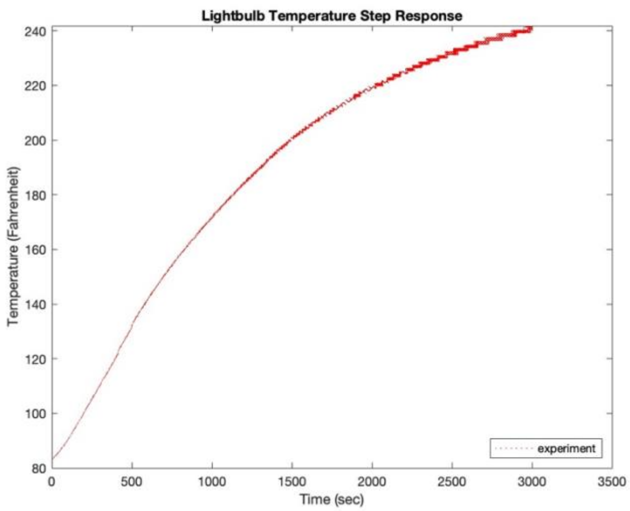
ELEE 4220: Feedback Control Systems
Lab 1
Emerson Hall
01/17/2025

I. Introduction

In this lab, the principles of control systems theory are brought to life through a hands-on experiment that uses a lightbulb as the controlled system. The primary goal is to explore key control strategies, including on/off control, proportional control, and their extensions, such as feedforward and feedback mechanisms. By integrating hardware components like a thermistor, solid-state relay, and Arduino, this lab allows students to implement, simulate, and test the dynamic behavior of a temperature regulation system. Furthermore, this exercise emphasizes safety protocols, system modeling, and Simulink programming to foster a comprehensive understanding of control system design and real-world application.

II. Experiments and Questions

A. Bump Test

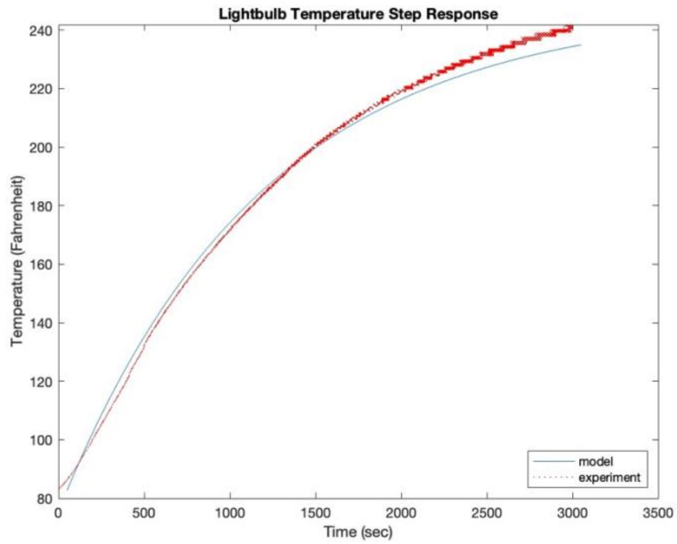


a.

B. Model

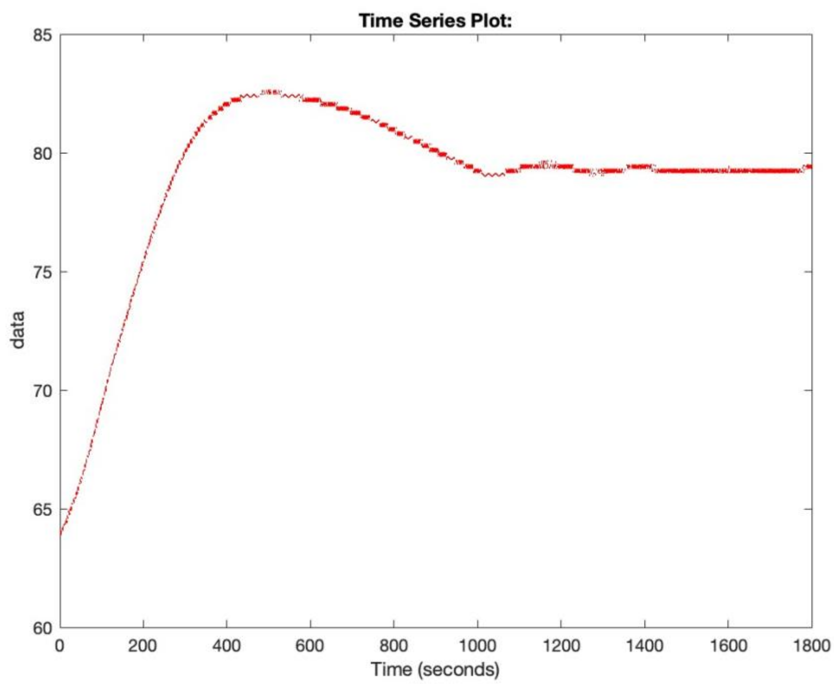
Max: 241.8 (degrees Fahrenheit), Min: 82.65 (degrees Fahrenheit)
Gain = K = max - min
Gain = 241.8 - 82.65 = 159.15
For 63 percent, the equation is .63(K) + min
.63*(159.15) + 82.65 = 182.9145 (degrees Fahrenheit)
On the graph, 182.9145 (degrees Fahrenheit) occurs at 1176.3 seconds.
τ = 1176.3 seconds, To = 82.65, K = 159.15
The transfer function is P(s) = $\frac{Y(s)}{U(s)} = \frac{K}{\tau s+1}$
For this model, P(s) = $\frac{Y(s)}{U(s)} = \frac{159.15}{1176.3s+1}$

a.



b.
c. The model follows the shape of the data but does not completely cover the increase from around 100 seconds to 200 seconds and then when the temperature begins to stabilize, the model reaches stabilization at a slightly smaller temperature value.

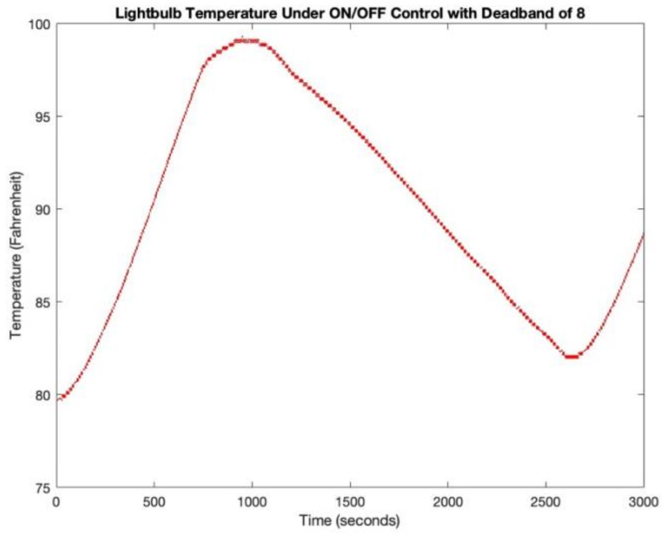
C. On/Off Control



a.
b. On/Off control is suitable when precise control is not necessary such as home air conditioning systems or water heaters. On/Off control should not be used for battery charging systems or chemical reactions as they can cause unsafe conditions. They require more precise control to ensure safe environments.

D. On/Off Control with Deadband

a.

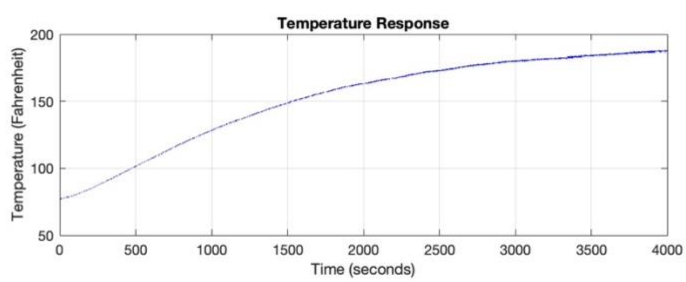


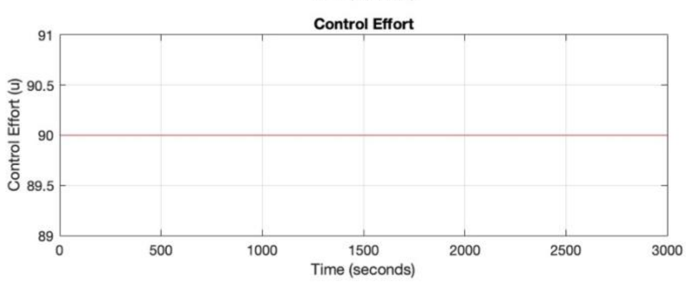
b.
c. 90 degrees Fahrenheit was chosen to regulate at and the time was extended to show the effects of the deadband.
d. Refrigerators perform with an ON/OFF control with a deadband so it can regulate temperature so food within does not spoil.

E. Under P Control

The closed-loop transfer function is $G_{el} = \frac{C(s)P(s)}{1+C(s)P(s)}$
For this system, $C(s) = K_p$
From the previous model, $P(s) = \frac{Y(s)}{U(s)} = \frac{159.15}{1176.3s+1}$
So for this closed-loop system, $G_{el} = \frac{159.15K_p}{1176.3s+1+159.15K_p}$

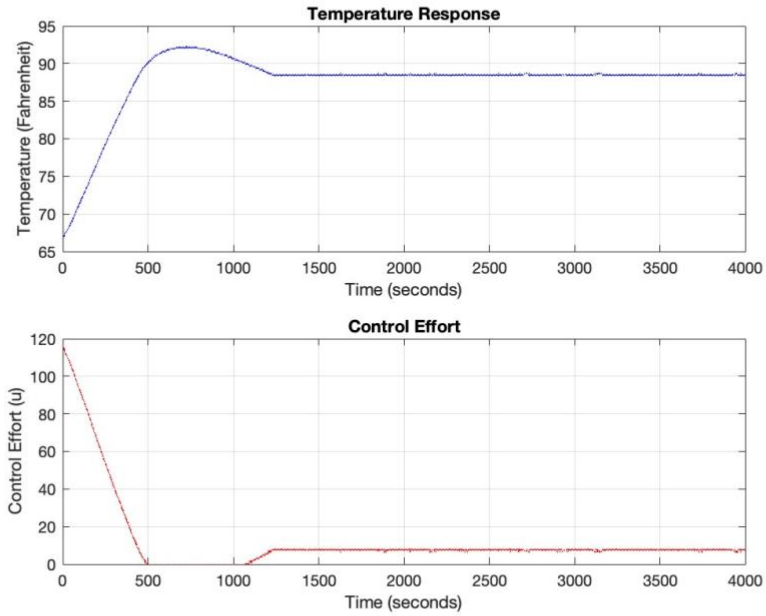
a.





b.

i. The temperature response will increase and since the control efforts inversely matches the response, the control efforts will decrease in value.



ii.

F. Questions

a. Inversion:

i. Why did this lab not create a model?

1. In this lab, the primary goal is to design a control system to regulate temperature, and modeling a system is often not feasible or necessary due to complexity, especially when the system involves nonlinear behavior While a model could theoretically be, it's often easier and more practical to apply a feedback control strategy that does not require an exact model.

ii. Why did this lab not find an inverse?

1. Finding the inverse of a temperature control system is difficult because the system is inherently nonlinear, especially due to thermal dynamics and the saturation behavior of the heating element. The temperature response may not be proportional to the control effort due to thermal delays and nonlinearities. Additionally, the system's dynamics would likely be too complex to directly find an accurate inverse that would be reliable under all conditions.

iii. Why did this lab not use the high gain feedback to get rid of the temperature sensor all together?

1. Using high-gain feedback to eliminate the temperature sensor would theoretically involve using the control effort to determine the temperature directly. However, this is impractical and likely to cause instability due to high sensitivity to noise or disturbances. High-gain feedback can

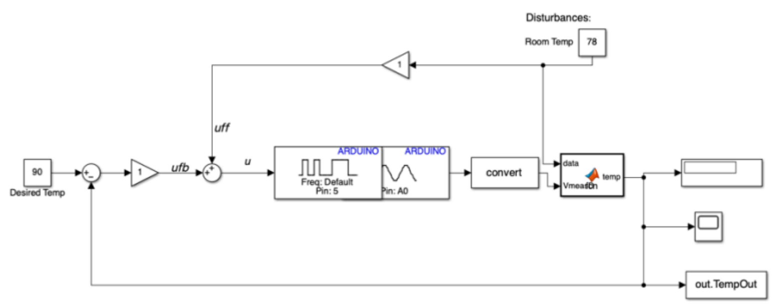
amplify errors in the system, making it highly susceptible to small changes or inaccuracies in the control loop. Instead, using a temperature sensor provides real feedback that allows the controller to measure the system's actual state and make appropriate adjustments. Without the sensor, the system could become unstable, resulting in oscillations or overshooting of the desired temperature.

iv. **Explain what would happen if we did this?**

1. If high-gain feedback were used to eliminate the temperature sensor, the system would likely become unstable or respond with large overshoot and oscillations. The control effort could become very large in trying to compensate for small errors in temperature measurement, and the system could fail to converge to the desired temperature. This would undermine the entire objective of temperature regulation.

b. **Feedforward:**

i. **Create a diagram showing what feedforward would look like for this problem.**



1.

ii. **What would feedforward potentially help in this control problem?**

1. Feedforward control could help by anticipating the required control effort before the temperature begins to deviate. For instance, if there's an initial disturbance, the controller can proactively increase the heating power without waiting for the temperature sensor to detect the change.
2. This could lead to faster and more accurate responses, reducing overshoot and the need for aggressive feedback. However, it would still be necessary to have feedback to correct any inaccuracies in the model or disturbances that were not predicted.

c. **Controls:**

i. **Do you see this loop?**

1. Yes, this feedback loop is visible in the lab's control system. The system continuously measures the actual temperature, compares it to the setpoint, and applies corrective actions to keep the temperature within an acceptable range of the

setpoint. This ensures the system is stable and responds to changes or disturbances in real-time.

IV. Conclusion

This lab successfully demonstrated the interaction of control theory and practical implementation by regulating the temperature of a lightbulb through various control techniques. Key takeaways include the benefits and limitations of on/off control, the importance of proportional gain in achieving stability, and the enhanced accuracy provided by feedforward and feedback systems. The experiment also highlighted challenges such as system nonlinearity and hardware constraints, fostering a deeper understanding of control systems' real-world complexities. By bridging theoretical concepts with hands-on experimentation, this lab serves as a foundation for further exploration into advanced control strategies.