Development of an automatic chili drying controller based on computer vision

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Abstract: Color of dried chilies is one of the most key factors that influences consumers' preference. It is mainly affected by the drying process. Traditionally, drying temperature is fixed during the drying process without regard to the quality of chilies being dried. Thus, the aim of this research is to develop a controller for the chili drying process that determines the drying temperature according to the change of chili color. To measure the chili color, we built a hot air tray dryer incorporated with a computer vision system which measures the chili color during drying. We converted the RGB color model to the L*a*b* color model and calculated the change of the a* component (Δa). If Δa within 15 minutes was less than 2, then, the drying temperature was set to 90°C for ten minutes and set back to 80°C, otherwise, it was set to 80°C. The experimental results showed that the drying time was shortened, compared to the 80°C drying temperature. The color of dried chilies was improved, compared to the 90°C drying temperature.

Keywords: dried chili color, image processing, drying control, closed-loop control

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1 Introduction

Drying is one of the most popular food preservation methods and it is value-added to agricultural products. The drying process is related to the moisture reduction in food which reduces the risk that micro-organisms will grow. Furthermore, it also stops the enzyme action or retard the chemical and bio-chemical reaction which incorporates with water, resulting in spoiled food. Furthermore, the drying process reduces the weight and the volume of the product, resulting in reduction of expense used for transport and store. In some special cases, drying leads to the by-products, e.g., easier consuming and better tastes.

The drying process is a complicated process since it is related to heat and mass transfer. During drying, products are changed in physical and chemical properties in a desired and undesired ways. In particular, dehydration and heat exposure during drying lead to the dramatic change of cell structure. The phenomenon creates the change in physical properties (e.g., shape and volume) and change in color and texture of the product. The change affects the preference of the consumers.

The drying process with high efficiency has to take the food quality after drying into account. The main quality indexes of dried food include rehydration, nutritional values, color, smell, taste, shape, etc. Furthermore, energy consumption is also of concern to

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operators. In general, a number of factors that affect the quality of products during drying are manipulated variables. For example, manipulated variables of the hot air tray dryer are the drying temperature, flow rate of hot air. If these values are set improperly, the quality of drying food may be worse dramatically. Thus, to maintain the best quality and to reduce the drying cost, researchers of the drying research community focus on experiments that find the optimal settings of those variables for such products. After that, these drying settings will be constant throughout the drying process. The idea of this scheme is called "open-loop control". Obviously, the final product quality is not guaranteed because characteristics and conditions of products during drying are not measured; thus, preset variable values may not be optimal any longer for the current conditions of the products. Besides, variable adjustments on the fly based on the current conditions of the product can also reduce the energy consumption of the drying process. For example, moisture contents in the fresh products are initially rather high. The energy requirements are high. When the drying process is running for a while, the moisture contents of the product decrease. If the open-loop drying controller is adopted, the energy applying to the process cannot be adjusted freely. On the other hand, the energy requirements, when the closed-loop controller is implemented, can be changed according to the current conditions of the product. That is, the change of the moisture contents decreases, the energy requirements can also decrease.

As mentioned above, to reduce the drying cost and increase the quality of the dried products, a closed-loop control scheme is an interesting and challenging idea. In the literature, a closed-loop controller for the drying process is still very rare. For example, Dufour et al. (2004) developed a model predictive control for the infrared drying process. During drying, the controller evaluated the optimal control output with given drying constraints. Abdel-Jabbar et al. (2005) designed a state observer to estimate the moisture content online for drying quality control. They also developed a linear model to describe drying behaviors in the fluidized bed dryer. Martynenko and Yang (2007) developed an intelligent control system for ginseng drying. They proposed a neural network model using color and texture of ginseng to estimate the moisture content of ginseng. The drying temperature was changed according to the estimated moisture content. Han et al. (2012) proposed a model predictive control for cereal drying considering drying constraints into account.

One of the main problems concerning this technique is how to measure the product quality online. The common solution is to use computer vision. The computer vision has been employed in a variety of food and agricultural research (Davies, 2009). For example, Hatamipour and Mowla (2002) studied the shrinkage of carrot during drying in an inert medium fluidized bed dryer. Ebrahimi et al. (2012) employed image processing techniques to measure the shape change of banana slice during drying. Khazaei et al. (2013) proposed a method based on the computer vision to evaluate the dried grape. They addressed the shrinkage and quality during drying. Di Scala et al. (2013) studied the effect of drying conditions to color, water holding capacity, and the amount of phenolic of apples. Huang et al. (2014) developed a regression model to estimate the color and moisture content of soybean during drying using a hyperspectral imaging technique. Amjad et al. (2015) assessed the effect of drying temperature homogeneity on color and shrinkage of potato slices by analyzing the captured images.

In our work, a computer vision system with an image processing algorithm is adopted to extract the quality information from the image of the chilies being dried. The controller takes this information to adjust the control input of the temperature controller. When the control input is changed, the manipulated variable of the dryer is also changed, resulting in change in chili properties. Based on this idea, the control input can be optimized to maintain the acceptable quality of the dried chilies, and to reduce the drying cost and the drying time.

The rest of the paper is structured as follows: in Section 2, the characteristics of the chilies were investigated before the experiment. Then, the tray dryer with the proposed two-loop control law was explained in details. Section 3 reported our results and discussion.

Finally, we concluded in Section 4.

2 Materials and methods

2.1 Characteristics of raw material

Freshly harvested chilies (*Capsicum annuum* c.v. Jinda) were purchased from a local market in Maha Sarakham province. Fully ripened chilies were purely red. They were cleaned, packed in plastic bags and stored in a refrigerator at 13°C for 2-3 days before the experiment.

2.2 The proposed drying control

Conventionally, sun drying is a cheap way to produce dried chilies. Chilies are exposed directly to sunlight. However, the sun drying method takes 3-5 days (depending on weather conditions) to get the desired moisture content (less than 13%wb). To reduce the drying time, one of the most common dryers is the hot air tray dryer, since it is not costly and it is simple.

In this work, we propose a novel control scheme consisting of two control loops as shown in Figure 1. The inner loop is the conventional temperature control, while the outer loop is the quality control loop. For the inner control loop, the temperature of the dryer was controlled by a proportional-integral-derivative (PID) temperature controller with silicon controlled rectifier (SCR) outputs being able to adjust the voltage output. The drying air was heated using an electric 5-kW heater. The temperature of the chamber was measured by a thermocouple type k. The air was flown to the drying chamber using a blower with a 1/2 HP induction motor. We built it with a drying chamber of 50×50×48 cm. The tray dryer fully functioned is shown in Figure 2(a).

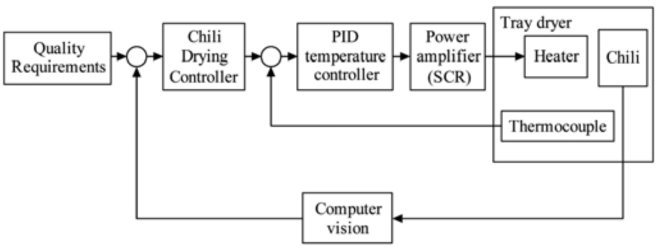
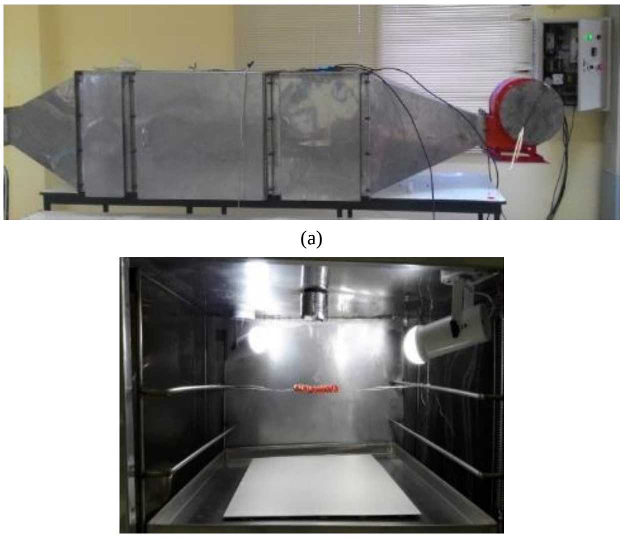


Figure 1 Diagram of two control loops for the drying process

For the outer control loop, the CMOS camera (Basler acA2400-14gm) with 6 mm lens was mounted on the top of the drying chamber to capture the image of chilies being dried. The lighting source consisted of two 7-Watt LED bulbs (see Figure 2(b)). The image processing algorithm was proposed to extract the quality information from the image. In this work, the quality information was the color change of the chilies. The outer controller determined the drying temperature of the dryer automatically using this information. Then, the drying temperature was sent to the inner loop.



(a)

(b)

Figure 2 (a) The fully functioned dryer (b) camera and lighting sources

Conventionally, to monitor the quality of the product being dried, a sampling method is adopted. That is the product is taken out of the drying chamber to be measured outside the dryer. In general, moisture contents, color and chemical properties are measured using laboratory instruments. Apparently, the sampling method is not practical and intervenes the drying process. On the other hand, in this work, computer vision has been used in the outer loop control to replace human inspectors. This technique is less time consuming and is non-destructive. It is also able to monitor the whole area of the products continuously. To implement the outer loop with the computer vision system, we used a Raspberry Pi single board computer for the whole drying process control. We installed the OpenCV library for image processing, the Pylon Library for camera interface, and the Qt framework for user interface as shown in Figure 3. The user interface program can control the dryer manually and automatically. Also, it can record the required information into the database, e.g., time, color values. It captures an image from the camera and processes the image based on the following image processing algorithm:

(1) Remove background noises and crop the region of

interest out of the original image;

(2) Extract the chili region from the background using the Otsu's method;

(3) Find the average RGB values of the chili region;

(4) Convert the average RGB color model to the L*a*b* color model;

(5) Calculate the change of the average a* component between two sampling time intervals.

Figure 3 User interface for our proposed drying control

As mentioned above, a few research projects address the drying controller. Thus, we proposed the following drying control scheme consisting of two control loops:

(1) Set the drying temperature to 90°C;

(2) Capture the image of chilies being dried in the chamber;

(3) Process the image based on the given image processing algorithm;

(4) Calculate the change of the a* component (Δa);

(5) Set the desired drying temperature as follows: If Δa is less than 2, then, the drying temperature is set to 90°C for ten minutes and set back to 80°C, otherwise, it is set to 80°C;

(6) Send the desired drying temperature to the PID temperature control via serial communication;

(7) Repeat step (2) at every 15 minutes until the desired moisture content is met.

The reason for setting such drying temperature is that, chilies contain high moisture contents at the beginning, thus drying temperature should be high. When the chili color is dramatically changed, the drying temperature should be decreased automatically. The change of the a* component (Δa) is considered a main criterion for determining the drying temperature since the a* component represents the green-red color.

3 Results and discussion

In the first experiment, the color and the moisture content of chilies being dried were measured when the drying temperature was set to 70°C, 80°C, and 90°C. In the second experiment, the proposed two control loop scheme using the result from the computer vision as a feedback of quality was evaluated.

3.1 Chili color and moisture content

The fresh chilies were taken from the refrigerator and were wired in a row as shown in Figure 3. The initial weight was recorded and color was measured by a hunter lab colorimeter. Then, they were held in the drying chamber. The drying temperature was set to 70°C, 80°C, and 90°C. The speed of the outlet air was 1 m s^{-1}. The chilies were taken out of the drying chamber at every 30 minutes to measure the weight and the color, repeated three times and the average was calculated. The image of the chilies was captured every five minutes. This experiment was repeated twice.

Figure 4 shows comparison of final results when the moisture content of chili was less than 13%wb. Apparently, the higher the drying temperature was, the shorter the drying time lasted, but the worse the color was obtained. We also found that although there was a different lighting condition, the a* components estimated by using the image processing algorithm and the a* component measured by the colorimeter were alike, but with some offsets.

3.2 A two-loop control scheme

In this experiment, the proposed control scheme was implemented to adjust the drying temperature during drying automatically. As seen in Figure 5 and Table 1, the proposed drying method shortened the drying time, compared to the results when the drying temperature was set to 80ºC. The change of the a* component was less than the case that the drying temperature was set to 90ºC. Moreover, during the drying process, we found that the drying temperature was switched to 90ºC three times, i.e., at the drying time of 90, 150, and 195 minutes. Apparently, our proposed drying method can compromise between the drying time and the color change by changing the drying temperature automatically.

(a) 70ºC

(b) 80ºC

(c) 90ºC

Figure 4 Comparison between the fresh chilies before experiment and dried chilies when the drying temperature was (a) 70ºC, (b) 80ºC, and (c) 90ºC

(a) (b)

Figure 5 (a) Fresh chilies before experiment and (b) dried chilies after experiment using our proposed drying method

Table 1 Conventional drying method vs. proposed drying method

Drying Temperature (ºC)	Initial Moisture Content **(%** wb)	Δa	Drying Time
70	73.8 +/- 0.58	14.83 +/- 1.16	7 hrs 00 mins
80	75.7 +/- 0.74	14.77 +/- 1.66	4 hrs 30 mins
90	74.7 +/- 1.03	20.15 +/- 1.76	3 hrs 30 mins
Proposed method	77.3 +/- 0.82	14.94 +/- 1.47	3 hrs 45 mins

4 Conclusions

The proposed drying control scheme consists of two loops. The inner loop is the PID temperature control which is commonly used in the conventional drying methods. The main contribution of this work is the outer loop which uses the quality information as a feedback to the controller and then the control output is adjusted according to that quality information. In this work as a case study, the chosen material was chili and the drying method was the tray dryer since it is simple, cheap, and one of the most common dryers. The quality information addressed in this work was the change of the color. It was extracted from the captured image using the image processing algorithm. As seen in the experimental results, the color of the dried chilies was improved and the drying time was shortened when our proposed drying controller was employed.

In the future, we would like to develop a smart drying controller which considers more factors, e.g., the shrinkage of the chilies being dried and the speed of the hot air in the chamber.

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