Praveen Ravishankar **Fall 2019**
ME 4405 Section B

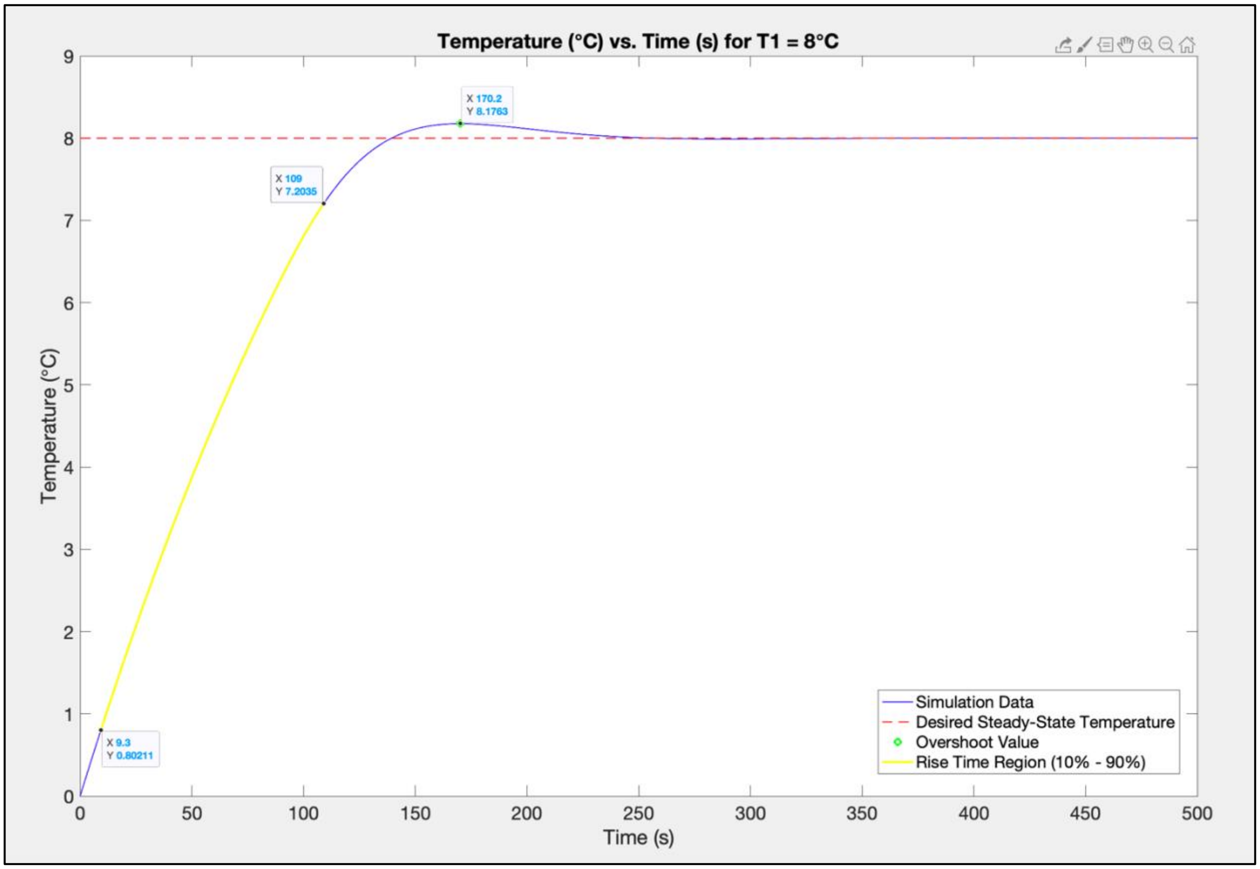
Lab Assignment Ten

Feedback Control of a Thermal System Using the MSP432

Questions:

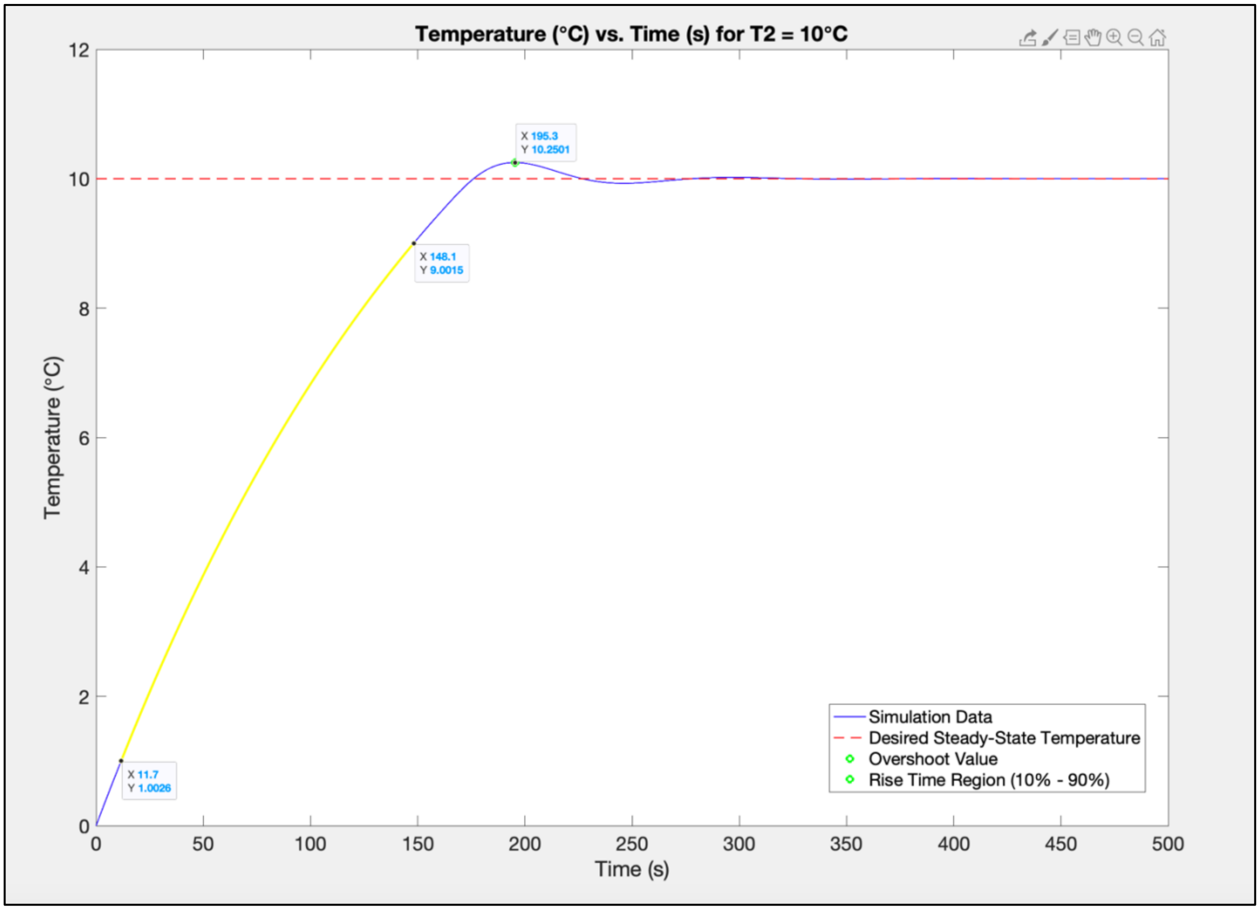
1. Create two plots of the simulated step response of your closed loop system, one each for desired temperatures of T1 and T2. On each plot highlight the rise time and overshoot, and show that they meet the specified requirements. State the PID gains you used for these simulations. **(20 points)**

For T1 = 8$_{o}$C:



The rise time was calculated assuming it is equal to the difference in time between when the system reaches 10% of its steady-state value and when the system reaches 90% of its steady-state value; as a result, for a desired steady-state temperature of 8$_{o}$C, 10% of the steady-state value is 0.8$_{o}$C, while 90% of the steady-state value is 7.2$_{o}$C. As seen in the plot above, the rise time is approximately equal to 99.7 seconds, which satisfies the requirement of being less than 3 minutes (or 180 seconds). Additionally, by observing the above plot, the overshoot is seen to be approximately equal to 8.1763$_{o}$C, which satisfies the requirement of being less than 20% of its desired steady-state value (which is 9.6$_{o}$C). The PID gains used for this specific simulation were a value of 50 for the proportional gain, a value of 1.5 for the integral gain, and a value of 0 for the derivative gain.

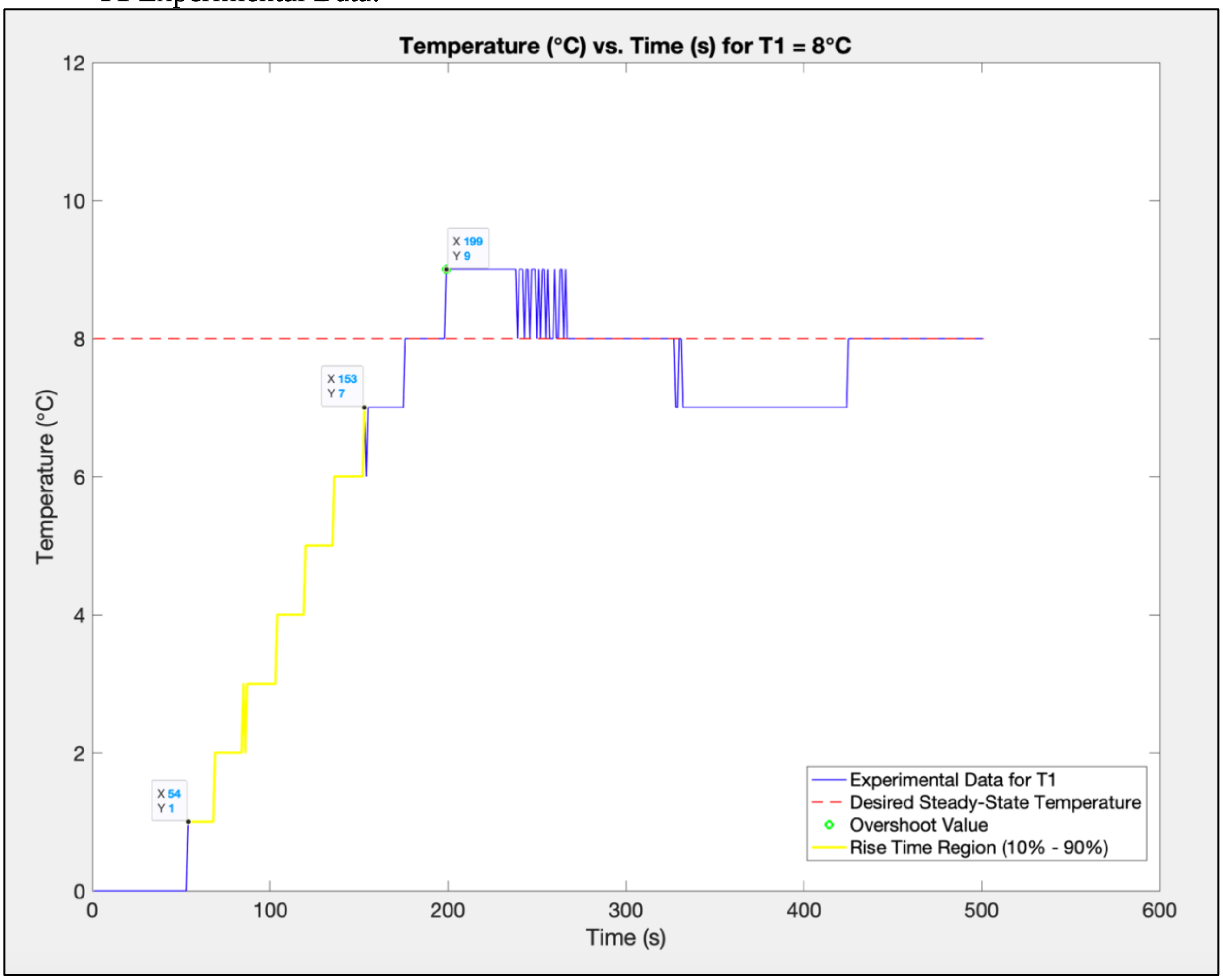
For T2 = 10$_{o}$C:



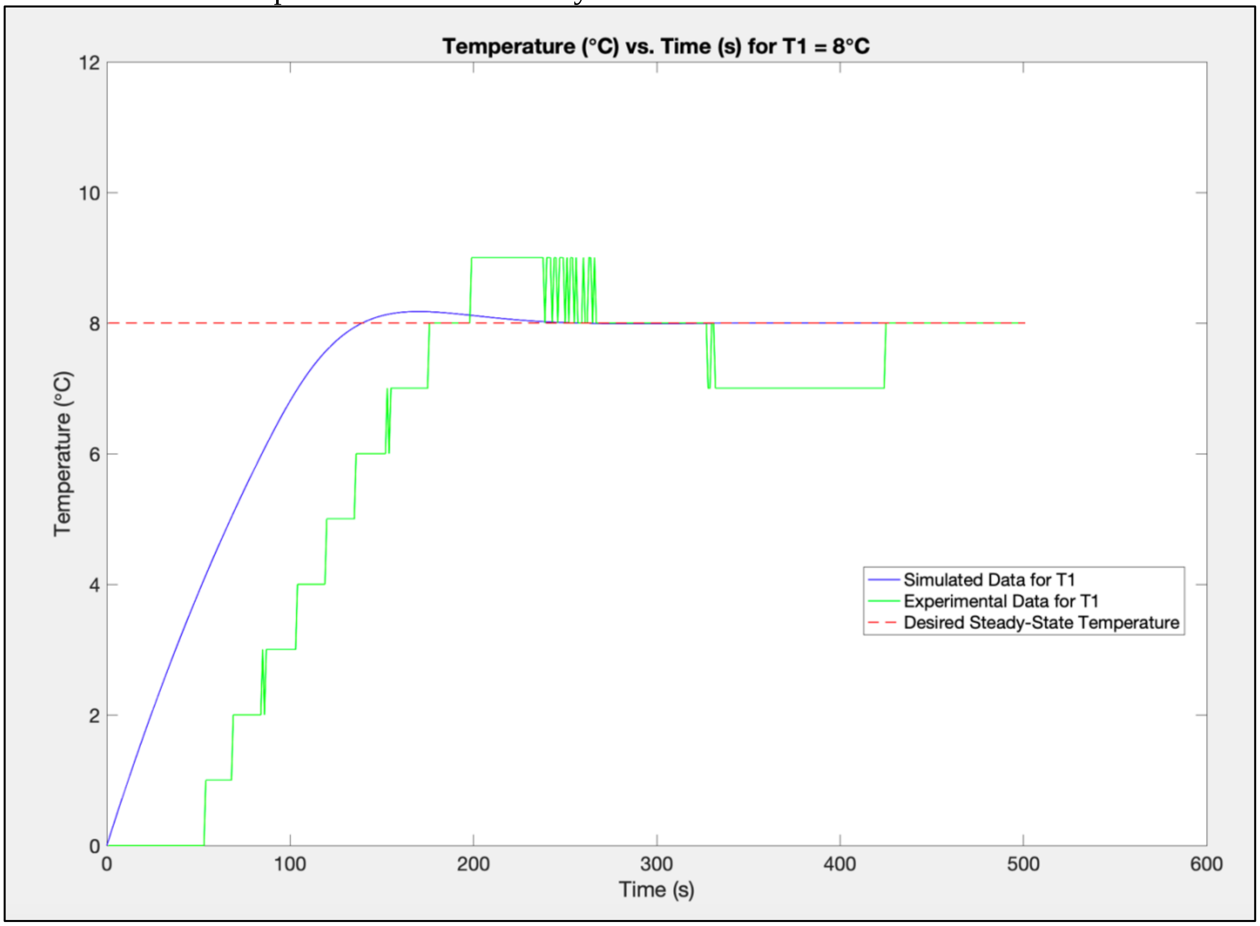
The rise time was calculated assuming it is equal to the difference in time between when the system reaches 10% of its steady-state value and when the system reaches 90% of its steady-state value; as a result, for a desired steady-state temperature of 10$_{o}$C, 10% of the steady-state value is 1$_{o}$C, while 90% of the steady-state value is 9$_{o}$C. As seen in the plot above, the rise time is approximately equal to 136.4 seconds, which satisfies the requirement of being less than 3 minutes (or 180 seconds). Additionally, by observing the above plot, the overshoot is seen to be approximately equal to 10.2501$_{o}$C, which satisfies the requirement of being less than 20% of its desired steady-state value (which is 12$_{o}$C). The PID gains used for this specific simulation were a value of 50 for the proportional gain, a value of 5 for the integral gain, and a value of 0 for the derivative gain.

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)**

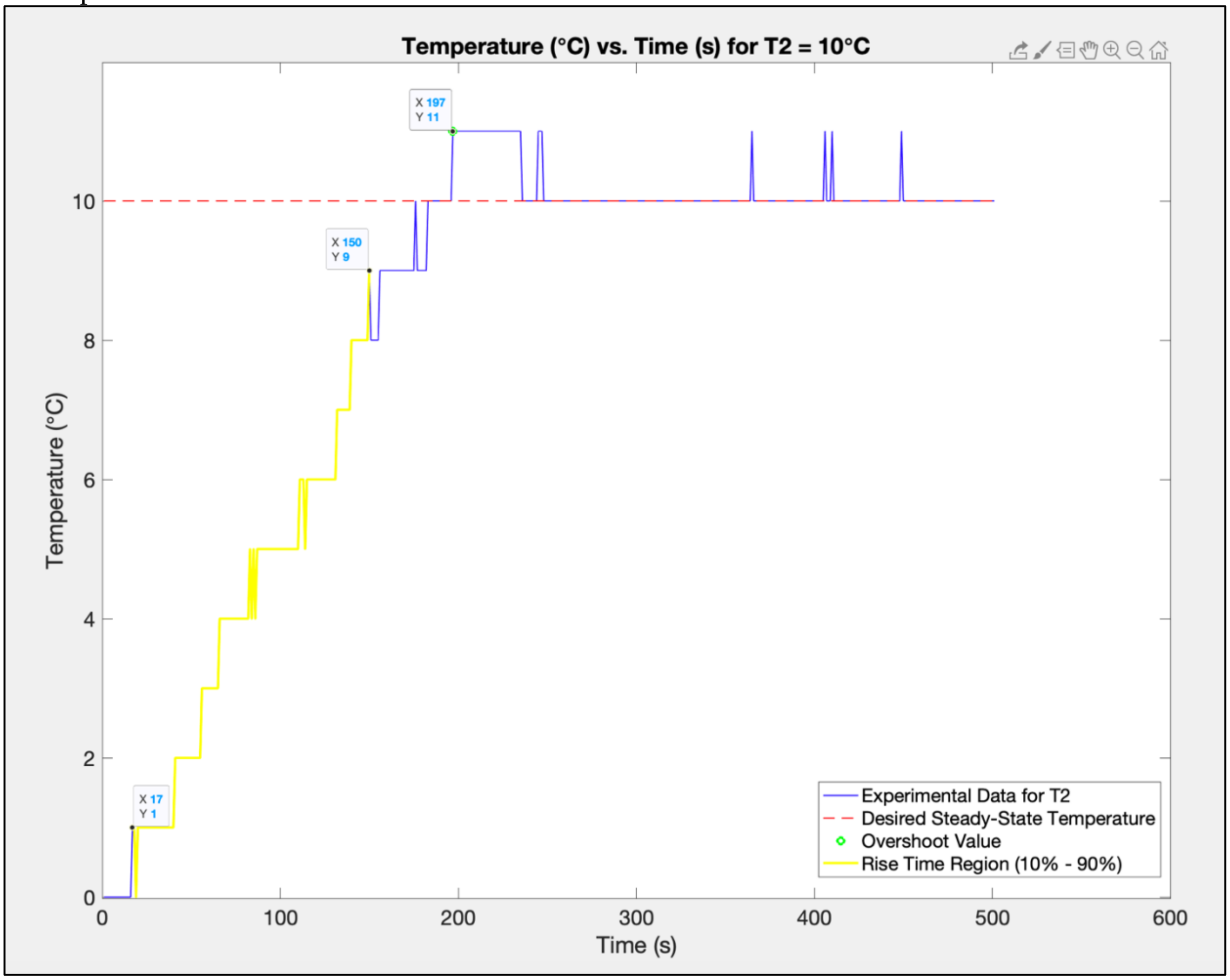
T1 Experimental Data:



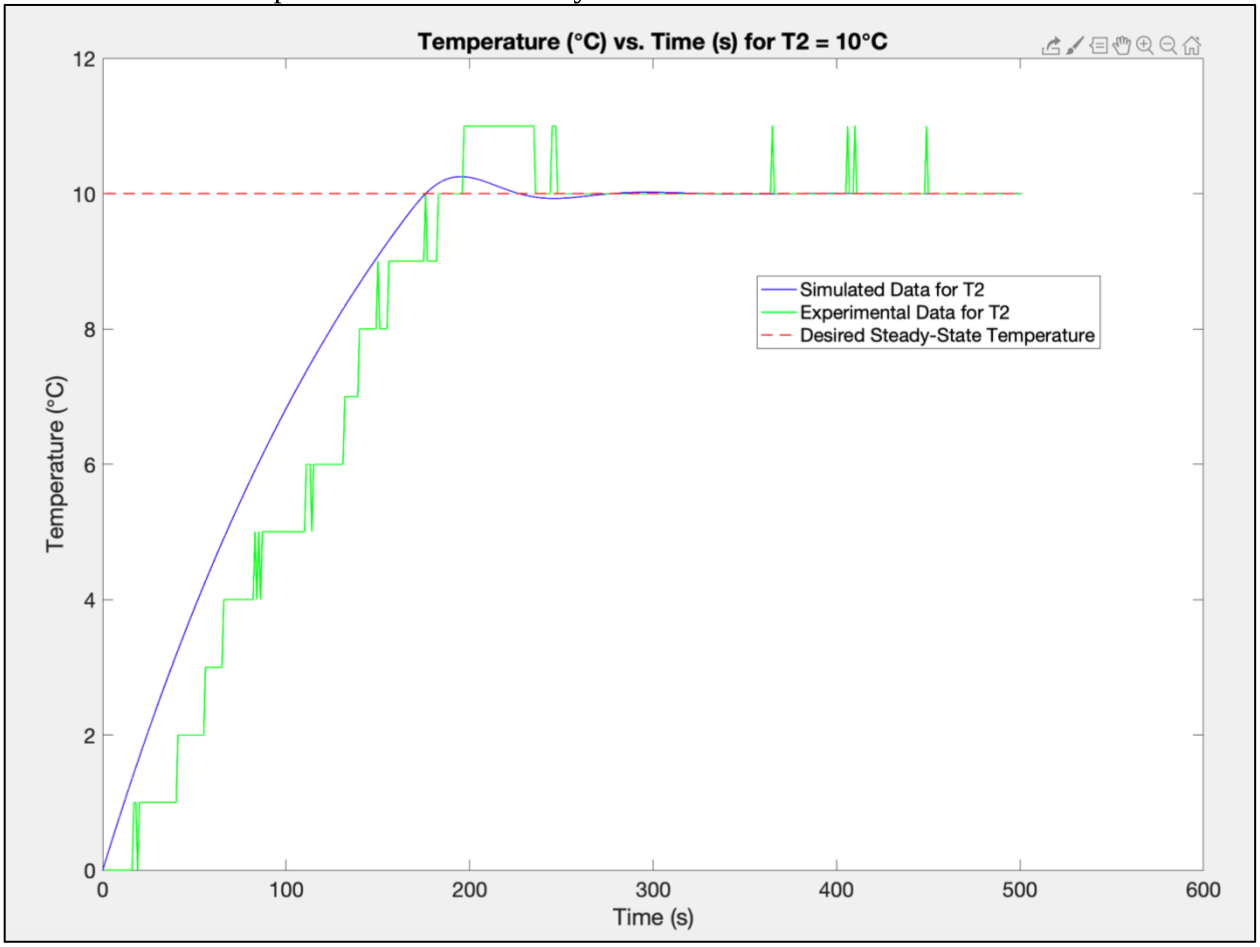
T1 Simulated and Experimental Data Overlay:



T2 Experimental Data:



T2 Simulated and Experimental Data Overlay:



All of the experimental data was obtained using the same corresponding PID gains for the simulated data. For both desired steady-state temperature values (T1 and T2), the simulated and experimental responses definitely look noticeably different. These differences can be attributed to multiple different reasons. Firstly, the resolution of the temperature sensor used in this lab is extremely low, as it outputs the measured temperature values only in integer form (which corresponds to a resolution as low as 1_oC); this causes values that are below the halfway point between two integers (such as 5) to be rounded down to the nearest integer, while causing values that pass this halfway point (such as 5.5) to be automatically rounded up to the nearest integer (to 6). Additionally, the temperature sensor is separated a certain distance away from the 100Ω resistor (which heats up due to the applied PWM signals from the MSP432) by a fluid instead of being in direct contact with the resistor; this indicates that the heat from the resistor travels to the temperature sensor primarily through convection and radiation and not through a method as quick as conduction. Both of these reasons imply that the temperature values measured by the temperature sensor may not necessarily be an accurate representation of the true temperature values of the 100Ω resistor, causing differences between the simulated and experimental responses.

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)**
   Our experimental responses do meet the required rise time and overshoot specifications. Firstly, by observing the graph of the experimental data for T1, the rise time of the system is approximately equal to 99 seconds, satisfying the rise time requirement of being less than 180 seconds; additionally, the overshoot value is approximately equal to 9$_{o}$C, which satisfies the overshoot requirement of being less than 20% of the desired steady-state temperature value of 9.6$_{o}$C. Secondly, by observing the graph of the experimental data for T2, the rise time of the system is approximately equal to 133 seconds, satisfying the rise time requirement of being less than 180 seconds; additionally, the overshoot value is approximately equal to 11$_{o}$C, which satisfies the overshoot requirement of being less than 20% of the desired steady-state temperature value of 12$_{o}$C. Hence, all required rise time and overshoot specifications were met, and our PID gains did not need to be tuned any further.