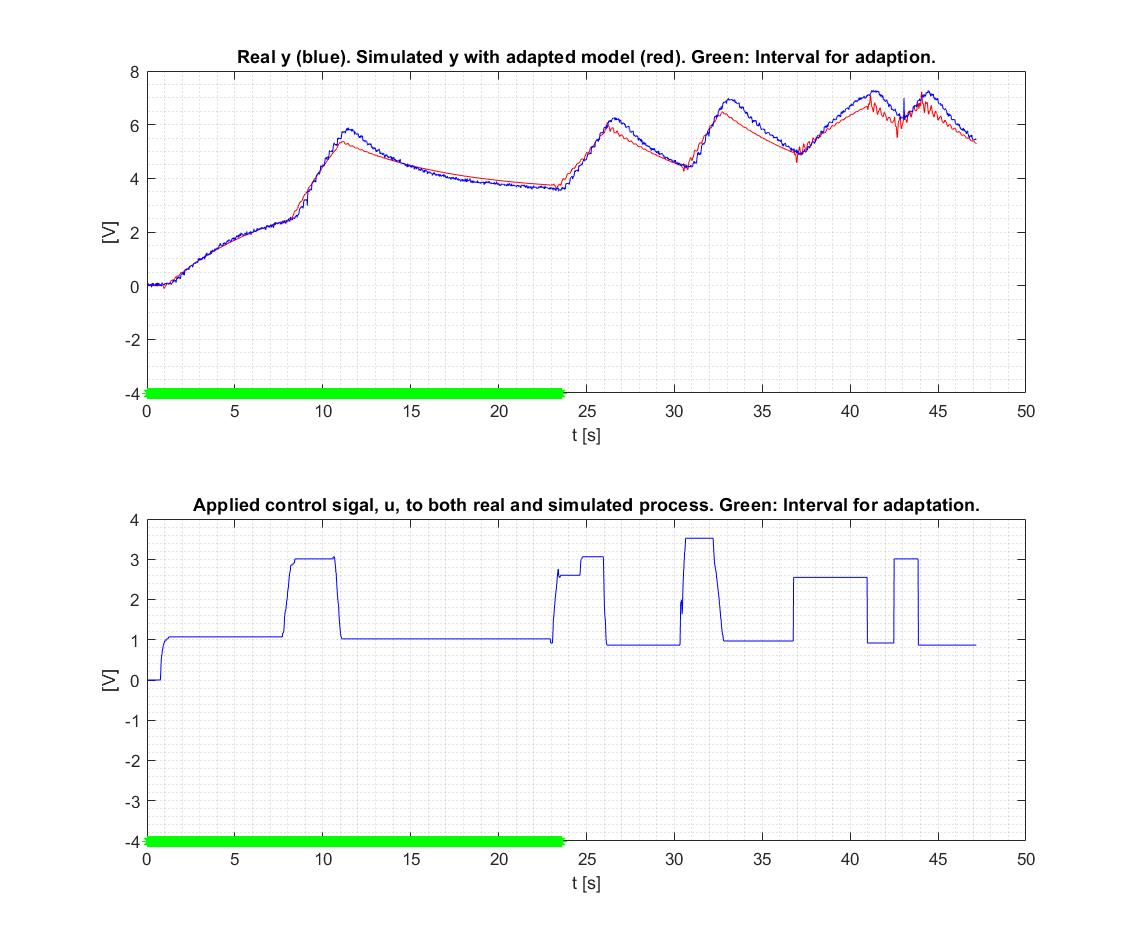
Estimated parameters: , = 0.1 s, s, K/V

**5. Subspace identification of the air heater:**  Try to identify an input/output model (a discrete-time state space model) of the air heater using subspace identification (n4sid() in Matlab). Check if the model is good.

Simulated process is the most precise with the model order 5, because of the time delay.

Discrete-time identified state-space model:

Sample time: 0.02 seconds.

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