Stochastic Adaptive Control

Project part 24

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This project has to be handed in on (or before) the last day in the examination period (1.6.2016).

The focus in this project is system identification and adaptive control of stochastic systems. At your disposal there is a series of work benches and a toolbox. (Make sure the links in *startup.m* is correct ie. pointing to the location where you have stored the tool box). Among the work benches you can find a direct implementation of a fixed parameter controller (*wb_xreg.m* canonical realization of fixed parameter controller, *wb_xregd* direct realization of fixed parameter controller), an explicit adaptive controller (*wb_expl*) and an implicit PZ controller (*wb_impl*). You are off cause welcome to make and use your own implementation.

Excercise 1

In the first part of the project we will be dealing with identification of a stochastic system based on measured data. You are presented with time-series of input-output data from simulations with an unknown system. The times series are given in the data files *data1.mat* and *data2.mat*. In each file there is a matrix called *data* which contains output values in the first column and input values in the second column. The input is a PRBS signal. You should use one data set as estimation data and the other as test data.

Besides the data-sets you know that the system has a single time-delay from input to output and that it has an ARMAX structure.

Question 1.1 Determine the structure of the external model based on the time-series. You are required to make the descision based on all of the following methods:

- F-test
- AIC, BIC, FPE information criteria
- Comparing loss function for the estimation-data and test-data.
- Significance of estimated parameters

State your candidate model. □

Question 1.2 Check the candidate model found above for overlapping poles and zeros. Also check the correlation structure. □

Excercise 2

In this part of the project we will be dealing with adaptive control of a stochastic system.

Consider a third order system (ie. the transfer function from control to output) with one real and two complex poles. Assume the sampled ($T_s = 1.5$ *sec*) description of this transfer functions is

$$y_t = \frac{0.06\ q^{-1}}{1 - 2.36\ q^{-1} + 2.16\ q^{-2} - 0.74\ q^{-3}} u_t \tag{1}$$

This is equivalent to a time constant equal 8.5 *sec* and an undamped resonance with a period equal to 15 *sec* and a damping coefficient equal 0.1.

Question 2.1 Study (ie. plot) the (sampled system) step response. *Notice, if you use dstep , make sure you have the right amount of padded zeros, in order to comply with forward notation used in dstep .* Discuss the step response (ie. time delay, oscillation/no oscillations and DC gain). □

Question 2.2 Determine the poles and zeros of the system. □

A closer study of the stochastic disturbances results in a total model of the system

$$A(q^{-1})y_t = B(q^{-1})u_{t-1} + e_t \qquad e_t \in \mathbf{N}_{iid}\left(0, \sigma^2\right)$$

where $A(q^{-1})$ and $B(q^{-1})$ are given in (1). Change the work bench (or more precisely *sysinit.m*) such that it simulates the system mentioned above with $\sigma^2 = 0.001$.

The objective is to use a PZ controller and to control the system such the deterministic part of the closed loop is given by

$$(1 - \alpha q^{-1})y_t = (1 - \alpha)w_{t-1}$$

where w_t is a reference signal. The tuning parameter (α) has to be chosen such that the poles of the closed loop is twice as fast (measured as the distance to origin) as the fastest open loop pole.

Question 2.3 Find α and design (find Q, R and S) a PZ controller which fulfill the design objective mentioned above. □

Implement the resulting controller in the work bench. In relation to the rest of the project it is recommended to use a direct realization of the controller (ie. to implement the fixed parameter controller in *wb_xregd.m*). Notice, in the direct realization the control signal can be determined as an inner product between control parameters (*thr*) and control regressors (*fir*), which is old and present signal of u_{t-1}, y_t and w_t. It can be determined as:

```
% Ru=Qw-Sy  or u=fir'*thr/thr(1)
fir(2:end)=fir(1:end-1);
fir(pilr)=[0 -wf y];
u=-fir'*thr/thr(1);
fir(1)=u;
```

Also notice, the variable *pilr* indicates where u_t, w_t and y_t has to be entered into *fir* . In the workbench this is done i flexible way, but you can change that into a more direct way. (Use eg. the settings in the work bench to check you own determination of *pilr*).

Question 2.4 Perform a deterministic simulation (reference is a square wave) with the designed PZ controller and plot the signals (y_t, w_t and u_t). You can visually check if the performance is satisfactory. □

Question 2.5 Also do a stochastic simulation with constant set point (equal zero) and compare experimental loss functions (Je and Ju) with expected values. □

Let us now focus on the adaptation and assume we are starting with explicit types of controllers, where the parameters in the system description is estimated directly. The controller is redesigned each sample.

Question 2.6 Determine the structure in θ and φ_t. Especially, determine the position of the y_{t-1} and u_{t-1}. The variable *pil* indicates where in the regressor vector, *fi* , these signals enters. □

In the next question you can use the work bench implementation of an explicit controller as a source of inspiration (ie. use comments to achieve a specific implementation).

Question 2.7 Estimate the system parameters when the input signal is a PRBS signal ($\sigma^2 = 0.001$) and study the track of the estimates. Also do the same when the input is the control signal from the PZ controller mentioned above (ie. a fixed parameter controller based on an assumed correct knowledge to the system). The reference is constant and zero. □

Question 2.8 Perform a deterministic simulation with the explicit adaptive controller when the reference signal is a square wave. Plot the signals and the track of the estimate (check *pltth*). Also perform a stochastic simulation (reference is zero) and compare the evolution of J_e (accumulated sum a control errors) and J_u (accumulated sum of control actions) with expected values for correct estimates and obtained with the fixed parameter controller. □

Let us now turn to the implicit type of adaptive control in which the system model is rephrase in terms of the control parameters.

Question 2.9 Determine the structure in such a model. Which signals are involved and what is the structure in θ and φ_t. □

When plotting the estimate (of the control parameters) use the command *pltthi* .

Question 2.10 Again, perform a deterministic simulation and study the signals and parameter estimates, when the reference is a square wave. Also carry out a stochastic simulation (set point is zero) and check the signals, the loss functions and parameter estimate. □