Predicting Fruit Maturity Stage Dynamically Based on Fuzzy Recognition and Color Feature

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Abstract—**Developing and ripening fruit are often classified for vary purposes according to its maturity classes. We propose an approach that predicts tomato fruit maturity stage during development and ripening according to their surface color. Tomato fruit maturity is divided into four stages in which the ripening time is short. The purpose of this paper is forecasting tomato fruit surface color change process which is reflected in surface color during every maturity stage based on temperature conditions. Fruits' current status should be get using fuzzy recognition before forecasting their maturity stage. This approach allows user to input the forecasting short-term temperature so as to get the ripening process dynamically during every maturity stage. This can lead to a decision making for farmer to maximize the profit.**

Keywords-Maturity stage; Temperature; Predict; Fuzzy Recognition

I. INTRODUCTION

Tomato is the most investigated member of the fleshy fruit regarding fruit development and ripening [1]. And tomatoes in different maturity stages have different purposes. Lajos Helyes have carried out a research on tomato fruit quality and content depend on its different maturity stages[2]. And at specific times during the crop-growing season, the farmer will face the problem of deciding when to harvest. Because of the variety uses of tomato and its huge market, the accurate assessment of tomato maturity is one of the most important economic decisions a grower must make. Harvest too early can cause loss of yield and lower flavor quality. However, harvest an overly mature fruit often leads to mechanical losses and difficult storage.

Tomato maturity is closely related to its surface color feature, so evaluating their levels of maturity by visual analysis of the tomato's surface color feature is a feasible mean. As is known, tomato contains large amounts of lycopene. Several researches have been showed that during tomato fruit ripening process, chemical and physical properties of lycopene were different and influenced by many factors[3]. In addition, assessing lycopene content during processing tomato have been studied[4,5]. A number of studies have shown a strong positive correlation between temperature and fruit ripening time[6]. So, lycopene content could be a standard to predict tomato maturity stage.

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Lycopene content is closely related to its surface color, so evaluating its maturity stage by analysis of the tomato's surface color feature is a feasible means [7]. According to its maturity stage, fruit grading have been developed for years. Based on the grading research maturity prediction have been carried out automatically. Katharine B.Perry et al. (1997) studied to compare different methods of calculating heat units and determine the most reliable method to predict tomato harvest [8]. But simple heat unit summation formula can't accurately predict maturity stage and harvest date. Different kinds of fruits were studied using different methods. Sugarcane maturity was estimated using its physiological feature which is related to photo assimilate and respiration losses [9,10]. Neural network was also used in green peas and spring wheat maturity forecasting [11,12]. Some other fruits maturities were predicted during recent years [13,14,15,16].

The researches about tomato are rare and with low accuracy. In addition, tomato is sensitive to natural conditions especially for temperature. We proposed an approach based on lycopene variation which can predict the maturity stages according to its current status and the natural conditions. Getting future maturity stage can provide a reference for logistics system to distribute their resource efficiently on the basis of market demand.

In this paper, Section 2 begins with an introduction of the framework about our maturity stage prediction. Fuzzy recognition was also shown in this section. Then, Section 3 introduced the specific approach of prediction. And an experiment is presented in Section 4. Section 5 ends the paper with some conclusions.

II. THE METHOD FOR PREDICTING MATURITY STAGES

Tomato fruit maturity is especially influenced by temperature. The higher temperature is, the shorter ripening time it will be. In the same way, low temperature will prolong the ripening time. In this paper, surface color is the standard of tomato fruit maturity stages. Its red color results from the accumulation of lycopene. Lycopene level of tomato fruits is determined by the genetic potential of the cultivar and environmental conditions, mainly temperature and light. 19° to 24°is the best temperature for accumulation of lycopene, and higher than 30°or lower than 15° is against the accumulation. If the temperature is low, tomato will ripen in 45 to 50 days after blooming. With high temperature, the ripen time will be shorten to 40 days.

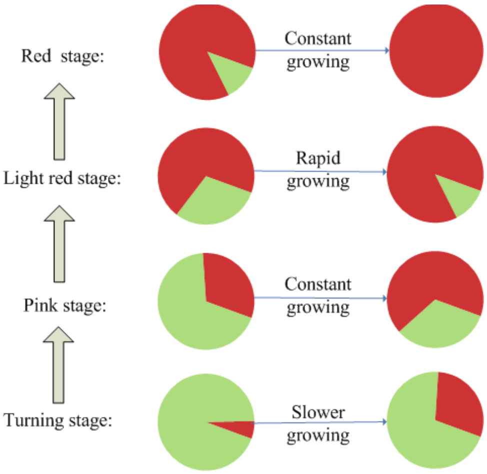

Figure 1. The classification of tomato maturity stage.

Generally, the size of red area on tomato surface is the maturity classification standard. Generally, tomato fruit maturity is divided into four stages in Figure 1: turning stage(the color gradually turned into red, from the top of the fruit, but most of them were green, even though the red color level achieved 3-30% in the aggregate), pink stage(the orange-red extended from the top of the fruit to the abdominal, and the red color level achieved 31-70% in the aggregate), light red stage (the red color of the fruit expanded to an almost full color, but the bottom was still green and the red color level achieved 71-90%), and red stage(more than 90% of the surface, in the aggregate, showed red color). The classification of maturity stage is fuzzy. We should recognize using a fuzzy method.

In our paper, fuzzy recognition was used to determine fruit maturity stage based on two features which are red areas and hue.

A. Maturity Recognition

The ripen status of every sample can be analyzed by the image system. Generally, maturity recognition is based on the hue values and red areas which are abstracted from the signal tomato image. The framework of maturity stage prediction is described in Figure 2.

Picture acquisition is the first step and after which is the processing of the picture. Tomato picture contains both tomatoes and leaves. But only the fruit tomato is useful to us for maturity recognition. So, signal tomato should be segmented from the background. The framework of maturity stage prediction is shown in Figure 2.

1) Step 1: Tomato image acquisition

Existing methods for image segmentation covers two aspects, boundary detection and threshold segmentation. Boundary detection has developed many operators such as Roberts, Canny, Sobel, Prewitt, and Laplacian operator [17,18]. The primary methods about threshold segmentation are bimodal gray histogram and maximum inter-class variance which is short for Otsu. Through calculating target class and background class of the image, as the smallest intra-class variance and maximum inter-class variance, the Otsu method automatically derives the fruit's goal [7].

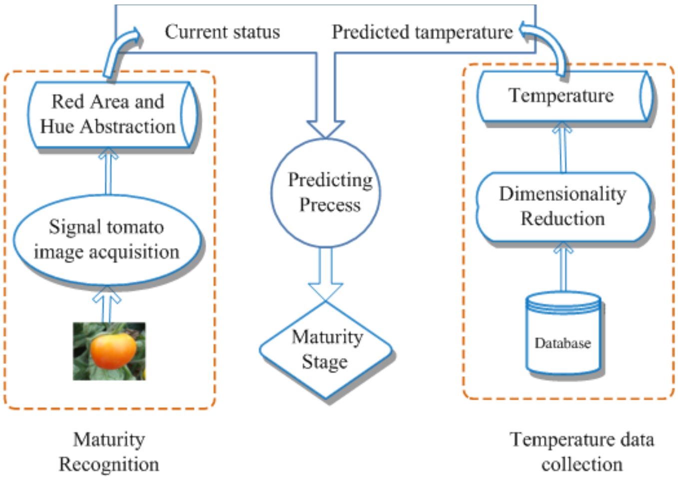

Figure 2. The framework of maturity stage prediction.

Because of the obvious color difference between fruits and leaves boundary detection is used in our paper. Robert operators and Canny operators are experimented. The results are shown in Figure 3.

2) Step 2: Hue abstraction

Maturity stage can be recognized using the signal tomato picture based on the corresponding relationship in Figure 1. The HIS model is based on human vision and is short for Hue, Saturation, Intensity. The conversion between RGB and HIS is described as follows,

$$\begin{cases} I = \frac{(R+G+B)}{3} \\ S = 1 - \frac{3}{(R+G+B)} \quad [\min(R,G,B)] \\ H = \begin{cases} \theta & \frac{B<G}{} \\ 360-\theta & \frac{}{B>G} \end{cases} \end{cases} \tag{1}$$

where

$$\theta = \left\{ \frac{0.5\times[(R-G)+(R-B)]}{\sqrt{(R-G)^2+(R-G)(G-B)}} \right\} \tag{2}$$

As the tomato grows up from the turning stage to the red stage, the average of the hue component tends to decrease.

3) Step 3: Fuzzy recognition

Every fuzzy set should be described by a membership function. Fuzzy theory is used in all kind of areas. One of which is fuzzy recognition.

In our research, two features were extracted for tomato maturity stage recognition. They are red areas and hue of tomato fruit. The two features about tomato fruit are two fuzzy concepts which are just similar with old and young. So, maturity recognition should be carried out using fuzzy theory. It works in our paper.

Firstly, membership functions of the two fuzzy features should be defined according to expert in this area. Following the membership of five maturity recognition classes based on every feature would be calculated. In the last, calculating every recognition class's membership and selecting the class which its membership is maximum. So, the selected class is what we recognized.

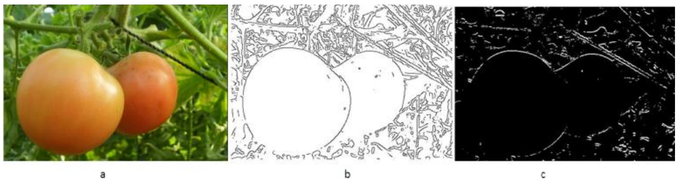

Figure 3. The image segmentation results. a, the original image; b, the segmentation image using Canny operators; c, the segmentation image using Roberts operators.

Red area membership functions about the four different maturity stages are shown in Figure 4.

Another feature which is called hue can also be described using membership functions which can be got from expert.

Every objective which will be recognized has three features. We describe the objective as $x = (x_1, x_2) \cdot x_1$ and x_2 are its two features. The recognition algorithm is described as follows.

a) Calculating every identifying class membership $R_{ik}(x)$ relative to every feature f_i. We all have four classes which are described as X_k, k is in 1, 2, 3, 4.

b) Calculating the membership of every class.

$$R_k(x) = \bigcap_{i=1}^{2} R_{ik}(x) \tag{3}$$

c) Calculating the max membership of every class. $M_k(x) = maxR_k(x)$.

d) Calculating the max of all the classes. $M(x) = M_j(x)$.

e) A threshold α was given before calculating. If $M(x) < \alpha$, the class was not recognized. If $M(x) > \alpha$, the class is recognized as j which is the max membership.

For example, supposing that a fruit will be recognized. Firstly, its red area and hue can be got in subsection A. Assuming that 74 and 100 were the calculating data. Then the membership function result is shown in table 1.

TABLE I. MEMBERSHIP FUNCTION RESULT OF EVERY FEATURE

class	Hue	Red Area
M_1	0.2	0.0
M_2	0.8	0.1
M_3	0.7	0.8
M_4	0.1	0.0

The membership of every class is calculated as follows.

$$R_1(x) = R_{11}(x) \wedge R_{21}(x) = 0.2 \wedge 0.0 = 0.0 \tag{4}$$

$$R_2(x) = R_{12}(x) \wedge R_{22}(x) = 0.8 \wedge 0.1 = 0.1 \tag{5}$$

$$R_3(x) = R_{13}(x) \wedge R_{23}(x) = 0.7 \wedge 0.8 = 0.7 \tag{6}$$

$$R_4(x) = R_{14}(x) \wedge R_{24}(x) = 0.1 \wedge 0.0 = 0.0 \tag{7}$$

If the threshold is 0.6, then 0.7>0.6. So, the fruit is belong to class three.

B. Maturity Stage Prediction

And the hue is directed reflected by lycopene. If lycopene content could be predicted, tomato maturity stage is also known. According to current research on tomato, lycopene content in tomato at different stages varied different. Overall, in the first few times lycopene content increase relatively slowly. At light red stage, it grows quickly. Not only that, lycopene content is closely related to weather conditions, especially temperature.

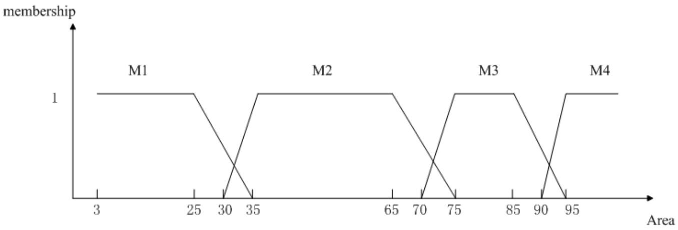

Figure 4. The membership function of red area.

We assume different variation trends about lycopene content at different stages based on temperature. The forecast temperature data can be easily achieved. Next is to integrate the two types of information to predict future variation trends.

III. PREDICTION PROCESS

A. Basic Notions

In our paper temperature is the only input. We aim to forecast tomato fruit maturity stage based on weather condition which is temperature. Some variables have been defined for the achievement of forecast. Once temperature (T) is given, following variables can be achieved.

1) Membership functions for temperature:

$$A(T) = \begin{cases} e^{k_1(T-a)} & T < a \\ 1 & a \le T \le b \\ e^{-k_1(T-a)} & T > b \end{cases} \tag{8}$$

In this paper, a and b can be 19°and 24° .

2) The influence of every maturity stage time result from temperature is reflected in tt_i. $tt_i = -log_2 A(T_i)$.

3) The interval time of every stage is defined as following: $t_i = t_{i-1} + tt_i + 10$.

$p_i = 10A(T_i)$ is another auxiliary variable.

For all the variables and formulas, $t_0 = 8$, i=1,2,3,4.

B. Method Definitions

Lycopene increases differently in tomato maturity stages. The short-term forecast is defined to forecast the lycopene variation trend in every maturity stage. Four functions were given to do this.

According to maturity recognition results, different calculation was used. If recognition result is turning stage, the variation trend in its stage can be described follows:

$$T(t) = 5\, log_{p_1} t\,, 8 \le t \le t_1 \tag{9}$$

while the pink stage is:

$$P(t) = \eta p_2(t - t_1) + m_1, t_1 \le t \le t_2 \tag{10}$$

the light red stage is:

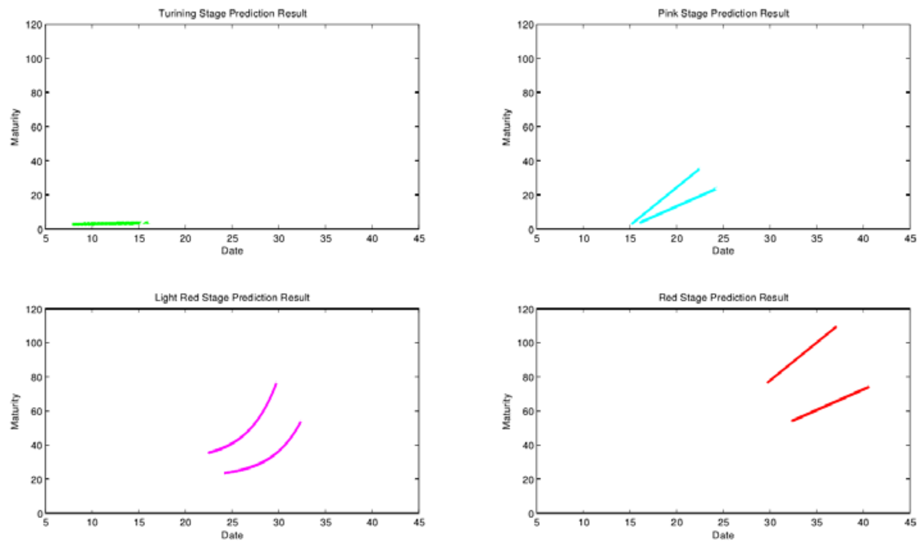

Figure 5. Every maturity stage with different temperatures.

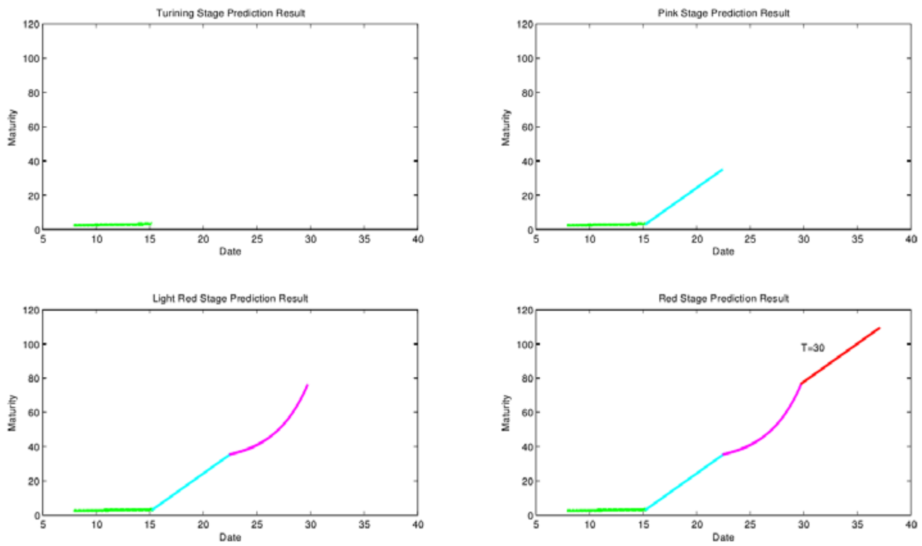

Figure 6. Different stages with the same temperature.

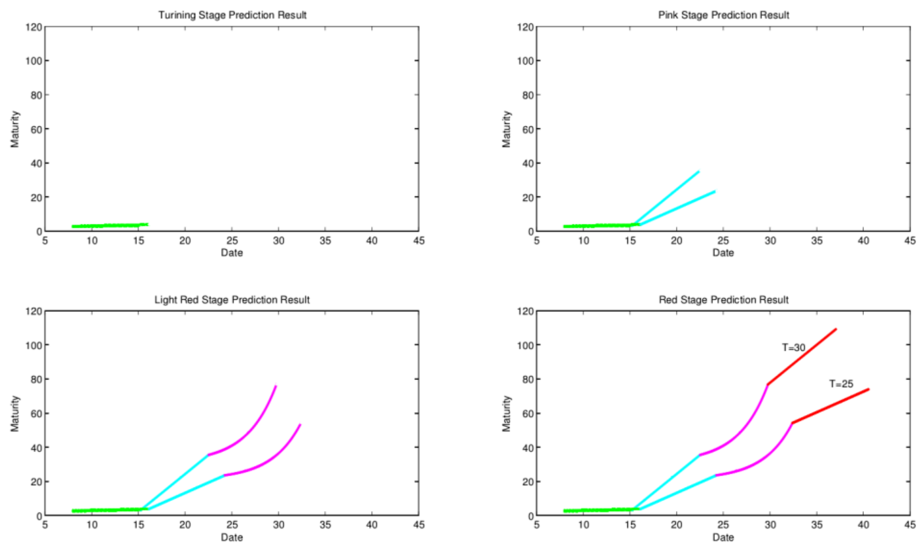

Figure 7. Different temperatures with different stages.

$$L(t) = \eta p_3 \cdot 1.9^{\frac{1}{2}(t-t_2)} + m_2, t_2 \le t \le t_3 \quad (11)$$

and red stage is:

$$R(t) = \eta p_4(t - t_3) + m_3, t_3 \le t \le t_4 \quad (12)$$

In the formula,

$$m_1 = 5 \log_{p_1} t_1$$

$$m_2 = \eta p_2(t_2 - t_1) + m_1 - \eta p_3$$

$$m_3 = \eta p_3 \cdot 1.9^{\frac{1}{2}(t_3-t_2)} + m_2$$

η is balance coefficient. In our paper η is 1/15.

IV. Experiment Results and Discussionsing

In order to validate the efficiency and performance of our approach, we carried out an experiment. According to maturity stages, two different operations of the method have been tested.

The same stage with different temperatures:

High temperature promotes lycopene content synthesis. This is almost the same in every stage. Its result is shown in Figure 5. There are two curves in each maturity stage. The upper one is with higher temperature than the nether. Every stage fruits ripen faster with higher temperature, and the maturity time is shorter than the low temperature. In the figure, slope of curve reflects it. If fruits current status and future temperature are acquired, fruits' maturity variation (lycopene content) will be predicted.

The same temperatures with different stages:

Different stages with different lycopene content vary in growth rate. According to our assume, its results is shown in Figure 6. This figure shows that maturity varied in the same temperature. It can be seen from it that different maturities varied different with the same temperature. The third stage rises fastest with exponential growth and the first stage rises slowest. The time fruits get to every stage can be predicted using fruits' current status and future temperature. For example, if fruit's maturity is 40 and temperature is 30, after 10 days its maturity will be 90.

The different temperatures with different stages:

The predicting relationship between temperature and maturity stages using our method is shown in Figure 7. Through the comparison between different temperatures and different stages' maturity, their relationships were displayed clearly.

V. Conclusion

According to tomato lycopene content variation during different maturity stages and the impact that temperature promotes it, we defined a variation process during tomato ripening process. Using the variation process, tomato lycopene content can be predicted based on its classification standard. Following we will tested the effectiveness of my method. Further tests must be carried out to test the robustness of the method and to validate it. In further studies, we hope to complex the method, for example, including other nature conditions such as rainfall, light. In other hand, abnormal weather should be considered.

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