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Linear Quadratic Control for Temperature Regulation of Solar Herb Drying System

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Abstract: Temperature regulation plays an important role to maintain product quality and the efficiency of the herb drying system. Therefore, this paper focuses on the implementation of Linear Quadratic Regulator (LQR) controller for temperature regulation of solar herb drying systems. The simulation result indicated that LQR is capable to provide better performance compared with PID controllers in regulating the temperature of the herb drying system. On the other hand, the result also shows that LQR is capable to prevent the response from overshoot and produce 82% faster settling time as compared with PID.

Keywords: LQR, PID, Solar Herb Drying, Temperature Regulation

1. Introduction

Herb is a plant with seeds, flowers, or leaves that are used for any sector such as medicinal, culinary, cosmetic industries, and many more. These herbs can be done by undergoing a drying process either using traditional methods such as direct sun or modern methods such as solar energy. The importance of herb drying in a previous study shows that the products being dried in the dryer were completely protected from rains and insects and the dried products are of high [1]. Many benefits could be exploited from solar energy for drying applications. Solar energy enables the industries and agricultural sectors to modify their energy requirement, improve their energy stability, and increase energy sustainability, which lead to improvement in the system efficiency [2].

The temperature control during drying allows uniformity of the product heating, saving energy, and improving the quality of the dehydrated products. Generally, the quality of aromatic and medical plants and also the quantity of essential oil are influence by the high temperature during drying [3]. Besides, a previous study also states that controlling the temperature will produce high-quality products.

Based on the above-mentioned factor, temperature play important role in determining the effectiveness of the herb drying system. Therefore the improvement of temperature regulation in herb

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*Corresponding author: hafizz@uthm.edu.my drying will contribute in increase the effectiveness of the process. Therefore this study will apply Linear Quadratic Controller (LQR) towards improving the regulation of the herb drying system.

2. Materials and Methods

This section will present the methodology applied for this work including system modeling, LQR controller design, Proportional Integral Derivative (PID) controller design, and performance evaluation of the controller. This study is conducted using MATLAB 2019b. The detail for each topic will be explained in the following subsection.

2.1 System Modeling

In this work, the first-order model is used to represent the heating process of the herb drying system and the MATLAB system identification Toolbox is used for developing the model. The input and output experimental data used in this study is based on the data obtained in [4]. The input and output data have been split into two via interlacing technique in which even data is for model development while odd data is for validation. Based on the even data and by using MATLAB system identification Toolbox, the first-order model for the system obtained is as shown in Eq. 1.

$$\frac{\mathrm{C}(s)}{\mathrm{R}(s)} = \frac{0.09151}{\mathrm{s} + 0.001197} \qquad Eq.\ 1$$

Meanwhile, the accuracy of the model is 92.5% as shown in **Figure 1** and from the best fits percentage, it shows that the model posses high percentages of best fits thus indicated the model has high accuracy and sufficient to model the heating process of herb the drying system.

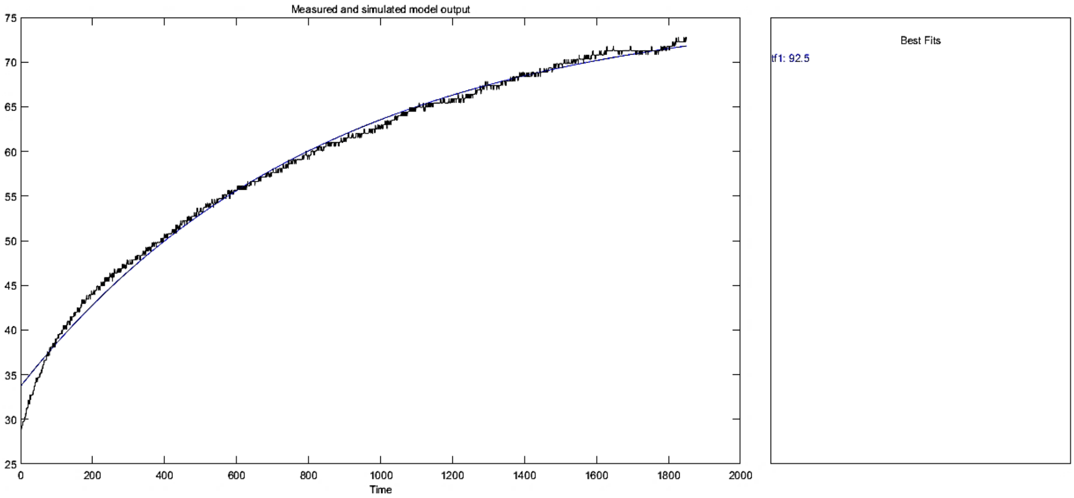

Figure 1: Best Fits accuracy graph

2.2 Linear Quadratic Regulator (LQR) Design

LQR is a method that provides optimally controlled feedback gains to enable the high-performance design of systems and make the closed-loop stable. LQR is divided into two main components which are the state-space equation and feedback gain, K. Based on a transfer function that has been obtained from system identification in *Eq.* 1, the value of gain which is A, B, C, and D can be obtained by using a command program in MATLAB. The value of gain K also was obtained using the MATLAB command of “lqr(A, B, Q, R) [5] where Q is a number of states and R is a value of inputs [6]. The block diagram of the LQR controller applied for this study is as in **Figure 2** . Meanwhile the system parameters and controller parameters that applied for this work are as tabulated in Table 1.

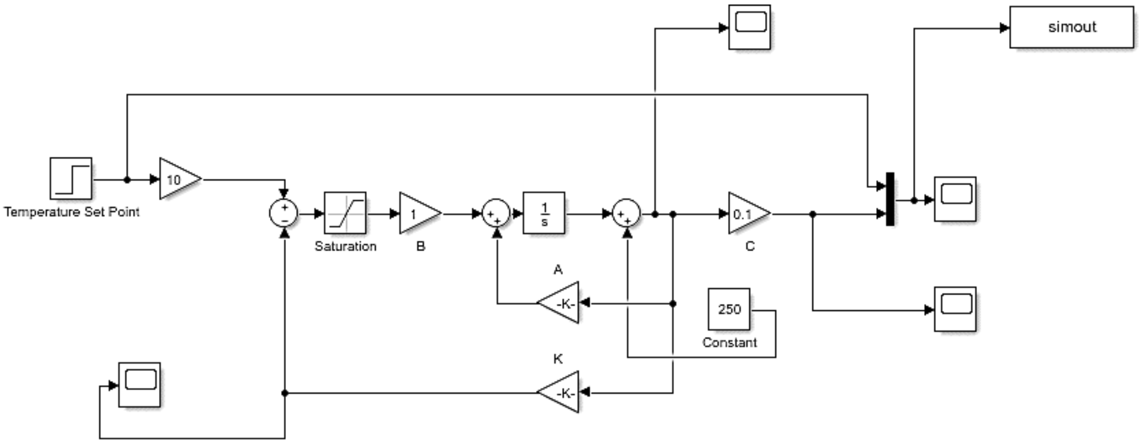

Figure 2: LQR design

Table 1: Parameter values of LQR block diagram

Item	Parameter	Value
1	Step (Temperature set point)	40℃
2	Gain A	-0.0012
3	Gain B	1
4	Gain C	0.1
5	Gain D	0
6	Gain K	0.9988
7	Saturation	Upper limit = 1 Lower limit = 0
8	Transfer function	$\frac{0.09151}{s+0.001197}$
9	Constant	250

2.3 Proportional Integral Derivative (PID) Design

PID controller is a controller that consists of the three-term controller which is Proportional, Integral, and Derivative. A PID has an operator which is a set point that can be set the desired temperature. There are three basic combinations of PID controllers that are usually used which is P, PI, and PID. The method that is used to tuning all of the parameters (P, PI, and PID) are by using an open loop or closed loop. The open-loop method is consists of Ziegler Nichols tuning rules and Cohen Coon tuning rules. This study is using the Ziegler Nichols Tuning formula to get the values of proportional gain (Kp) and integral time (Ti).

In order to obtain the value for Kp and Ti for this study, the transfer function for First Order Plus Dead Time (FOPDT) Model needs to be obtained. The formula of FOPDT can be defined as **Error! Reference source not found.**.

$$G(s)\ \frac{Ke^{-\theta s}}{\tau s+1} \qquad Eq.2$$

First Order Plus Dead Time (FOPDT) model is a method that is used to obtain the parameter's value of process gain (K), time delay (θ), and time constant (τ). The formula of FOPDT is shown in **Error! Reference source not found.**. From the formula of FOPDT **Error! Reference source not found.**, the value of PID parameters can be obtained. The formula of Proportional gain (Kp) can be defined as Eq. 2.

$$\mathrm{Kp} = \frac{1.2 \times \tau}{\mathrm{K} \times \theta} \qquad Eq.\ 2$$

where K is process gain, θ is a time delay, and τ is time constant.

Next, to obtain the integral time and the integral gain the formula can be defined as Eq. 3 and Eq. 4.

$$\mathrm{Ti} = 2 \times \theta \qquad Eq.\ 3$$

$$\mathrm{Ki} = \frac{\mathrm{Kp}}{\mathrm{Ti} \times \mathrm{s}} \qquad Eq.\ 4$$

Lastly, to obtained time delay and derivative gain, the formula can be referred in Eq. 5 and Eq. 6.

$$\mathrm{Td} = 0.5\theta \qquad Eq.\ 5$$

$$\mathrm{Kd} = \mathrm{KpTd} \qquad Eq.\ 6$$

Based on FOPDT model in **Error! Reference source not found.** [7], the parameters setup for the system and PID controller is as shown in Table 2 whereas **Figure 3** shows the PID block diagram applied for this work. In a constant block, the value of 25 is indicated as room temperature which means 25℃.

Table 2: Parameter values of PID block design

Item	Parameter	Value
1	Step (Temperature set point)	40℃
2	Proportional Gain, Kp	0.2264
3	Integral Gain, Ki	0.004528
4	Derivative Gain, Kd	2.83s
5	Time Delay, Td	25s
7	Saturation	Upper limit = 1 Lower limit = 0
8	Transfer function	$\frac{0.09151}{s + 0.001197}$
9	Constant	25℃

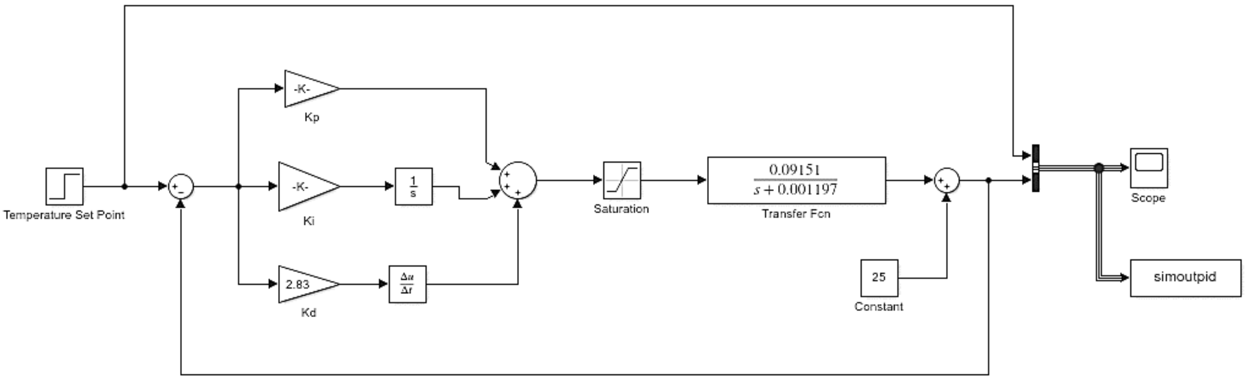

Figure 3: PID design

2.3 Controller Performance Analysis

In this work, the performance analysis of the controller is based on transient analysis namely settling time, rise time, peak time, and percentage overshoot. A detailed description of response analysis based on settling time, rise time, peak time, and percentage overshoot is shown in [8].

3. Results and Discussion

The section will discuss the results obtained from this study that are related to the comparative study between LQR controller and PID controller performance. The detail related to the comparative performance between both controller performance in regulating the temperature of the herb drying system is described in the following subsection.

3.1 Comparative between PID and LQR Response

Figure 4 shows the performance of the PID and LQR controller. The temperature started at 25 which indicated the room temperature which is 25°C. From the comparison between both of the controllers, it is clearly shown that LQR is more stable than the PID controller. The comparison of the transient response between PID and LQR controller can be referred to in Table 3. From the comparison that has been made in Table 3, in terms of time LQR is faster than PID controller with a difference of 52s for the rise time. In terms of settling time, PID produces 1380s and LQR shows the settling time in 244s. For the peak time, there is not much time difference between PID and LQR which the difference only 57s. Lastly, for the overshoot percentage, PID contained 24% of the overshoot while LQR does not show any overshoot. This actively demonstrates that LQR has a 0% overshoot.

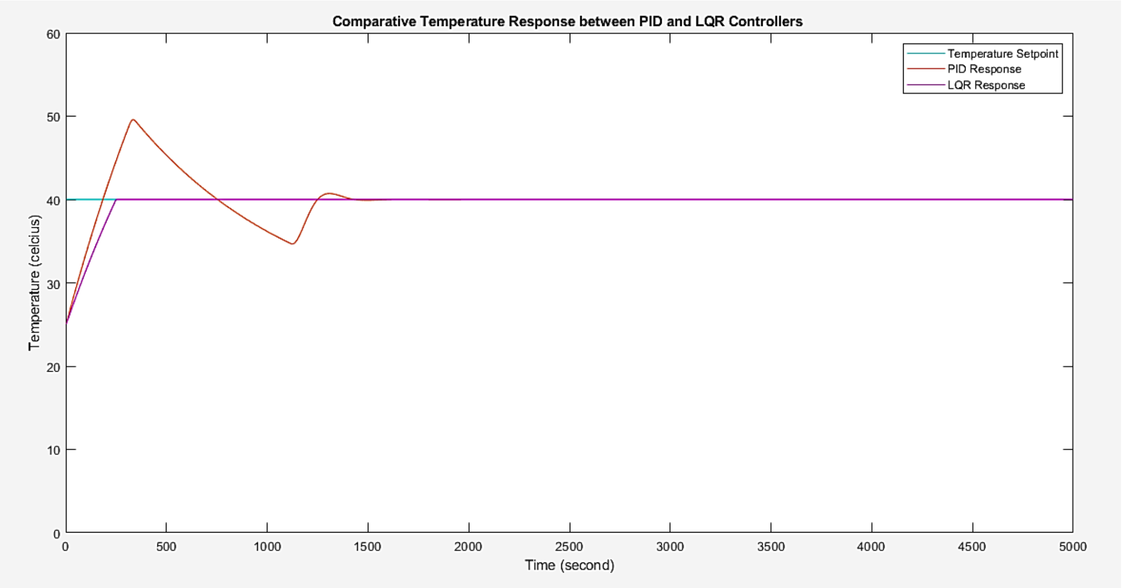

Figure 4: Comparative response of PID and LQR

Figure 5 shows the result of the response when the system undergoing a test called setpoint change. The purpose of setpoint change is to see if the temperature changed to another new temperature, the performance of the system will remain the same or not. As shown in **Figure 5**, the system had a test for two different temperatures which are 45°C and 55°C. With these two different temperatures, the response still in stable response, and no overshoot occurred same as the result in step response.

Table 3: Comparison between PID and LQR Transient Response

Item	Transient Response	PID	LQR
1	Rise Time, Tr	146s	198s
2	Settling Time, Ts	1380s	244s
3	Peak Time, Tp	335s	278s
4	Overshoot, %μ(s)	24%	0%

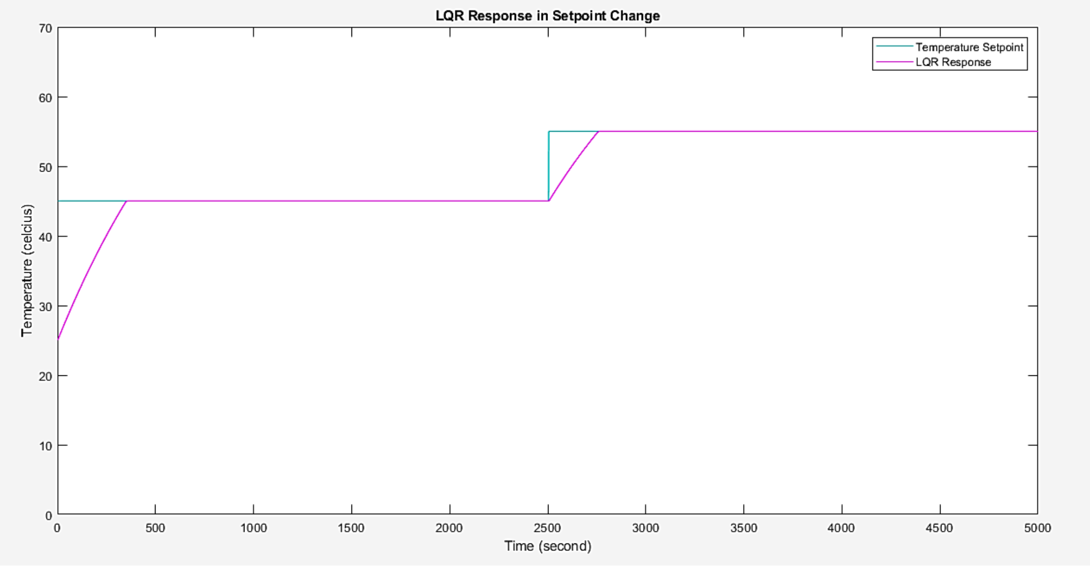

Figure 5: Setpoint change response

4. Conclusion

The study aims to improve the temperature regulation of the herb drying system using an LQR controller. The results clearly show that LQR provides better performance as compared with the PID controller particularly in preventing the response from overshoot and provide fast settling time. This indicated that LQR is one of the candidate controllers that capable to provide proper temperature regulation of solar herb drying towards increasing the overall effectiveness of herb drying processes.

Acknowledgement

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