ME4405 - Fundamentals of Mechatronics (Fall 2019)

Lab Assignment Ten

Feedback Control of a Thermal System Using the MSP432

Due Thursday, November 21th, 2019

Objective: This main objective of this lab is to learn how to implement a feedback controller for a thermal system to drive it to a desired temperature.

Deliverables and Grading:

To get credit for this lab assignment you must:

1. Submit a written report answering the questions below. You must write your own Simulink and C code for this lab – no lab groups are allowed. **(60 points)**.
2. Submit the commented final version of your code on Canvas. Also submit a zipped folder with your MATLAB code, including any .m, .mdl, or .slx files used for your simulations. **(Pass/Fail)**

Setup:

This lab requires Code Composer Studio, MSP432, and the thermal system and circuit used for Lab 9. The lab uses onboard features of the MSP432 such as GPIO pins, ADC, and Timer A.

Problem Statement:

Write a program for the MSP432 that implements feedback control for the thermal system created in Lab 9. The goal of the feedback controller is to drive the internal temperature of the canister to a desired value (which you select) using duty cycle as the control input. You will implement a PID controller that satisfies the following performance specifications: rise time of less than 3 minutes and overshoot of less than 20%.

Background:

Simulation Model:

To begin, construct a simple simulation model of the thermal system in Simulink. You may use the example Simulink models provided on Canvas as templates. The plant model for the thermal system should be a first-order system with the time constant you measured in Lab 9:

$$G(s) = \frac{T(s)}{D(s)} = \frac{K}{\tau s + 1}$$

where K is a constant. In the above equation, D(s) represents duty cycle and T(s) represents temperature. The value of K is determined by the control effectiveness (slope of the line) that you determined in Lab 9. Use this control effectiveness as your value of K.

The input to your block diagram should be desired temperature. The current temperature should be subtracted from this to form the error signal. The error signal should be input to the PID control block. The output of the PID control is the duty cycle value, which should be input to the first-order plant (you can eliminate any amplifiers used in the example Simulink templates).

Make sure to limit the output of your PID controller to a minimum of 0 and maximum of 100 (100% duty cycle). This can be done by double clicking on the PID block, and going to the PID Advanced tab.

Select two desired reference temperatures T1 and T2. These should be selected at some values between the steady-state temperatures you observed for your thermal system in Lab 9 between 30% duty cycle and 70% duty cycle. Simulate the step response of your closed-loop system to each of these two desired temperatures (this will require running two different simulations, each with a different desired temperature). Tune the PID gains to achieve the performance specifications above. Plot the step responses and show that your response meets the required performance specifications for each case.

In these simulations, assume that T = 0 corresponds to the ambient temperature (at duty cycle = 0%) and thus T1, T2 are measured relative to ambient (not absolute).

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Hardware:

The circuit and canister used in the Lab 9 will be used for the experimental portion of this lab as well. The MSP432 should be used to implement the PID controller for setting the PWM duty cycle that controls the temperature inside the canister.

Software:

Implement a PID controller on your MSP432 that controls the canister temperature using duty cycle as the control input. Use the rectangular integration method and first order finite differencing described in class. Make sure to enforce saturation on your duty cycle so it can never be set below 0 or above 100%. Run the controller at 10 Hz (but only output your data to the screen at 1 Hz).

Hint: This can be done using a Timer A interrupt and a counter (global variable) which is incremented during each interrupt. Every time the counter reaches 10, a *printf* statement is called and the counter is reset.

Requirements:

1. Create two plots of the simulated step response of your closed loop system, one each for desired temperatures of T1 and T2. On each plot highlight the rise time and overshoot, and show that they meet the specified requirements. State the PID gains you used for these simulations. **(20 points)**

2. Now using your hardware setup and the same PID gains used in simulation, control the thermal system to each temperature T1 and T2 starting from ambient each time. Record the step response for each case. Plot the experimental step response (two plots, one for each case) and highlight the overshoot and rise time. Does it match the required performance specifications? Now create two new plots where you overlay the simulated and experimental response. How similar is the experimental response to the simulated one? If the simulated and experimental responses look noticeably different, explain why you think that is the case. **(20 points)**

3. If your experimental response does not meet the required rise time and overshoot specifications, tune your PID gains until it does. Report your new PID gains, and show plots of the two responses for this case (showing that you now meet the required specifications). **(20 points)**

4. Submit the commented final version of the MSP432 code on Canvas.