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A novel integrated system for real-time monitoring of tobacco leaf images in the bulk curing barn

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Abstract— **Curing is the key stage to determine the quality and economic benefits of tobacco leaves, which directly determines the income of tobacco farmers and the quality of cigarette raw materials. Proper control of temperature and humidity based on the condition of tobacco leaves plays a decisive role during the curing process. However, the exiting researched are mainly focused on the monitor of temperature and humidity due to high temperature, high humidity and pure black environment in bulk curing barn. Here we designed a novel integrated system for real-time monitoring of tobacco leaf images, temperature and humidity during curing process. TEC semiconductor cooling module, fill light and corrosion-resistant sensor housing were designed in hardware and an image color optimization algorithm was embedded in software. A control experiment was conducted using the image sensor before improved to validate the availability and feasibility of the novel integrated system. The results showed that the novel system was feasible to acquire the real-time and high quality images of tobacco leaves during the whole curing process, and the ΔE of the images decreased from 20 to 10 when the novel integrated system was applied. These results proved that the novel integrated system developed in this study was able to monitor the images, temperature and humidity during whole curing process, which has distinct advantages and potential application in the future of tobacco production.**

I. INTRODUCTION

As a typical crop, tobacco is one of the main economic crops in agricultural areas of countries such as Brazil, China and India[1]. Different from staple crops such as corn and wheat, tobacco leaves are used as products. After harvest, it is necessary for the experience of dehydration of fresh tobacco leaves before they turned into commodities. The curing process of tobacco leaves is a controlled dehydration process characterized by well-defined stages of temperature and humidity[2]. Curing is the key stage to determine the quality and economic benefits of tobacco leaves, which directly determines the income of tobacco farmers and the quality of cigarette raw materials [3].

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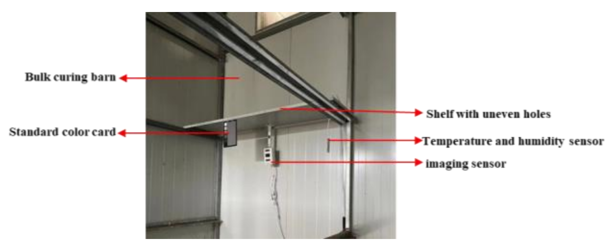
Monitoring in the curing process is mainly divided into two stages: (i) temperature and humidity monitoring in the bulk curing barn and (ii) tobacco condition monitoring indicated by images. The temperature and humidity monitoring has been applied widely in the curing process, and series of predicted algorithm were used to obtain the variations of temperature and humidity [4]. The control of temperature and humidity according to the actual and real-time curing conditions of the tobacco leaves during the curing process, especially the color and moisture content [5]. Therefore, researches focused on the tobacco images and recognition algorithms were appeared using different devices and deep learning models [5-8]. But due to the problems of high temperature, high humidity and dark environment in curing process, image distortion, out of focus, obvious color difference and only partial tobacco image acquisition are still the core problems limiting the acquisition of tobacco condition information. Therefore, it is urgent to develop new measurement techniques and devices to monitor the tobacco images during curing process. The primary objectives of this study are to (i) develop a novel integrated system for real-time monitoring of tobacco leaf images in the bulk curing barn from hardware and software, (ii) validate the availability of the novel integrated system with the image sensor before improved.

II. MATH

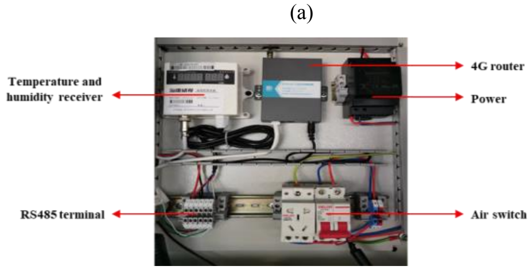
A. Design, measurement principle and main function of the novel integrated system

The novel integrated system was designed with an imaging sensor, a temperature and humidity sensor, a shelf with uneven holes and a distribution control box (Fig. 1). The imaging sensor consists of three functional modules to realize image monitoring of tobacco leaves under high temperature and high humidity environment in the bulk curing barn, including (i) TEC semiconductor cooling module, which is used to cool key components in the imaging sensor; (ii) fill light, which is used to ensure the stable fill light in the dark environment in the bulk curing barn; (iii) corrosion-resistant sensor housing, a desiccant is added inside it to absorb the water vapor entering the camera, so that the ambient humidity inside the camera is kept below 10%. The principle of the TEC semiconductor cooling module is a heat transfer tool, when the direct current flows through two groups of semiconductor materials composed of electric couples, one end of the heat absorption, the other end of the heat release, achieved the purpose of cooling the target device. When the temperature inside the bulk curing barn gradually rises (range: about 30~70°C), the cold end of the TEC semiconductor refrigeration module cools the key components of the imaging sensor to ensure its stable and normal operation. There are two fill light lamps in the image sensor, the fill light mode is hyperboloid transmission. The fill light intensity showed as a batwing distribution, with low light intensity in center and high light intensity in the edge. Therefore, in the pure black environment of the bulk curing barn, when the fill light shines on the surface of the tobacco leaves, it can make up for the defect of weak light at the edge, so that the light distribution forms a rectangular distribution that fits the angle of view. The color temperature of the fill light is set to 5700k, which is close to the natural light spectrum, and the color gain is appropriate and the color recovery is high. In addition, in order to avoid the temperature effect of the sensor, the black level in the image sensor is linked to the temperature to ensure that the color does not drift.

The temperature and humidity sensor is cylindrical and has a corrosion-resistant metal shell, which is used to long-term monitoring the variations of temperature and humidity during curing process and tagged on the images obtained using the imaging sensor. The shelf with uneven holes (length: 1.38m, width: 0.35m) is designed for airflow movement to reduce the impact of the installation of the novel integrated system on the tobacco curing quality.



(a)



(b)

Figure 1. Photo of (a) sensors and (b) distribution control box of the novel integrated system.

B. *Image color optimization algorithm*

An image color optimization algorithm was embedded in the imaging sensor to improve the effect of high temperature during tobacco curing on the image color temperature. The image color optimization algorithm is conducted as follows. At first, the raw data of the color card and its corresponding RGB value are obtained when the fill light is turned on. According to the color verification matrix，

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} a_1 & a_2 & a_3 \\ a_4 & a_5 & a_6 \\ a_7 & a_8 & a_9 \end{bmatrix} \begin{bmatrix} R' \\ G' \\ B' \end{bmatrix}$$

where R, G, and B are the standard RGB values for each color block of the standard 24 color card, R', G', and B' are the RGB values for each color block taken by the imaging sensor described above, a_1, a_2, …, a_9 are the optimal parameters in weighted color check matrix. And then, The mapping relationship between the RGB value of each color block of the color card and the corresponding standard RGB value of the color block is established. The weights of color blocks yellow, green and yellow-green were increased as 10 while other colors were set as 1, and the optimal parameters of weighted color check matrix were obtained by using weighted least square method. Finally, the weighted color verification matrix was applied to the tobacco leaf image to realize the color optimization of tobacco leaf image.

C. *Experiment procedure*

The novel integrated system was installed as Fig.2, where the imaging sensor was about 0.33m away from the tobacco leaves. It should be noted that the distance between the image sensor and the tobacco leaves changed with the increase of curing time, and the distance is 0.33m at the end of curing. The temperature and humidity probe was installed at a distance of 8~12cm from the leaf tip in the bulk curing barns. The control test was carried out using the image sensor before improved, and the installation position and method were the same.

The color of tobacco changed with the temperature and humidity in the bulk curing barns. The curing process lasted 7~8 days and the tobacco leaves experienced three stages according to the following guidelines and had been made a little improvement as shown in Table 1 [9]. The collection interval of images, temperature and humidity were set to 10 minutes. The system upload the collected information images marked with time, location, temperature and humidity information to the cloud platform.

TABLE I. THE APPROXIMATELY CONTROL CONDITIONS FOR THE CURING PROCESS IN A BULK CURING BARN

Stages	**Temperature (°C)**	**Humidity (%)**	**Time (h)**

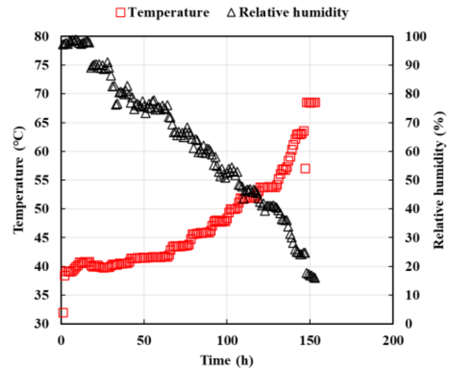
Yellowing	30 to 42	>88	≈60
Color fixing	42 to 54	>55	≈96
Stem drying	54 to 70	>20	≈30

Figure 2. The inside view of the installation of the novel integrated system in bulk curing barn.

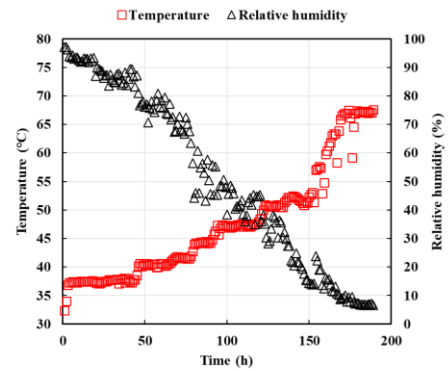
III. RESULTS AND DISCUSSION

A. Variations of temperature and humidity during curing processes

The optimal control of temperature and humidity during curing is the key to the quality of flue-cured tobacco, the changes of temperature and humidity during curing processes in this study were showed in Fig.3. The temperature monitored by the image sensor before improved was changed from 32°C to 68.6°C, and which was monitored by the novel integrated system was varied from 32.4°C to 67.6°C. There was a slight difference in the curing time, and this may attribute to the difference quality of the fresh tobacco leaves. Therefore, the two curing processes generally showed similar trends and temperature ranges.



(a)

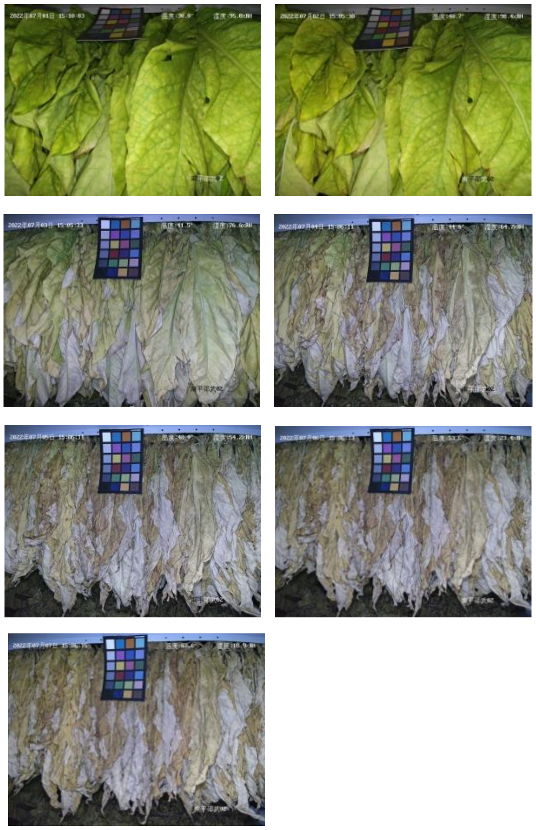


(b)

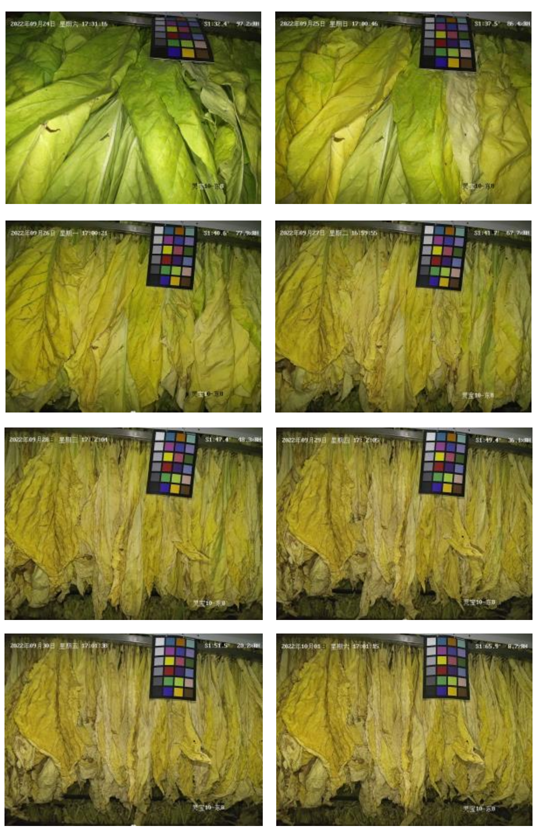
Figure 3. Variations of temperature (red hollow square) and relative humidity (black hollow triangle) monitored by (a) the image sensor before improved and (b) the novel integrated system during curing processes.

B. Comparison of the obtained images during curing processes

The images obtained by the image sensor before improved and the novel integrated system were showed in Fig.4. The quality of the images obtained by the image sensor before improved indicated a noticeable decrease when the temperature increased to 40°C, the color temperature was significantly cooler. The novel integrated system showed a stable performance throughout the curing process with high picture quality. Therefore, it was proved that the novel system was feasible to acquire the real-time tobacco leaves in the high temperature, high humidity and pure black environment in bulk curing barn.



(a)



(b)

Figure 4. Comparison of the images obtained by (a) the image sensor before improved and (b) the novel integrated system during curing processes.

C. Comparison of the chromatic aberration (ΔE) during curing processes

Sufficient moisture in the early stage of curing result in the close distance between the tobacco leaves and the image sensor. To avoid the influence of irregular pictures on the ΔE, the analysis of the ΔE will be started from 38°C. As showed in Fig.5, the ΔE of the images showed similar trends and changed with temperature during two curing processes. The ΔE of the images obtained by the image sensor before improved were significantly higher than that obtained by the novel integrated system. When the temperature reached to 40°C, the ΔE of the images obtained by the image sensor before improved gradually stabilized around 20, while it stabilized around 10 using the novel integrated system. In the different stages during curing process, the average temperature of the two baking processes was at the same level. However, the average ΔE and standard error of the images obtained by the image sensor before improved were higher than the novel integrated system (Tab.2). Therefore, the images obtained by the novel integrated system were not only less ΔE, but also more stable.

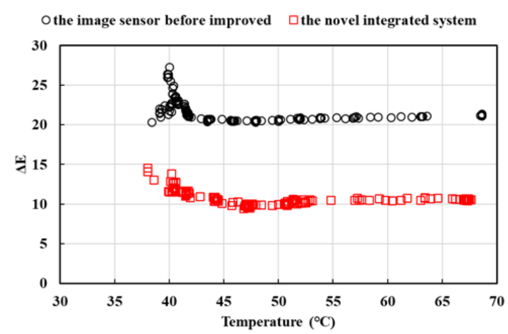


Figure 5. Comparison of the ΔE between the image sensor before improved (black hollow circle) and the novel integrated system (red hollow square) during curing processes.

TABLE II. THE ERROR ANALYSIS OF THE THREE STAGES DURING CURING PROCESSES

Device	Stages	Average temperature (°C)	Average ΔE	Standard error
The image sensor before improved	Yellowing	40.7	22.7	1.553
	Color fixing	48.7	20.7	0.162
	Stem drying	62.0	21.1	0.154
The novel	Yellowing	40.6	12.0	0.871

integrated system	Color fixing	48.5	10.0	0.340
	Stem drying	63.6	10.6	0.106

IV. CONCLUSION

In this study, we developed a novel integrated system that simultaneously monitored real-time tobacco leaf images, temperature and humidity in the bulk curing barn. On the one hand, TEC semiconductor cooling module, fill light and corrosion-resistant sensor housing were designed to ensure the stability of image acquisition. On the other hand, an image color optimization algorithm was embedded in the imaging sensor to improve the effect of high temperature during tobacco curing on the image color temperature. In order to validate the feasibility of the novel integrated system, the comparative curing experiments were carried out. The results showed that the images quality of the the image sensor before improved significantly dropped when the temperature was above 40°C, the novel system was feasible to acquire the real-time and high quality images of tobacco leaves during the whole curing process. The ΔE of the images decreased from 20 to 10 when the the novel integrated system was applied. Therefore, the novel integrated system developed in this study was able to monitor the images, temperature and humidity in the high temperature, high humidity and pure black environment in bulk curing barn. Further researches would focus on the intelligent recognition algorithms and intelligent control based on the images monitored by the novel integrated system.

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