BME 331 Project 1

Due Sunday, 16 September 2018

OBJECTIVE: Develop mathematical models of temperature and force dissipation to explore input-output and filtering characteristics of LTIC systems in the time domain.

BACKGROUND: Engineer Shuri is designing a high-tech suit that is meant to keep the wearer safe from high temperatures and from forces being applied with a high frequency. She is using LTIC system techniques to interpret her experimental data and to guide the system design process.

PART 1: Temperature analysis

Shuri has developed a new composite material that should be able to dissipate heat quickly so that high temperatures do not injure the person wearing the material. She is testing a sample of this material in a temperature-controlled environment in her lab according to the following protocol:

> A sample of material at an initial high temperature of 300° C is allowed to cool in a temperature-controlled room in the absence of additional high-temperature heating input. The temperature of the material is recorded every 0.1 seconds to quantify the rate of cooling. Collected data are available in the .m file "Project_Data.m" under the variable name tempdata, which contains two columns of data: the first is time (in seconds) and the second is temperature of the material (in ° C).

Modeling: Assume this material behaves as a LTIC system that produces a temperature output in response to a temperature input. Develop a *system equation* (differential equation model) that closely reproduces the behavior seen in this experiment. Note that you are *not* just coming up with a function that goes through the data points. Rather, you are developing a *differential equation model* (in the LTIC form we have been discussing in class) that produces the temperature *output* $y_T(t)$ seen in the data when the *input* $x_T(t)$ is the same as that used in the experiment. (What kind of response is being tested in this experiment?) Determine the order of your model, and explain why this is appropriate for the data observed in this experiment.

Testing: Shuri would like to know how this material will respond to two different high-temperature conditions: (1) a brief (1 second) pulse of heat at 300° C; and (2) a sustained (ongoing) temperature of 150° C starting at time t=0, and continuing indefinitely. For each of these two experiments, determine the following:

- What is the maximum temperature the material will reach under these conditions?
- Does this temperature exceed 70° C (the temperature at which thermal burns can occur in less than 1 second)?
- Does this temperature exceed 50° C for more than 20 seconds (which also will result in thermal burns)?
- If the material exceeds these safe temperatures, how long does it take from the start of the experiment until it reaches these temperatures? How long does the material remain at those unsafe temperatures?
- If the material does not exceed these safe temperatures, how long does it take from the start of the experiment until the material reaches its maximum temperature?

PART 2: Designing for force filtering

Because Shuri expects this suit will be subjected to frequent force inputs, she wants to design a system that will filter out (or at least significantly attenuate) high-frequency inputs greater than 4 Hz.

Modeling: Design a second LTIC system that relates force outputs $y_F(t)$ to force inputs $x_F(t)$. Consider what characteristics this system will need to have in order to produce outputs that are similar in magnitude to the inputs at low frequencies, but much smaller in magnitude than the inputs at higher frequencies. (You may want to consider how the system acts on inputs to produce outputs, or consider what the impulse response would need to look like to produce this result.) Explain your reasoning for the design choices you make.

Testing: Demonstrate that your system does in fact allow low-frequency signals to pass through with higher amplitudes, but attenuates high-frequency signals greater than 4 Hz. (It may be easiest to demonstrate this using sinusoidal inputs at several frequencies of interest.)

WRITE-UP: For each of your two systems (temperature response and force response), discuss the derivation of your LTIC differential equation model, any assumptions you made, and the order of the resulting systems. Discuss the response of the system to each input that is tested, and explain the type of response that each experimental condition represents (e.g. *zero-input response, impulse response, forced response,* etc.) The paper should show any calculations you used (for example, for finding outputs in response to inputs), but they may be included in the appendix; however, all work shown (even in the appendix) should be *typed*, not hand-written (or submitted as pictures of a white board or piece of paper with hand-written equations). You don't need to show every single step in these equations, but should show how to set them up, the major steps in solving them, and the final result. Feel free to use graphs, tables, or other data visualization aids to help explain your work – but make sure to label them appropriately and refer to them in the text!

FOR SUBMISSION: Model derivations, results, and discussion should be written up in scientific paper format. Citations should follow the IEEE standard (http://www.ieee.org/documents/ieeecitationref.pdf); in particular, sources are numbered and listed in the bibliography in the order in which they first occur in the text, and any citations made in the text use bracketed numbers. All equations should be typed using an equation editor, NOT hand-written.

While citing concepts from outside sources is very appropriate, simply stringing together large sections of quoted text (even if cited appropriately) is not. As a rule of thumb, if you submit your paper (without bibliography) to turnitin.com and get a similarity match of greater than 20%, you have not done a sufficient job of presenting your own ideas or your own understanding of the concepts.

Reports should be compiled in a single Word or .pdf document. Any supporting graphs and tables should appear in the appropriate section of the report and should be clearly labeled and referenced appropriately. If MATLAB code is used, it should be included in an appendix.