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Research Article

Intelligent Tobacco Curing Control Based on Color Recognition

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Abstract: To reduce the labor cost and the workload required in the tobacco curing process, an intelligent tobacco curing control technique adopting color identification of the tobacco leaves is proposed. The HSI color space is used in color segmentation and the color recognition with fuzzy decision is used in the curing process. The curing controller can identify the curing stage by the color features of the tobacco leaves and the environmental parameters of the barn. Then it adjusts the temperature, the humidity and the ventilation of the barn to prevent the leaves from bad colors. The controller can be used for various tobacco species and various mature states and harvesting weather. The intelligent control can reduce the workload and labor cost involved in the curing process and guarantee the quality and market value of the cured tobacco.

Keywords: Color recognition, image process, intelligent control, tobacco curing barn

INTRODUCTION

Tobacco curing is an important process for the flue cured tobacco production system. The quality of the cured tobacco leaves is subject to control process of the temperature and humidity in the curing barn. To get high quality and reduce the production costs, automatic control facilities are used to the curing process and many types of automatic controllers are currently available. In China, the bulk curing barns are adopted in the tobacco production. The structure and the controllers of the bulk curing barns are standardized by the State Tobacco Monopoly Bureau of China (Chen *et al*., 2009). The applications of the bulk curing barns improve the production efficiency and increase the tobacco farmers' incomes. However, the recent controllers for the bulk curing barns are labor dependent. Especially when the tobacco leaves to be cured are harvested in various maturity degrees and in various weathers, the required control process of the temperature and humidity in the curing barns varies. And various species of the tobacco leaves need various curing process. The controllers for the bulk curing barns can only control the temperature and humidity by the presetting curing phases. It cannot identify the features of the tobacco leaves to be cured and adaptively control the curing process. As a result, some curing specialists must be present to tutor the control process. That increases the workload and the labor cost for tobacco curing and the quality of the cured tobacco is subject to the specialists' experiences (Larry, 2008). As the labor cost increasing, it is essential to reduce the labor and the workload required in the curing process, reduce the fuel consumption and increase the benefits of the tobacco production.

To improve the automation level in tobacco curing process, many researchers have been done on the chemical process of the tobacco leaves in the curing process and the intelligent control and fuzzy control technologies are developed for automatically control the curing process (Ihosvany *et al*., 2005; Zhao *et al*., 2006; Ma *et al*., 2007; Liu *et al*., 2009; Kang, 2009). Relative to the tobacco chemical quality, color has a more influence on cured tobacco market value. To some extent, a clear yellow to orange color has been considered as an indicator of quality. And the greenish and dark leaves are considered tin pot. Practically, as a uniform yellow color with absence of chlorophyll assures the buyer that curing was not grossly mismanaged. Therefore, most of the tobacco curing specialists controls the temperature and the humidity of the curing barns just according to the color appearance of the curing tobacco leaves. In this study, a new intelligent control technique which adopts color identification of the tobacco leaves is proposed. The controller can identify the stages of the curing process by the color features of the tobacco leaves and the environmental parameters of the barn. Then it adjusts the temperature, the humidity and the ventilation of the barn to prevent the leaves to bad colors. The control technique can be used for various tobacco species and various maturity states and harvesting weather. The

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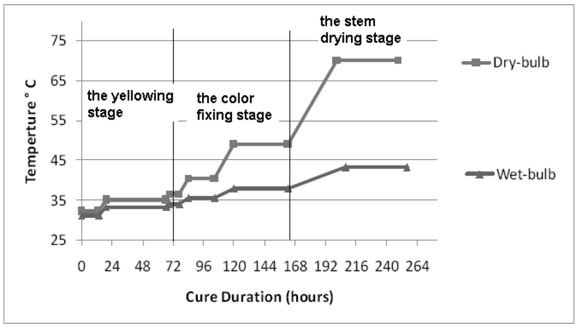

Fig. 1: The curing stages in the curing process

intelligent control can be used to reduce the workload and labor cost of the curing process and guarantee the quality and market value of the cured tobacco.

THE CONTROL PROCESS OF THE CURING BARN

The curing process: As is known, a proper tobacco curing process is both a chemical and a drying process (Deng *et al*., 2005). The curing process involves controlling the barn humidity and temperature by adjusting the temperature settings and fresh air intake. The curing process starts with a high relative humidity of approximately 85% or higher (Maw and Paul, 1986). Controlling the physiological processes during curing promotes the chemical conversions within the tobacco leaf. The barn temperature is gradually increased from 38 to 69°C, to remove the moisture from the leaf at a controlled rate.

The common tobacco curing process can be divided to three stages: the yellowing stage, the color fixing stage and the stem drying stage. The needs of the environmental parameters in the barn for each stage are showed in Fig. 1.

The control process of the curing barn: A common curing barn is comprised of an oven, a distributor, several motors and windows, which are used to keep the environmental parameters in the barn. The primary function of the controller is to maintain or adjust the temperature and humidity of the curing barn according to the specific curing stage:

- **The yellowing stage:** When the tobacco leaves are filled into the barn, the windows for ventilation are closed. After the oven is fired, the curing stage is the yellowing stage. In this stage, one important process is the conversion of starches to sugars (Tso, 1990). Controlling the curing environment is critical to maintaining the desired leaf quality. Commonly, the temperature in the curing barn should be raised from 34 to 38°C in the rate of 1°C per hour (the range of the temperature in this stage is subject to the area where the tobacco lives, for instance, 34 to 35°C in south-west and southern China, 35 to 36°C in north-east China and 36 to 38°C in north-east China). As in the current control systems, two temperature sensors named the wet-bulb temperature and the dry-bulb temperature are adopted. And the wet-bulb temperature should be kept 1 to 2.5°C, respectively lower than the dry-bulb temperature in this stage, till the color of the tobacco leaf is turning pure yellow and the stem of the leaf is green to white and the leaf turns soft enough.
- **The color fixing stage:** During the color fixing stage, the goal is to fix the yellow color of the tobacco leaves by rapidly removing moisture from the leaves by increasing the ventilation in the barn. The windows for ventilation are opened to remove moisture. The dry-bulb temperature in the curing barn is gradually raised from 38 to 55°C in the speed of 0.3 to 0.5°C/h. And the wet-bulb temperature should be raised and kept around 37 to 41°C, respectively. If the moisture in the tobacco leaves is heavy, the wet-bulb temperature should be kept lower. Elsewize, the wet-bulb temperature should be kept in a higher level. To avoid scalding which damages the leaf, the dry-bulb temperature should not be raised too high too quickly.
- **The stem drying stage:** As in the former stage, the leaf is already dried. In the stem drying stage, the dry-bulb temperature is gradually raised to around 67 to 69°C. And the wet-bulb temperature is kept lower than 43°C. As over ventilating during these stage not only dries the leaf too fast but also wastes heat, the windows for ventilation should be closed gradually meanwhile. The temperature and humidity should be kept till the stem of the tobacco leaf is dried enough. Once completely dried to zero percent moisture, a small amount of moisture is added back to the cured leaf which allows the leaf to be handled for market preparation.

Typically eighty to eighty five percent of the tobacco leaf composition is moisture, which must be removed during the curing process. Approximately it costs 5 to 9 days for a whole curing process.

However, when the tobacco leaves to be cured are harvested in various maturity degrees and in various weathers, the required control process of the temperature and humidity in the curing barns varies. And various species of the tobacco leaves need various curing process. The control process cannot be done automatically for high quality. The quality of the cured tobacco is subject to the operator’s experience. For instance, curing specialists are hired in China for tutor the curing process. In curing process, they manually control the oven and the windows for ventilation to adjust the temperature and humidity of the barn and the raising rates of the parameters. It is labor dependent and as a result, the quality of the cured production is subject to the experiences of the specialists. As in fact, in the long-term curing process (above 120 h), the specialist may make mistakes in monitoring the curing states, which cause the wrong temperature and humidity of the barn and result in a lower quality.

COLOR RECOGNITION

Color space: To describe the real colors in a mathematical model, the colors are typically represented as three or four values or color components (Androutsos *et al*., 1999). The numerical representation of color needed for image processing is called color space or color model. There are many color spaces to describe the colors, each of which has advantages and disadvantages to be used by the specific requirements and characters of the application. The color spaces used most often in color recognition are RGB (Red, Green and Blue), HSV (Hue, Saturation and Value), TSL (Tint, Saturation and Lightness) and YcrCb (Luma, R chrominance and B chrominance). The ideal color model in color recognition point of view should simulate some characters of human visual system, such as: non-linear sensitivity to visible light with different wavelength and weak dependence on the intensity of light.

As the RGB color space is widely used in supporting hardware, the color information is often obtained directly from the photo cameras, usually is in RGB format. However, it is unnatural for humans. The main drawback of RGB color space is the high degree of correlation of information from color channels. The RGB model does not allow the separation of color from intensity. The HS based color spaces (HSV, HSB, HSI and HSL) correspond better to how people experience colors than the RGB color space used: Hue (H) is a color attribute that describes what a pure color is, H values vary from 0 to 1 (from red through orange, yellow, green, cyan, blue, magenta and back to red); Saturation (S) values vary from 0 to 1 and corresponding colors vary from unsaturated to fully saturated. An advantage of both models is that the brightness or intensity component is separated from the color information, which is represented by the hue and saturation components.

There are other color models that attempt to simulate more accurately human vision system, such as: CIELAB, CIEXYZ and CIELUV. However, experiments show that their use does not improve the characteristics of color recognition systems.

The HSI space classifies similar colors under similar hue orientations. Hue is particularly important, since it represents color in a manner which is proven to imitate human color recognition and recall. The transformation of RGB space to HSI space can be achieved by the following equations (Lidiya *et al*., 2005):

$$H=\begin{cases}\arccos\dfrac{(R-G)+(R-B)}{2\sqrt{(R-G)^2+(R-B)(G-B)}} & R\neq G \text{ or } R\neq B\\[2ex] 2\pi-\arccos\dfrac{(R-G)+(R-B)}{2\sqrt{(R-G)^2+(R-B)(G-B)}} & B>G\end{cases} \tag{1}$$

$$S=1-\frac{3}{(R+G+B)}\min(R,G,B) \tag{2}$$

$$I=(R+G+B)/3 \tag{3}$$

where, R, G and B are the red, green and blue component values which exist in the range (0, 255).

Color recognition: To identify the color of an object, some preprocessing of the image is needed and the color features are extracted. In some documents, color features of tobacco leaves are obtained by using Region Growing Method in the pre-processing and region classification is done by using Support Vector Machine (SVM) (Pan *et al*., 2012). As a fact that the tobacco leaves may crinkle in the curing process, the wrinkles and the stem of the leaf can not be used to identify the color of the leaf. In this study, a fuzzy-based algorithm for color recognition is proposed as follows (Kuan-Yu *et al*., 2010; Wang *et al*., 2008):

- **Color segmentation:** Color segmentation is implemented on the basis of the values of parameters H, S and I. The segmentation starts with checking whether the color is white, black or gray which is determined by the I and S components. If $I>I_w$, then the color is white and if $I>I_b$, then the color is black. And if $S<S_g$, the color is gray. If $S>S_g$, the color segmentation is realized based on the values of H component and ten color classes can be recognized: red, orange, yellow, green, cyan, blue and magenta, white, gray and black (Ivanov, 2007).
- **Color recognition:** Firstly, the HSI color space parameters (H, S, I) are calculated for each pixels of the image, according to the Eq. (1) to (3). Then the histogram of the H parameter is analyzed for color recognition. We threshold the peaks of the H histogram, which is known to contain most of the color information, while also taking into account S and I information. As the thresholds for color segmentation is not deterministic, the fuzzy decision method is used in color recognition (Paulraj *et al*., 2009).

Curing control based on color recognition: As described above, current curing control process is labor dependent and low production. As the color of the tobacco leaves play a role in the quality of the tobacco

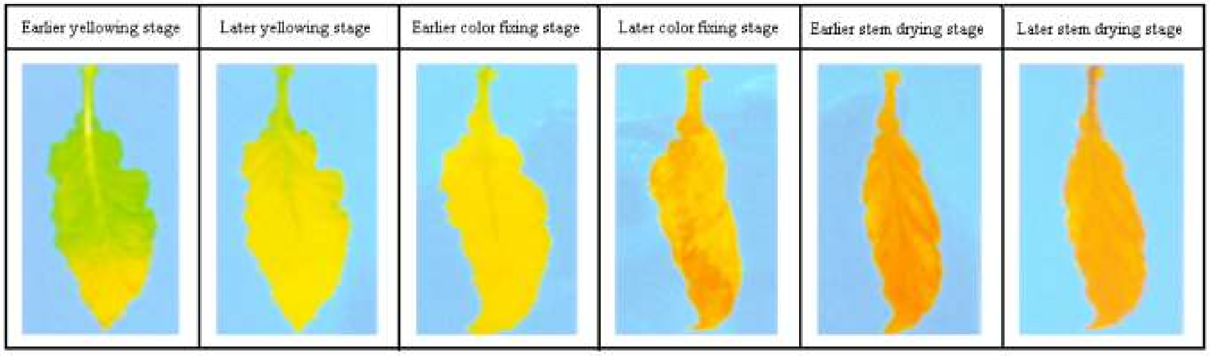

Fig. 2: The reference colors for the curing stages

production, we consider that the color of the leaves in curing process can be used to judge the curing states. Actually, the specialists adjust the parameters just according to the appearance of the leaves.

The color of the tobacco leaves in curing process is varying from green to yellow to orange, as shown in Fig. 2. Therefore, the colors of the tobacco leaves can be used to indicate the curing state. Then the controller can adjust the environmental parameters of the barn according to the color of the tobacco leaves in the barn.

To realize color recognition, a camera is used to take pictures on the leaves in the curing process. Then the color of the leaves are extracted and analyzed. The controller adjusts the parameters according to the color and the stages.

As is known, the yellowing stage is a period of major chemical conversions and color development. In earlier yellowing stage, the temperature in the barn is maintained between 30 and 40°C, with the ventilation windows kept closed. The relative humidity is kept 80 to 95% until the leaves turn yellow. Once the yellow area of the leaf covers about quarter of the leaf, it is in the later yellowing stage. Then the ventilation windows are opened and the wet-bulb temperature is kept 1 to 2°C lower than the dry-bulb temperature until the whole leaves turn yellow.

In the color fixing stage, the color of the tobacco leaves are to be fixed in yellow. The rising rate of the temperature should be kept lower with the rate of 2 to 3°C/h in the color fixing stage. As the leaves are all yellow and turn soft and curl in their edges. Now it is in the later color fixing stage. Then the rising rate of the temperature should be kept lower (such as 1 to 2°C/h) and the temperature can be kept higher, when the color of the whole leaves is always pure yellow.

In the stem drying stage, the color can be used to judge the over. It generally requires 36 to 48 h in the stage. Air temperature is increased to around 69°C with further decrease of relative humidity to permit rapid drying of the midrib. As the color of the whole leaf is near orange or the humidity in the barn is about 95%, the curing process is considered over.

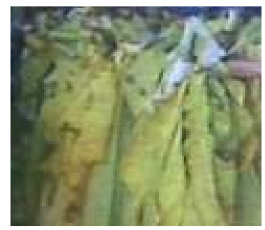

Fig. 3: The photo taken in the later yellowing stage

Fig. 4: The photo taken in the earlier color fixing stage

Table 1: The characters of the color feature of the tobacco leaves

Color characteristic parameters	Photo in Fig. 3	Photo in Fig. 4
H	0.344-0.724	0.505-0.564
S	0.222-0.478	0.167-0.226
I	90-124.7	160.3-174

SIMULATIONS

To verify the validity and performance of the method proposed, simulations with the tobacco photos are performed. The photos are taken in the curing barns, as shown in Fig. 3 and 4. The color components are calculated and shown in Table 1.

As Table 1 shows, the leaves in the Fig. 3 is in the later yellowing stage and those in the Fig. 4 is in the earlier color fixing stage and the curing stages work well.

CONCLUSION

To reduce the workload and labor involved in the tobacco curing process, a new intelligent control system based on color recognition for tobacco curing barn is proposed in the study. The colors of the tobacco leaves are identified along the curing process, which are used to judge the curing stage and the correctness of the settings of the environmental parameters of the curing barn. Then the controller can adaptively adjust the temperature and the humidity of the curing barn to assure the quality of the tobacco cured. The control system can be used to control the environmental parameters in the curing barns for various tobacco leaves. It has characters of convenience, high level of automation, high efficiency and low labor cost.

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