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An optical automatic measurement method for the moisture content of rough rice using image processing techniques

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ABSTRACT

This study proposed an automatic measurement method for the moisture content of rough rice using image processing techniques. Under a fixed hot air temperature and humidity, this measurement method uses drying time as a variable. After the rough rice with stalks is placed in the rough rice test carrier, an image acquisition system is used to set the multiple thresholds for the color histograms of the images. Based on the distribution of the colors, the stalk images are separated from the rough rice images, and edge enhancement and shape detection are applied to more accurately acquire specific detected areas from the image. Finally, the moisture content of rough rice can be determined according to the specific colors of the stalks. This study also explored the impact of the dynamic equilibrium moisture content on the drying of rice, rendering it more consistent with the actual drying behavior. The experimental results were compared with the results of other measurement methods for correction, in order to achieve real-time measurement and analysis of the batch re-circulating rice drying process.

1. Introduction

In batch re-circulating rice drying, the grain is dried in an intermittent pattern. Many drying, heating, and analytical methods have been proposed (Tiwari et al., 2011; Moongngarm and Saetung, 2010), including the intermittent drying method (divided into early and late drying stages), and the re-circulating rice dryer method. These drying methods require considerable resources and time at the experimental stage. Therefore, a set of simple measurement devices for the moisture content of rough rice is important (Kawamura et al., 2003).

In order to save time and cost, electronic measurement of moisture content has been widely applied. However, whether capacitive or resistive, there remains a gap between the measurement and the actual value (Chen, 2008), and the gap expands along with increasing moisture content. Although this type of moisture content measurement devices has the advantage of short testing time, its accuracy in high humidity remains unsatisfactory, and the complex measurement process makes the verification process difficult. Meanwhile, for different devices of the same model, there are instrumental errors. As a result, further studies on automatic measurement of the moisture content of rough rice are necessary.

This study aimed to establish an optical automatic measurement model, using drying times as the variable and under a fixed hot air temperature and humidity. An automatic rice-drying device is consisted of a vibrator, a heater, a test carrier, a tank, and fans; while a testing device is composed of CCD, a light source, and a personal computer (Yadav and Jindal, 2001), as shown in Fig. 1. Rough rice with stocks is placed in a rough rice carrier, and an image acquiring system is used to determine the moisture content of rough rice according to the specific colors of the stalks. This study also discussed the impact of the dynamic equilibrium moisture content on the drying of rough rice, so as to render it more consistent with the actual drying behavior. Meanwhile, this study compared the experimental results with other measurement methods to achieve an accurate, real time measurement analysis of overall rice drying.

2. Relevant mathematical theory

2.1. Rice drying simulation model

Partial differentiation model has been established for rice drying simulation (Zare and Chen, 2009). The equilibrium moisture content in the model can be directly calculated from the drying data of the experiment. However, the calculated value is often higher than the recognized value of the equilibrium moisture content under the conditions of dry air temperature and relative humidity. This is because the calculated value is obtained under changing hot air conditions. The grain drying process is similar to the principle of Newton's law for cooling, where the drying rate

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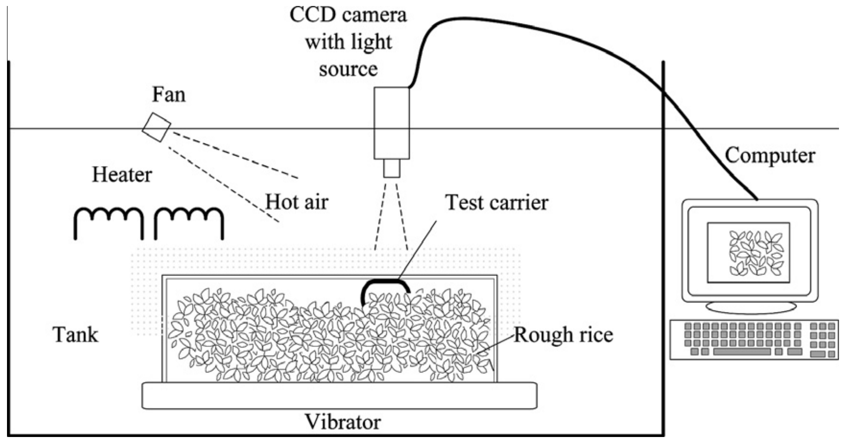

Fig. 1. The rice dryer and inspection device for the rough rice.

is proportional to the difference between moisture content and equilibrium moisture content (Othman et al., 2006), namely,

$$\frac{dM}{dt} = -k(M - M_e) \tag{1}$$

Taking the integral of the above equation can result in a solution similar to Newman's law (Newman, 1931), where an exponential model, expressed by the following equation, is obtained to describe the drying characteristics of rough rice (Cao et al., 2004):

$$MR = \frac{M - M_e}{M_o - M_e} = Ae^{-kt} \tag{2}$$

where A, k is the drying constant, M_o is the initial moisture content of the rough rice, M_e is the equilibrium moisture content, M is the instantaneous moisture content, and t is the drying time.

During the drying process, the moisture content of the central area of the grain is much higher than the surface of the rough rice. The M of the above equation is obtained by calculating the weight after drying in an oven, and is the overall average moisture content; M_e is obtained according to the equation of the equilibrium moisture content, and not the dynamic equilibrium moisture content.

As the value of the dynamic equilibrium moisture content is larger than the static equilibrium moisture content, the accumulated results of the value added method during the simulation process will affect the drying results. The establishment of the dynamic equilibrium moisture content model is based on Newton's law of cooling to deduce a Newman-like equation. The moisture loss rate is proportional to the difference between grain moisture content and equilibrium moisture content (Pabis and Henderson, 1961), as expressed below.

$$\frac{dM}{dt} = -k(M - M_e) \tag{3}$$

The logarithm of the above equation from the integral results in:

$$\ln\left(\frac{M - M_e}{M_o - M_e}\right) = \ln A - kt \tag{4}$$

When $t = t_1$, the above equation is

$$\ln\left(\frac{M_1 - M_e}{M_o - M_e}\right) = \ln A - kt_1 \tag{5}$$

M_1 is the moisture content when $t = t_1$.

When $t = t_2$, it becomes

$$\ln\left(\frac{M_2 - M_e}{M_o - M_e}\right) = \ln A - k(t_2 - t_1) \tag{6}$$

M_2 is the moisture content when $t = t_2$.

When $t = t_3$, it becomes

$$\ln\left(\frac{M_3 - M_e}{M_o - M_e}\right) = \ln A - k(t_3 - t_2) \tag{7}$$

M_3 is the moisture content when $t = t_3$.

When the intervals of the drying time are the same, namely, $\Delta t = t_1 = (t_2 - t_1) = (t_3 - t_2)$, the above three equations are summarized as:

$$\ln\left(\frac{M_1 - M_e}{M_2 - M_e}\right) = \ln\left(\frac{M_2 - M_e}{M_3 - M_e}\right) \tag{8}$$

where

$$M_e = \frac{M_2^2 - M_1 M_3}{2M_2 - M_1 - M_3} \tag{9}$$

Using hot air temperature, hot air humidity, drying time, and median time as variables, this study obtains the dynamic equilibrium moisture content model of rough rice, in cases of intermittent drying by the value method and the statistical regression approach:

$$M_e = \frac{M_i^2 - M_{i-1} M_{i+1}}{2M_i - M_{i-1} - M_{i+1}} \tag{10}$$

2.2. Segmentation of stalks in rough rice image

Small spots may randomly appear in the background pixel areas of the actual images, which may affect the average value of the background strength (Kindi and Shirinzadeh, 2007). In order to remove the randomly distributed noise, this study used a 2×2 median filtering mask to filter noise. By making the image noise more moderate and removing high frequency noise, the filter can reduce the noise energy by four times; however, image sharpness is also reduced. The main purpose is to inhibit non-random noise, while maintaining the moderately high frequency characteristics of the images (Lin et al., 2008).

If, $f(x,y)$ contains non-random noise $n(x,y)$, then

$$f(x,y) = f'(x,y) + n(x,y) \tag{11}$$

where $f'(x,y)$ is the image before interruption, the following equation is obtained after median filtering:

$$g(x,y) = \frac{1}{4}\sum_{k=0}^{1}\sum_{l=0}^{1} f'(x-k, y-l) + \frac{1}{4}\sum_{k=0}^{1}\sum_{l=0}^{1} n(x-k, y-l) \tag{12}$$

where $g(x,y)$ is the image after filtering.

Color segmentation is to judge all colors in the image and acquire specific colors. The basic method is to implement a