Session 1426

AUTOMATED ANALYTICAL MODELS FROM TEST DATA

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ABSTRACT

In applying classical control system theory, it is important to have an analytical model of the process which is to be controlled. An analytical model is also desirable when a circuit or system is to be redesigned for other purposes.

Frequently, a circuit or system must be defined by test data taken in the laboratory or in the field, and it is desired to find numerical values for parameters in a specified analytical model or else to determine the “best” of several possible model forms.

This paper reports on undergraduate laboratory experience in determining parameters and model forms based on test data. A digital computer is interfaced to the physical process through input/output equipment. The equipment or process to be tested is driven by either steps or sinusoids under computer control and the response is measured under program control, using Hewlett-Packard BASIC. The data is exported to a MATLAB program in which the modeling is done.

Three processes are reported. In order of speed the processes are (1) an audio amplifier, (2) an ac motor-dynamometer-tachometer test set, and (3) a tank level experiment.

INTRODUCTION

It is frequently necessary to provide an analytical model of an engineering process or system based on the results of testing such systems. This need may arise in designing a control system for such a process or in providing a summary description of test results. In some practical cases, the process is of such complexity that the equations describing the process are either not available or else are too unwieldy to be useful. In less complicated cases, such as described here, the equations may be readily obtained but either the parameters are unknown or else there is a need for an experimental check on the parameter estimates obtained by approximations.

The three cases reported here arose from three separate undergraduate engineering courses. The audio amplifier experiment originated in a junior-level course in electronics. The ac motor-dynamometer-tachometer experiment arose in a senior-level course in control system design. The tank level control experiment arose in a freshman course in introduction to engineering methods.

The basic system arrangement in each of these experiments involve connecting a digital computer (386 at present) through input-output equipment to a physical process or device. The computer output is applied to the process through a digital-to-analog (D/A) converter. The measurement of the process output variable is returned to the computer through an analog-to-digital (A/D) converter. In the experiments described here, this process proceeds in an open-loop manner. However, in some cases this is a necessary preliminary procedure to obtaining a closed-loop operation ultimately.

Since these experiments are at different levels in the educational process, it might be expected that the ability of the students to carry out the details would vary greatly. Surprisingly, it is found that the students at the lower levels perform the experiments with about the same facility as those at the higher levels. This is tentatively attributed in general to greater ease with which lower-level students have adapted to computer operations. The principal differences in performance of the experiments appear to be the greater facility with which the higher-level students obtain and accept the describing equations of the system. This is attributed to increased exposure to such activities and greater knowledge of physical principles by this point in the educational process.

EXPERIMENTS

(A) Audio Amplifier

At this stage of development the junior students are in the process of studying in a standard textbook [1] on electronics and can easily obtain the expected form of the transfer function, G(f), and an estimate of the cutoff frequency, f_o. The freshmen students who perform such an experiment are given this information and are asked to obtain the experimental verification. For both groups, typical results are shown in Appendix A. The “challenge” problem indicated is relatively easily understood by the more advanced group, but must be carefully explained to the lower-level group. The concept of minimizing a performance index such as the mean square error (MSE) between model and experimental data is easily grasped by both groups.

The lower-level (freshman) group runs this experiment by manually adjusting the signal generator, as indicated in the program of Appendix A. The higher-level (junior) group may use a voltage-controlled oscillator and adjust the frequency from the program if they so desire. This difference is made to provide simplicity and more “hands-on” experience for the freshman group as well as avoid the purchase of additional voltage-controlled oscillators.

Typical results are shown in Appendix A.

(B) Motor-Dynamometer-Tachometer

At this stage of their development the senior level students are in the process of studying in a standard textbook [2] on linear feedback control systems. The open loop dynamics determined by this test is later used in posing a closed loop design problem. The freshmen students are introduced to the basic concept of feedback before being asked to perform the experiment and are introduced to measurements of speed and torque and their relationship to power. This experiment is run at integral horsepower levels.

In this particular experiment the unexpectedly large discrepancies between “best” model responses and the measured response led to student questions and their independent “discovery” that the commercial power electronic controller had a “built-in” torque limit which masked the natural dynamics of the motor and load. This led to the conclusion that a saturation non-linearity should be included in the model.

Typical results of the experiment are shown in Appendix B along with descriptions of the experiment as presently implemented.

(C) Tank Level

This experiment was initiated to introduce freshmen students to concepts in engineering, computer interfacing to industrial processes, and computerized measurement of fluid flow rate and fluid level. The practice of early introduction of engineering concepts is generally recognized at present as an aid in attracting and retaining engineering students [4]. The experiment has been used also to provide the seniors in control systems with an example of the obtaining of process dynamics by test.

The laboratory equipment is arranged as indicated in Appendix C. Under program control the pump speed is adjusted to obtain a specified flow rate and the level is measured. Then the program causes the control valve to be moved and the level response is measured as a function of time.

Lower-level students are given the expected form of the response and upper-level students are asked to derive the equation. The goal is to determine the parameter τ in the first-order level response:

$$h(t) = h_0 + H\left(1 - e^{-t/\tau}\right)$$

A “challenge” problem is given which requires determination of the parameters $a = 1/T_2$ and $b = 1/T_1$ in the second-order level response:

$$h(t) = h_o + H \cdot \left[1 + \left(\frac{b}{a-b}\right)e^{-at} + \left(\frac{a}{b-a}\right)e^{-bt}\right]$$

and to identify the physical source of the second time constant after observing the operation.

CONCLUSIONS

Experiments such as those indicated here are useful in providing lower-level students with an introduction to engineering methods, computer interfacing with physical systems, and model equation representation of engineering systems. Such experiments also serve upper-level students in providing “unidentified plants” in control system courses and in providing students in electronics with examples defined by test data but which are to be described by analytical models.

Good agreement between model predictions and test data reinforce belief in the applicability of the theory presented in the course work. Poor agreement between model predictions and test data may indicate either an inappropriate model, lack of understanding of hardware functions, or need to include non-linearities in the model.

Some of the more advanced students learn that the results obtained in these examples by elementary methods may be more easily obtained by application of more advanced tools such as, for example, the MATLAB toolbox on system identification [3].

Further simplification is now possible by using data collection and control hardware which requires only the MATLAB software [5].

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ACKNOWLEDGEMENT

The computers, interfacing equipment, and software used in the three experiments described here, as well as the process equipment in the tank level experiment, were obtained under grant number USE-9052268 by the National Science Foundation and the State of Tennessee. Equipment gifts from Magnetek and Electrol are also recognized. This support is recognized with gratitude.

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