System identification & parameter estimation (wb2301)

Final assignment: course 2009-2010

III – The Human Controller

In manual control tasks the human controls a (dynamic) system. The human observes the difference between the real position of the system and the desired position, and tries to minimize the difference through control actions. The combination of human and controlled system is a closed loop system, in which the human has the role of controller ("Human Controller"). McRuer (1967) has shown that humans in combination with the controlled system try to mimic a servo-system, i.e. a system with an open loop transfer function of an integrator (1/s). In order to achieve this, the human will (within his abilities and limitations) adapt to the dynamics of the system. According to the theory of McRuer, humans are able to control pure gain systems, 1st order systems and 2nd order systems. To do so, they will respectively adapt to an integrator, a proportional gain or to a differentiator. An extensive description of the behavior of the human operator can be found in the article of McRuer which is obligatory literature for this assignment. The goal of this assignment is to verify the theory of McRuer with a simple experiment on a human (you) controlling a computer mouse.

Experiment

For the experiment you will use a Matlab program "bmeLab". It can generate different types of manual control tasks. In a pursuit task, the human controller is asked to follow a target on screen with a crosshair cursor. In a compensatory task, the human is asked to maintain at a fixed cursor position on screen, while this position is (randomly) perturbed. Both tasks can be performed horizontally, vertically, or in a 2D plane. The crosshairs represent the controlled system and their dynamics can easily be adjusted by defining a transfer function. The output of the bmeLab program is a data structure which contains the necessary vectors to do system identification on the human controller. For a full description on the program, type help bmelab in the Matlab command prompt. For a quick demonstration, type bmelab_student_demo.
It is recommended to leave the bmeLab program itself unchanged, and only modify the demo program to suit your needs for the experiments. Use a sample frequency of 40 Hz, unless you get a warning that your computer cannot maintain this frequency.

General hints:

- When generating disturbance signals, make sure you make them 5 seconds longer than your actual measurement time. You can then throw away the first 5 seconds of your data to minimize the effects of startup behavior of the human controller. Make sure the remaining part does not have frequency leakage.
- Practice each experiment a few times before making your final recording to minimize learning effects in your data which make your system time-variant.
- To calculate the coherence you will need do averaging. Frequency averaging is not possible, since we will only use a limited number of 10 frequencies. Instead, you will have to average over multiple repetitions. Repeat each experiment at least 4 times (with the same subject, of course), calculate the spectral densities and then average the spectral densities before calculating the FRF and coherence.

Questions

When preparing your report, address the following questions:

Part 1: system identification

1. Give the block schemes of a pursuit task and a compensatory task. Indicate where noise enters the system. Motivate this choice.
2. Give the estimators (formulas) for the FRF and the coherence of the human controller for both tasks.
3. Create four different realizations of a 35 second disturbance signal $w_x(t)$ which is the sum of 10 sines, with frequencies logarithmically spaced between 0.1 Hz and 3 Hz and random phase. Scale

$w_x(t)$ such that all values are between -0.5 and 0.5. Plot the last 30 seconds of the four signals together with their auto-spectral densities. Make sure you don't have leakage.

4. Estimate the frequency response functions (FRFs) of the human doing a horizontal pursuit task on three different systems: $H_1 = 1$, $H_2 = \frac{1}{s}$ and $H_3 = \frac{1}{s^2}$. Repeat each experiment four times and average. Present the transfer functions in a Bode diagram. Make sure the plots are correctly labeled. What can you conclude?
5. Repeat question 4 for a compensatory task. What are the differences / similarities with the results in question 4? Explain.
6. Determine the coherence of the input and output signals for both tasks, and show them in one figure. What can you conclude about the linearity of the model and about the measurement errors in the experiment?
7. Re-plot the results of questions 4, 5 and 6 using the knowledge that the input signal only contained 10 frequencies. Thus: analyze the experiment only at these 10 frequencies. Comment on the results.
8. To estimate the human controller with time-domain models one has to determine the structure of the model (OE/ARX/ARMAX/Box-Jenkins). Determine the correct model structures for both tasks and give the derivation. Hint: use the block scheme of question 1.
9. Estimate the human controller via time-domain models for the two tasks and three different systems. How did you determine the optimal order? To reduce computational time you may take the orders of the polynomials equal. Show the models in two Bode diagrams, one for each task. Only show 1 repetition of each condition.
10. Compare the results of the estimators based on spectral densities (question 4/5) and based on time-domain models (question 9).Use the Bode diagrams to discuss the differences. Which method do you prefer? Why?
11. It is possible to perturb the vertical and the horizontal direction at the same time using different disturbances. Perform a pursuit experiment in 2D on system H_2. Make sure to use different realizations for the horizontal and vertical disturbance. Determine the partial coherences from the two inputs to the two outputs. Is vertical control influenced by horizontal disturbance and vice versa? Are the inputs uncorrelated?
12. Determine a scalar value based on error signal e which assesses the human's performance ("score"). Is performance affected by increasing the number of control dimensions?

Part 2: parameter estimation

13. Fit McRuer's (Eqn 2) human controller model on the two tasks and three controlled systems. For each condition, estimate the human's static gain K_p, lead time constant T_L, lag time constant T_I and time delay τ_e. Use the estimator you prefer, via spectral densities or time-domain models, see question 10. What criterion did you use and why? Give a table stating the estimated parameter values for each condition.
14. Give an indication of the accuracy (SEM) of the estimated parameters via the covariance matrix. Make a table with the values of the parameters together with the SEM. What can you say about the value of the parameters?
15. Calculate the variance-accounted-for (VAF) for your estimated models (for all repetitions). Is the model a good description of the data?
16. What can be concluded about the adaptation abilities of the human being? Is the theory of McRuer verified by your experiment? Explain why or why not.

Support

For all questions concerning this assignment you can contact Stijn van Eesbeek or Asbjørn Klomp (email: s.vaneesbeek@tudelft.nl or a.klomp@lumc.nl).

Literature

McRuer DT, Jex HR (1967). *A review of quasi-linear pilot models*. IEEE Trans. on Human Factors in Electronics 8, 231-249.