International Journal of Integrated Engineering, Vol. 9 No. 3 (2017) p. 24-28

A Temperature Control System for Near Infrared Spectroscopic Analysis using Proportional Controller

Ammar Ariff Aminondin[1], Kim Seng Chia[1,*]

[1]Faculty of Electrical and Electronic Engineering,
Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat, Johor, MALAYSIA

Received 1 August 2017; accepted 15 September 2017, available online 18 September 2017

Abstract: Near infrared spectroscopy (NIRS) has been widely investigated as an alternative to replace conventional chemical analysis. However, NIRS analysis is susceptible to the change of surrounding temperature. This would affect the NIRS analysis and could cause the result to be inconsistent. Therefore, this paper presents a work in designing the temperature control system for NIRS data acquisition. First, the cooling element of the system was designed using a TEC1-12706 Peltier as a cooling element, and a temperature sensor LM35 was used to measure the temperature inside the data acquisition container. The pulse-width modulation signal of a microcontroller was used to control the N-channel MOSFET so that the desired temperature can be achieved. The Arduino Uno was used as the microcontroller of the system. Lastly, a proportional controller was applied for forming the temperature control system in the container and the performance of the system was analyzed. Results show that the proportional controller outperformed the logic controller. Findings indicate that the proposed control system with optimal K_p value is able to maintain the desired temperature.

Keywords: Near Infrared Spectroscopy (NIRS), Proportional Controller, Peltier, Temperature control system.

1. Introduction

Near infrared spectroscopy (NIRS) has been widely investigated as an alternative to replace conventional chemical analysis [1]. This technology played a crucial role for researcher to obtain better and precise data analysis. NIRS has been contributed in wide range of agriculture sector for the past 10 years. The implementation of this technology increased the efficiency of time consumption for postharvest in sorting process which could help eliminating the manual process of fruit grading.

However, the main challenge faced by many experiments is the increment of temperature during handling of this process [2]. NIRS analysis is susceptible to the change of surrounding temperature. This is because temperature is the critical factor that affects the molecular bond frequency and vibration intensity [3]. Exposure to the temperature change has been shown adverse effects in the spectra of organic molecules in the near infrared (NIR) region. In the previous years, research have shown that NIR spectroscopy being used to estimate the amylose content of rice by studying the influences between 4 different temperature levels [4]. Results showed that the temperature at each of the states had produced difference in absorbance, also produced difference in stabilities. In other words, a slight change in temperature would affect the accuracy of the data analysis.

Control system has been widely used in many industrial applications. Even though modern control theory such as neural networks, fuzzy control and neuro-fuzzy controller [5] have been widely introduced, over 90 percent of the control loops still use conventional proportional-integral-derivative (PID) controller [6]. Therefore, this paper presents a work in designing the temperature control system for NIRS data acquisition. using proportional controller. The focus of this study is to control the temperature inside the designed container, and evaluate the performance of the proposed temperature control system.

2. Methodology

a. Temperature Control System

Figure 1 shows the hardware used in this study. The mini container consists of an Arduino UNO as the microcontroller of the system; a 12V 120Watt power supply to provide a stable 12V to the system; a DC fan with heat sink; four units of LM35 at every edge of the mini container to measure the temperature of each edge; a TEC1-12706 Peltier as a cooling element, and a halogen lamp as a heating element to simulate the data acquisition process during NIRS analysis. The size of the mini container is 200mm x 245mm x 150mm. The performance of the temperature control system was evaluated based on the time taken and the accuracy of the proportional controller to achieve the desired temperature (a.k.a. set-point). Next, a thermometer was added into the mini container to measure the actual temperature inside the mini container, and then compared with the temperature measured by the temperature sensors (i.e. LM35).

*Corresponding author: kschia@uthm.edu.my

penerbit.uthm.edu.my/ojs/index.php/ijie

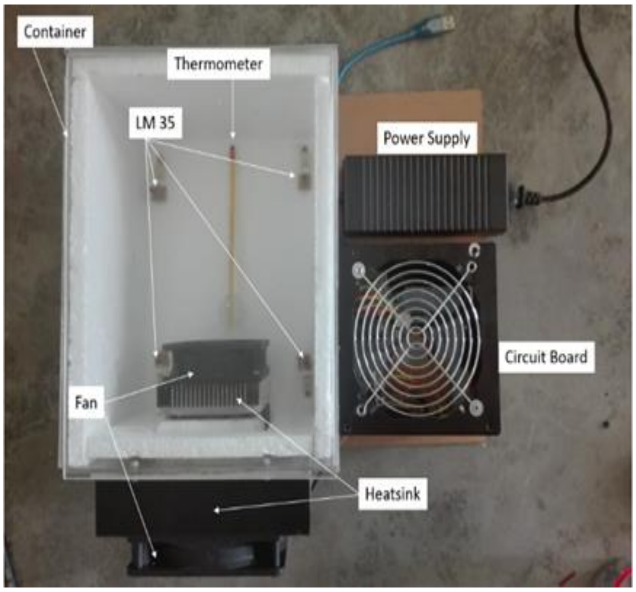

Fig. 1 Prototype of temperature control system.

b. Hardware Testing

The hardware testing started with the circuit connectivity of the system. After that, the system was tested with the four temperature sensors, LM35 to check the connectivity, sensitivity, and accuracy of the sensors. The temperature sensors were placed at each of the corner of the container. The accuracy of the sensor measured temperature could be determined by comparing the value recorded with the mercury thermometer that was placed inside the container. The testing phase of the temperature sensor was separated into two parts that are the room temperature, and the temperature measured when the halogen lamp was activated.

The cooling element was attached at one side of the container to supply cool air to the container. The MOSFET was used as the cooling element driver. A 12V 10A power supply was used to power up the cooling element and also the cooling fan at the hot side of the cooling element. The effect of the cooling element to the proposed design was investigated accordingly.

c. Logic Controller

Logic controller was implemented as an ON/OFF switch to control the temperature inside the container. The feedback was sent to the system to indicate the temperature difference that measured by the system. The pulse-width modulation (PWM) triggered the signal to the cooling element to control the temperature inside the container. The desired temperature was 25 degree Celsius. When the temperature reached the desired temperature, the PWM signal would be turned to zero. Otherwise, the PWM signal would be turned to 255 (i.e. the maximum value).

d. Proportional Controller

Proportional controller is a feedback controller that was implemented to control the temperature inside the container. A manual tuning method was used to identify a suitable K_p. In order to obtain the desired temperature, the proportional gain K_p was tuned with various values until the system achieved the best performance. The value of K_p was arbitrarily set to K_p=1, K_p=30, and K_p=100. The result for each value of K_p would be recorded and analyzed according to the performance of the system to control temperature. The performance of the system was evaluated in terms of the rise time, the overshoot, and the settling time. The performance between logic controller and proportional controller would be compared and discussed.

3. Results and Discussion

a. Hardware Performance

Figure 2 illustrates the room temperature recorded using the temperature sensor. The temperature reading were different according to the temperature surrounding. All temperatures that were sensed by the sensors were slightly different. This may be due to the position of the sensors that might have different temperature inside the container. However, the difference in temperature was around one degree Celsius. The average temperature from the four temperature sensors were recorded simultaneously in every 10 seconds. The average value of these four temperature sensors was used to represent the average temperature inside the container.

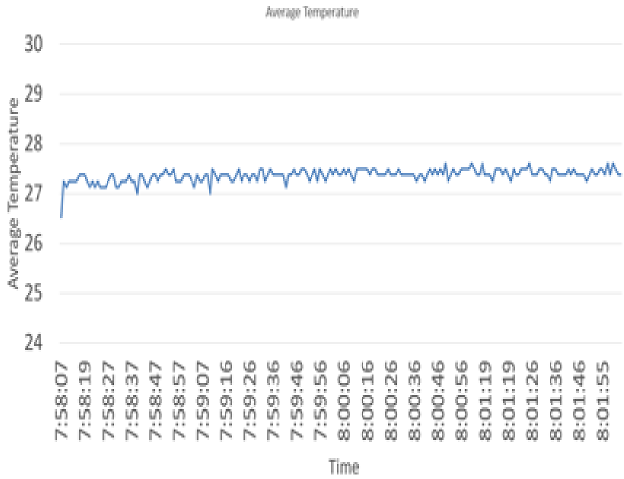

Fig 2. The average temperature of room temperature.

Table 1 tabulates the temperature difference measured by the temperature sensor and the mercury thermometer at different temperature. The temperature difference using temperature sensor and thermometer was around one degree Celsius. This indicates that the temperature sensor used in this project is accuracy and reliable.

Table 1. The comparison between the actual temperature that measured by the thermometer and the measured temperature from LM35.

	Temperature Measured Using Thermometer	**Average Temperature Using LM35**
1	29	28.36
2	27	26.23
3	31	30.41

Figure 3 illustrates the average temperature inside the container when the NIRS halogen lamp was activated. When the lamp was activated at time 3:03:48, the sensors detect the changes of temperature inside the container. The temperature was increasing from 28 degree Celsius to 32.50 degree Celsius in around 18 minutes, i.e. from 3:03:17 to 3:19:38 with the temperature surrounding outside the container being at 28 degree Celsius. This temperature change would have negative effect to NIRS analysis and should be eliminated.

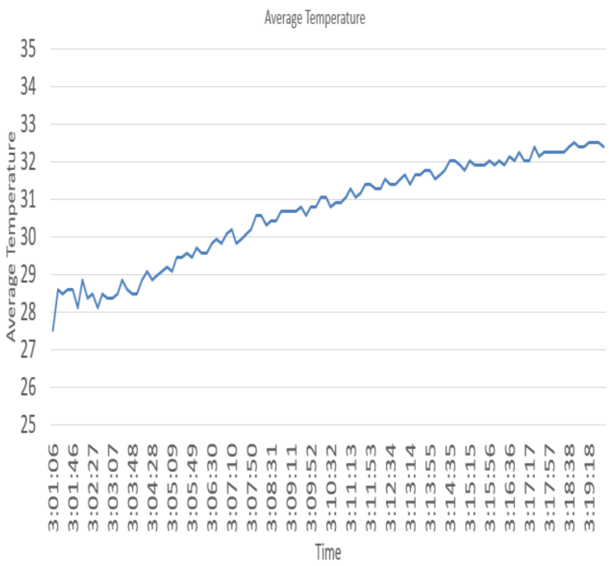

Fig 3. Average temperature inside the container when the NIRS halogen lamp is activated.

Figure 4 shows the effect of the cooling element that was activated for about 30 minutes without a feedback control system. Point A shows the time where the cooling element was activated. Point B was the time recorded when the temperature in the container reached the lowest temperature level and maintained in that level. Results indicates that the lowest temperature that can be achieved was 19.56 degree Celsius in a time interval from 2:25:02 until 2:38:31.

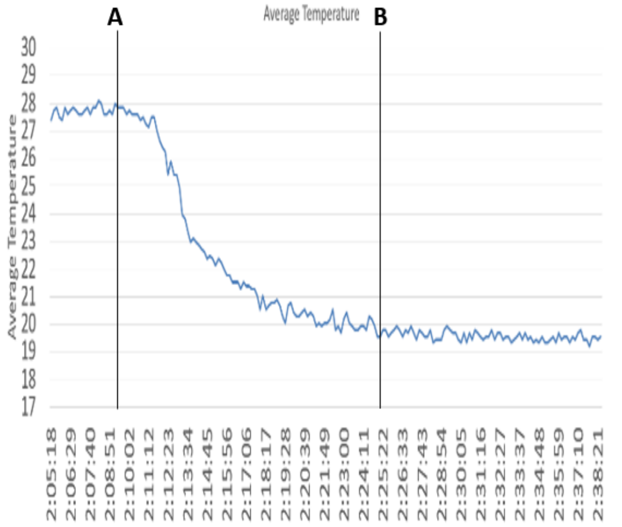

Fig 4. The average temperature changes when cooling element was activated without a feedback control system.

b. Effect of Logic Controller

Figure 5 shows the average temperature when the logic controller was applied. The desired temperature was 25 degree Celsius that needs to be achieved in the container. Point A shows the time when the cooling element was activated. The logic controller feeded 100% duty-cycle of the PWM signal (i.e. 255) to the cooling element if the temperature was above the desired temperature. Otherwise, the controller supplied 0% duty cycle of PWM signal. In other words, the cooling element was either completely turned off or completely turned on. Results suggest that the logic controller was able to control the temperature from around 30 degree Celsius to the desired temperature with a fluctuation of less than one degree Celsius.

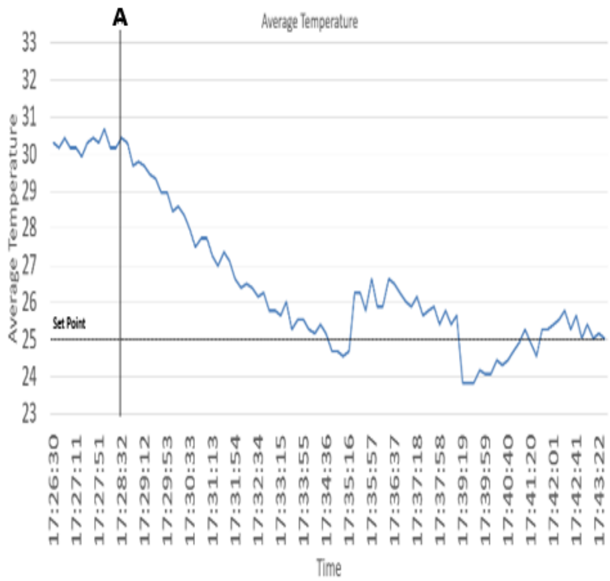

Fig 5. The temperature change when logic controller was applied.

c. Effect of Proportional Controller

Figure 6 illustrates the performance of the proportional control system when K_p=1. The point A was the time when the halogen lamp was activated. The temperature increased to around 34 degree Celsius. At the point B, the proportional controller was activated to cool down the temperature. The rise time was around 39 minutes as that illustrated from point B to point C in Figure 6. The offset or steady state error was around one degree Celsius. This suggests that the value of K_p was too low.

Figure 7 shows that the performance of the proportional control system when K_p=100. When the halogen lamp was activated at time 16:45:16 (point A), the temperature would be increased. On the other hand, when the controller was activated (point B), the temperature would be reduced toward the desired temperature. The rise time of the temperature was around 20 minutes. An overshoot of 2 degree Celsius was observed after the measured temperature was same as the desired (point C). The settling time for the temperature was about 30 minutes. A fluctuation was observed after point D. This suggests that the value of K_p was too high.

Figure 8 depicts the performance of the proportional control system when K_p=30. Results show that the overshoot was relatively smaller compared to that used K_p=100 with a compromise of lower rise time of 27 minutes and settling time of 18 minutes. This observation justifies the intuitive manual tuning approach that used in this study.

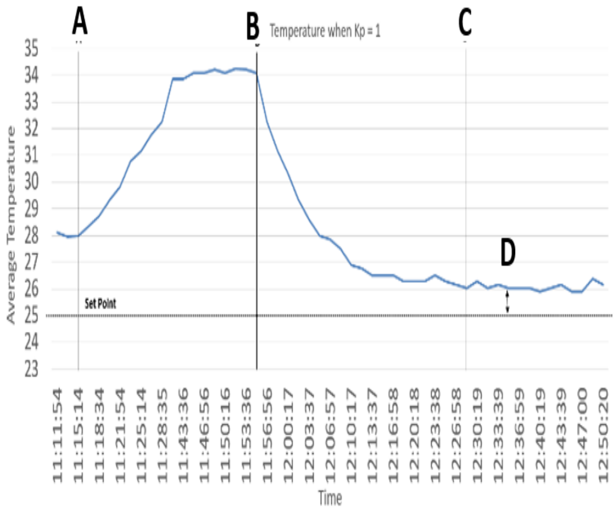

Fig 6. The performance of the temperature control system when K_p=1

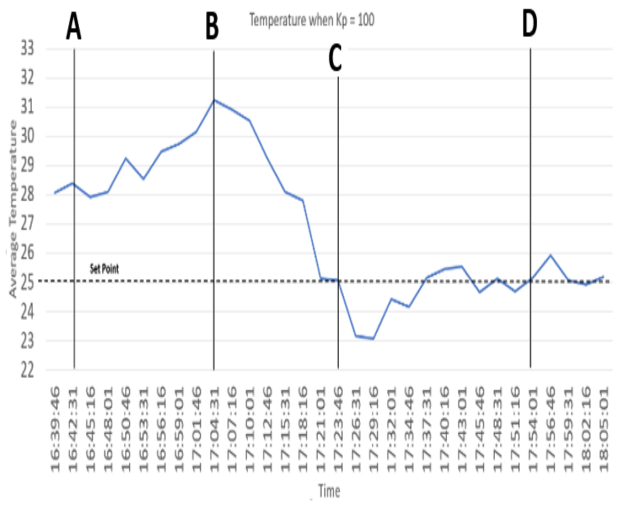

Fig 7. The performance of the temperature control system when K_p=100.

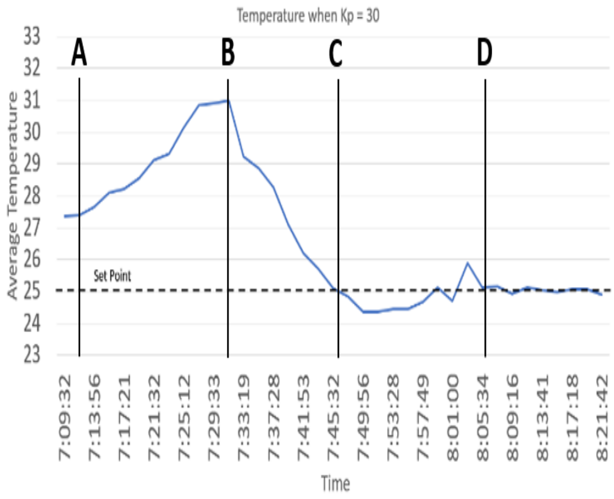

Fig 8. The performance of the temperature control system when K_p=30.

Table 2 tabulates the performance of proportional controller in controlling the temperature for NIRS analysis. Results depict that the controller with too low K_p might not be able to achieve the desired temperature, on one hand. On the other hand, the controller with too high K_p might lead to the undesired temperature overshoot and oscillation. Next, even though the logic controller achieved a faster response in terms of rise time, the undesired effects of oscillation and overshoot cannot be eliminated.

Table 2. Comparison of performance using Proportional Controllers.

Parameters	Kp=1	Kp=30	Kp=100
Rise time, (minutes)	39	27	20
Overshoot, (%)	No overshoot	35	80
Settling Time, (minutes)	39	45	50
Steady State Error	0.5	0	0

4. Conclusion

This study presents a development of a temperature control system by means of proportional controller to control the temperature inside the mini container during NIRS data acquisition process. The performance of the temperature control system could be directly observed when different value of K_p values were applied. The results show that the effect of different K_p values in the temperature control system are in-line with the control theory. Thus, a proper tuning approach is important to optimize the parameter. Additionally, the proportional controller with a proper tuning could achieve better steady state and transient response in controlling the temperature during NIRS data acquisition process.

Acknowledgements

This study was sponsored by Faculty of Electrical and Electronic Engineering (FKEE), Universiti Tun Hussein Onn Malaysia (UTHM). Authors would like to acknowledge UTHM and Advanced Mechatronic Research Group (AdMiRe), FKEE, UTHM for providing facilities for this study.

References

[1] Williams, P. C., and Norris, K. H., “Effect Of Mutual Interactions On The Estimation of Protein and Moisture in Wheat." *Cereal Chem*. 60 (1983). 202–207.

[2] Cozzolino D., Liu L., Cynkar W U., Dambergs R G., Janik L., Colby C B and Gishen M. “Effect of Temperature Variation on The Visible and Near Infrared Spectra of Wine”. Analytica Chimica Acta, (2007);588(2): 224–30.

[3] M. Shah., C. Bhatt and J. Dave. “Temperature Dependent NIR Spectroscopic Analysis for Food Grain Samples”. Indian Journal of Science and Technology, Volume 9, (2016).

[4] Xie X and Shi L. “Study of Temperature Influence in The Application of Near Infrared Reflectance Spectroscopy (NIRS) to Estimate Amylose Content of Rice”. African Journal of Agricultural Research, Vol.8 (25),(2013)pp.3334-3339.

[5] Bista, D. “Understanding and Design of an Arduino-based PID Controller”. Master Degree Thesis. Virginia Commonwealth University, (2016).

[6] Andria G, Cavone G, Guarnieri C, Carducci C, Member S, Spadavecchia M, Bari P and Orabona V E. “A PWM Temperature Controller for Thermoelectric Generator Characterization”, (2016), pp. 291–6.

[7] K. S. Chia and X. Y. Yap. “A Portable PID Control Learning Tool by Means of a Mobile Robot”. iJOE – Volume 12, (2016), Issue 6.