Color and Shape Grading of Citrus Fruit Based on Machine Vision with Fractal Dimension

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***Abstract*—**In order to improve the citrus grading accuracy, fractal dimensions which characterize the color and shape features of citrus fruit were analyzed. Samples were from Citrus unshiu Marc.cv.unbergii Nakai. For each sample, images from peduncle, calyx and two opposite sides were collected. These four images were cut, removed backgrounds, and converted from RGB space to HSI one, then by the following methods, the color and shape features of citrus were extracted 1) HSI images were segmented according to hue value of 0°~20°, 20°~40°, 40°~60°, 60°~80°and 80°~100°. And each segment image was converted to binary image to retrieve box dimension, which character the color feature of fruit. 2) HSI images were converted to binary images, and then the imagines were edge detected and the box dimension of fruits profile of peduncle and one side, which character the shape features of fruits, were retrieved. Based on the box dimensions, a wavelet neural network was constructed to model the fruit color and shape grading system. Test results showed that for 120 sample fruits, the average correctness of color and shape grading was 95.83%, which mean box dimensions of equal segmentation of hue value 0°~100° revealed the color feature, and box dimensions of peduncle and side profile revealed fruit shape information. Color and shape grading accuracy meet the requirements for auto-grading of system real-time machine-vision.

Keywords-box dimension; machine vision; citrus unshiu Marc.cv.unbergii Nakai; color and shape; grading Introduction

I. INTRODUCTION

By the grading of the appearance quality, not only the degree of observability, grade degree and market competitiveness of the citrus are enhanced, but also vast economic and social benefits are can be created. In recent years, the studies on fruits grading has been developed by some researchers. In 2004, F.Mendoza, et al converted the RGB imagine to the CIELAB format, by the brightness, red-green and blue-yellow colors, the authors graded the maturity of 49 bananas, and the accuracy of this method was 98% [1]. In 2003 and 2008, the authors evaluated the grades of peaches, oranges, apples and palms by the average value by red, green and blue [2, 3]. In 2008, I. Kavdıra, and D.E. Guyerb. Graded the Golden Delicious' apples based on the size of the red and the hue, and the accuracy of Neural Network was 90% [4]. By analyzing various of surface colors of standard test spheres, Y. B. Ying and F. Fu found that it was the brightness distortion that caused the color distortion, also, they built a brightness adjustment model of central imagine of the camera shooting visual area, and the correlation coefficient was 0.846[5]. And in [6], a method of the segmentation of strawberry image based on the RGB color model was proposed, in which only addition and subtraction operation were needed, and the segmentation efficiency was more than 85%. However, in the researches above, the character values were all accumulative values of the hue histograms, and the space distribution characters of the hues were not considered, therefore, the grading accuracy were low since they lacked adequate bases of grading. There exist five methods for describing fruits shapes with machine visual technique: geometry parameter method [7-8], wavelet multiple scale method [9-10], fourier descripto[11-13]r, active shape mode[14]l and Zernike moment[15-16]. There are some defects in each method above. As far as the geometry parameter method is concerned, the fruits shapes cannot be described accurately with a finite number of geometry sizes, for the fourier descriptor and zernike moment, some fine structure will be lost as the contour characters are extracted, and for the active shape model, the grade accuracy rate is depended on the trainer bank of various the citrus imagine samples. In this paper, the space distribution character, accumulative character and the shape character were described by the fractal dimensions of the colors of citrus, and with the wavelet neutral classifier, the grading of colors and shapes of citrus were completed.

II. TEST SCHEME

A. *Test samples*

The Citrus unshiu Marc.cv.unbergii Nakai, the bud mutation of Wenzhou mandarin citrus, are originally planted in Jinggang county of Japan. Since the 1980s, they are planted on a large scale China, and are distributed in each citrus production area at present. It possesses the attributions of oblate shape, smooth surface, red-orange or yellow-orange color, thin peel, nice flavor taste, and without seed. The fruit mature in the early or middle of October. The samples in the test were picked from the Institute of Horticulture of Hunan. Firstly, 30 citrus trees of the same growth period were selected according to the different terrain slope of the same base, then 7 citrus were picked from every tree according to the height of the above part, the middle part, the low part, and the east, south, west, north direction respectively, finally 120 training samples and test samples were reelected for the grading test, respectively.

B. *Machine vision system*

The size of the light box with black background was 500mm×500mm×500mm, and four incandescent lamps of 60W, were fixed symmetrically on the top of the box.

The camera was Olympus C-5000Z, with valid pixels 500 million, f 7.8-23.4mm, focal length 0.5 m-∞, shutter speed 16-1/1000s, aperture F/2.8-F/4.8, and the distance from lens to the bottom of box was 468 mm. The computer was Lenovo P□2.13G with the memory 512 M.

C. *Imagine cutter, background removing and conversion of color model*

After two days preserving, the citrus which had been dust removed were put into the light box. The imagines of fruit stem surface, calyx surface and the two opposite profile surfaces were collected, and the imagines would be processed as follows:

- 1）Imagine cutter

A M×N RGB imagine could be described as by a M×N×3matrix, and each of pixel point of the imagine corresponded to a 3-tuples (Red, Green, Blue). In the test, the cutting window was defined as

$$f(x,y)=M(L_t^{(1)}-L_l^{(1)})\times N(L_t^{(2)}-L_l^{(2)})\times 3 \qquad (1)$$

where $L_l^{(1)}$ and $L_t^{(1)}$ denoted the origin and end point of the row of the cutting window, and $L_l^{(2)}$ and $L_t^{(2)}$ denoted the column ones respectively. Thus by (1), the pixel point of $ML_l^{(1)}$ to $ML_t^{(1)}$ and $NL_l^{(2)}$ to $NL_t^{(2)}$ were detained, and the pixel points outside the window were deleted. By this method, the information that would be processed subsequently was reduced, and without leaking the memory and the process speed was improved ultimately.

- 2）Removing background of the imagines

Any color can be denoted by tri-stimulus values, which is called three primary colors, and the common three primary colors are red, green and blue. According to the CIE-RGB color system which was established in 1931, R, G and B were selected as 700nm, 546.1nm and 435.8nm respectively. Hence the brightness of red light of a unit is 0.1770，and for the green and blue one, is 0.8124 and 0.0106, thus the brightness Y of any color C is:

$$Y=0.1770R+0.8124G+0 \qquad (2)$$

The brightness histograms of the citrus imagine presented obvious double peaks distribution, and the left part and the right part corresponded to the black background and the citrus region respectively.

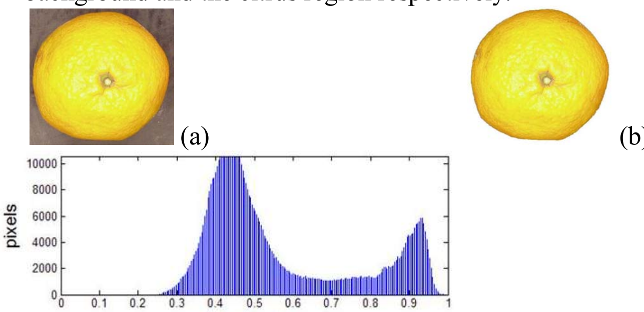


Figure1. Citrus unshiu Marc.cv.unbergii Nakai: 9.0oBrix、PH3.28、202.337g

(a) Originally image (b) Segmentation image

(c) Luminance histogram

In figure1, the juncture of two peaks was the demarcation point of the citrus region and the background brightness. The brightness valve was set as T=0.7, then the transformation of the citrus imagine was defined as following:

$$f(3,R,G,B)=\begin{cases} R,G,B=originalvalue, B>T \\ R,G,B=1, B\le T \end{cases} \qquad (3)$$

By (3), the background of the citrus was removed, and the imagine obtained by this method had clear and accurate citrus boundary, furthermore, there did not exist oillet in the fruit region, and the background was removed completely.

- 3）Conversion of color model

In the RGB space, the 24 color space is generated with red, green and blue component quantity detected in photoreceptors. In the HIS model, the hue H, saturation S and intensity I were used to describe the color character, in which H and S contained color information, and I was irrelevant to the color information. For the citrus imagine which had been removed the background, it could be converted to the HIS space from the RGB space.

$$I=(R+G+B)/3 \qquad (4)$$

$$S=1-\min(R,G,B)/I \qquad (5)$$

$$H=\begin{cases} \theta, G\ge B \\ 360^0-\theta, G<B \end{cases} \qquad (6)$$

Where：$\theta=\arccos\dfrac{2R-B-G}{2\sqrt{(R-G)^2+(R-B)(G-B)}}$.

III. FRACTAL DIMENSION AND GRADING CHARACTER

A. *Fractal dimension*

Since the growth process is affected by the external conditions, citrus possess different shapes and irregular hue, and the complexity of the shape differences and the hue of the space distribution cannot be described by the Euclidean space. Hence in the statistical sense, different shape of citrus and distribution of hue on citrus can be considered as some fractal structure, and the fractal dimensions can describe the shapes and hue accurately.

The fractal theory has made tremendous developments in the past decades, and it has been widely applied in the processing and analyzing of natural phenomena which bear complex details features. According to different objects, various fractal dimensions measuring methods, such as box-counting method, correlation method, and spectrum method are applied.

The fractal dimensions above reflect the properties of the object from different perspectives, and generally, they are irrelative to the scale in the sense of statistical. Specially, the box-counting method is the most common one for its simple calculation and wide application range. In this paper, the box-counting method is applied to study the shapes and the color classification of citrus.

Let $A \subset R^n$ be a non-empty set, and $N(r)$ be the minimum numbers of the sets that is needed to cover A, with the diameter not exceeding r, then the box dimension is defined as

$$D(A) = \lim_{\delta \to 0} \frac{\log N(r)}{-\log r} \qquad (7)$$

For citrus, the box dimension of the surfaces and shapes could be obtained by the following steps. Firstly, the contour and hue imagine of the citrus were cut by squares of side length $\delta_{i+1} = \delta_i / 2 (i = 1, 2, \cdots, k-1)$ pixels, then count the square lattices N_{i+1} which contain target pixel, the process will not stop until to the case that δ_k was one pixel, and the corresponding lattices number was N_k. By dealing the data points $(-\log \delta_j, \log N_{ji})(j = 1, 2, \cdots, k)$ with least squares fit, the slope of the fitting line, namely, the box-counting dimensions of citrus color and the shape, were obtained.

B. *Shape character value*

The typical shapes of Citrus unshiu Marc.cv.unbergii Nakai are oblate generally, and they bear different shapes according to the growth circumstance. But for the approximate circle contour imagine of citrus stem surface, the differences were not obvious, however, the profile ones were obvious, therefore. The fractal dimensions of the stem surfaces and the profile ones were used to characterize the shape character of citrus. Having been proceed by （4），（5）and（6）, the HIS imagine could be converted to a white-black binary one. By edge detecting, the boundary contour were formed, the fractal dimensions of the stem surfaces D1 and the profile ones D2 were obtained by (6). Table 1 is the mean value of 120 training samples.

Table.1 Fractal dimension

	Finest grade	first grade	second grade	substandard
SS	30	30	30	30
SSD	1.0658	1.0901	1.0955	1.1012
PSD	1.0787	1.0983	1.0992	1.1017

SS(Sample size), SSD(Stem surface dimensions), PSD(Profile surface dimensions)

Table.1 showed that the profile fractal dimensions were lager than those of the stem surface ones, which coincided with the fact that the contours of the stem surface of citrus are approximately round, and the profile ones are more complicate. This indicated that the more complicate for the contour, the lagers were the fractal dimensions, and the lower were the grades. Therefore, the shape characters of the citrus can be described by the fractal dimensions of stem surfaces and the profile ones.

C. *Color eigenvalues*

By (4), (5), (6), the imagines of the finest grade, firs grade, second grade and substandard citrus which were sorted manually were converted to three-layers imagines H,S and I. For the H imagine, the histograms of the four grades were obtained(see figure2), also, figure2 showed that the hue value of Citrus unshiu Marc.cv.unbergii Nakai ranged from 0o to 100o or so. For the four grades, the hue values range were 40o-70o , 47o-62o ,55o-79o and 82o-105o, the peak value were about 60o, 50o, 70o, and 98o in turn, and the fruits showed golden yellow color, orange yellow color, yellow green color and green color respectively. But the histograms showed only the cumulative information of various hues, and the distribution information of the above hues could not be showed. Since the same cumulative information may show different information distribution, and result in different coloring effect, the cumulative information and distribution information of the hue should be both considered as the color classification was deal with; hence, the fractal was necessary for the analysis.

In order to improve the speed of extracting color characters, the hue of fruits were divided into five regions: 0o-20o, 20o-40o, 40o-60o, 60o-80o and 80o-100o, by which five hue imagines were formed. Each of the imagine was binarized, then the fractal dimensions of the five hue regions were obtained by (7), and the color characters of citrus were displayed. The fractal dimensions and hue imagines of were showed in figure 3, which showed that there were more hue points gathered near the peak value point, and there existed the largest fractal dimension, also, the region that was the farer away from the peak value point, the smaller the fractal dimensions was. On the other hand, the hue distribution and the fractal dimensions varied with the colors of Citrus unshiu Marc.cv.unbergii Nakai. As a consequence, it was reasonable to grade the citrus color with the fractal dimensions of hue imagines.

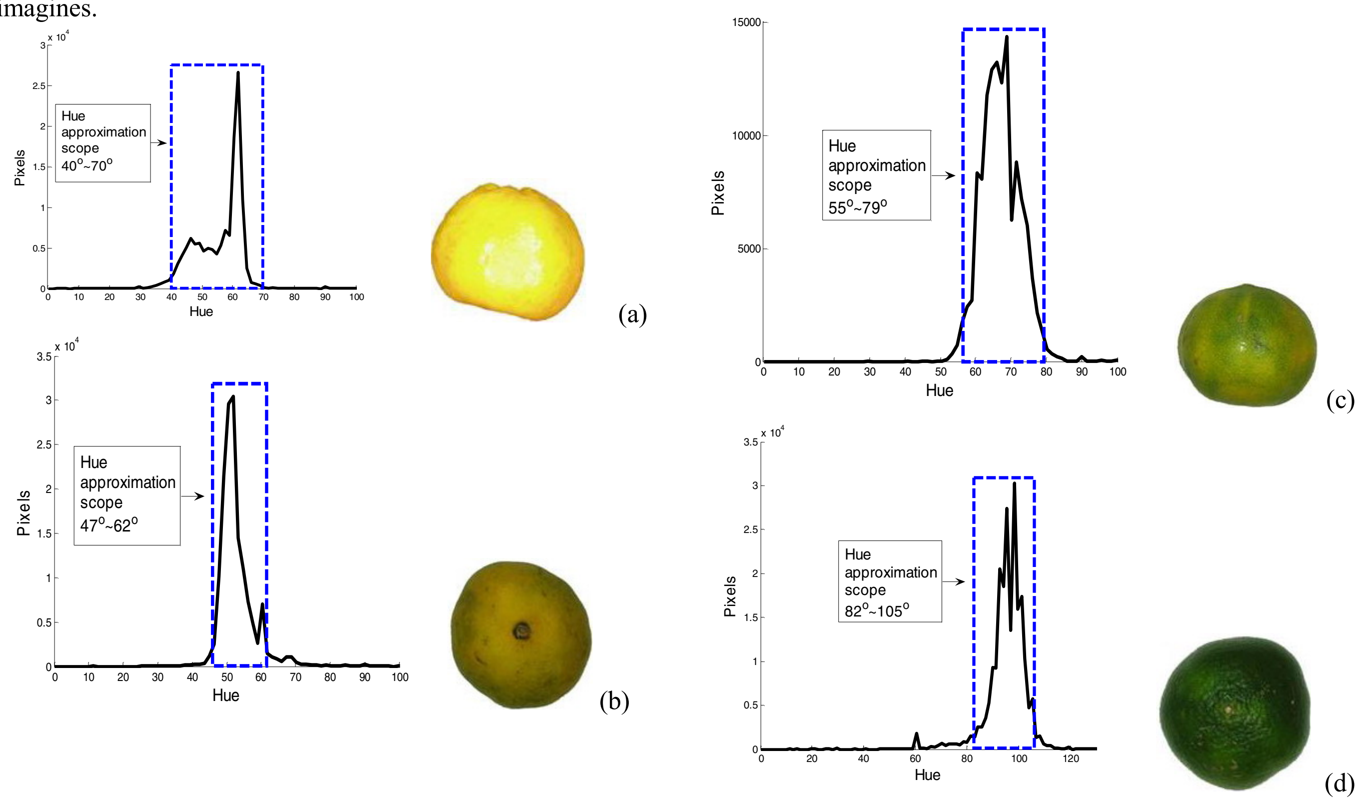
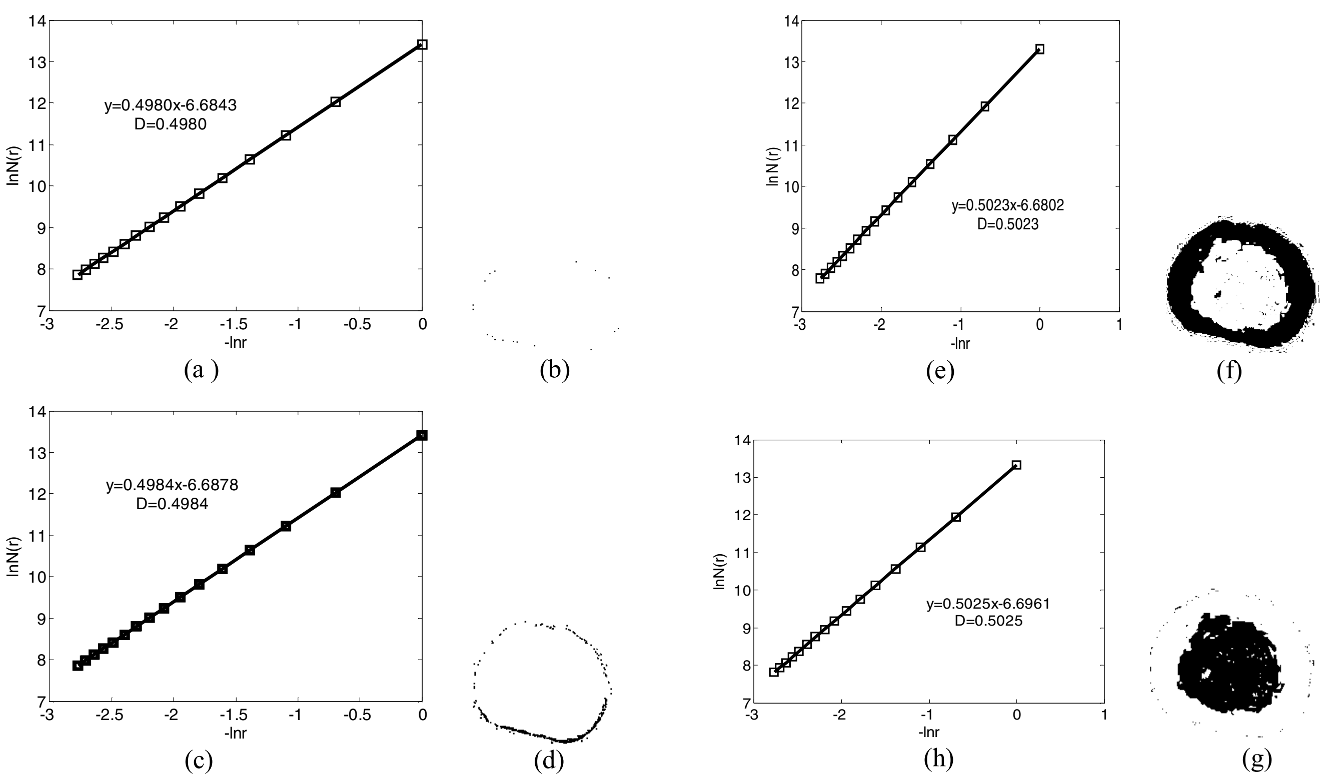
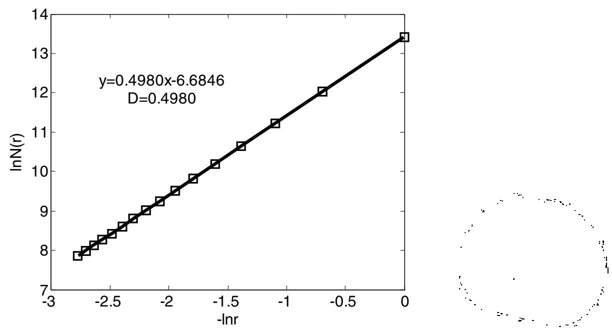


Figure 2 Hue component histogram
(a) Golden yellow fruit (b) Orange yellow fruit
(c) Yellow green fruit (d) Green fruit





(i) (j)

Figure.3 Fractal Dimension
(a),(c),(e),(g),(i)was the fitting line; (b),(d),(f),(h),(j) was the component histogram of 0-20o, 20-40o, 40-60o, 60-80o, 80-100orespectively

IV. WAVELET NEURAL NETWORK

Since the wavelet neural network was put forward in 1992 by Zhang and Benveniste[17], it has been applied in various fields for its excellent performance of the integration of wavelet transform and neural network. In fact, the wavelet neural maps of citrus color shape and grades were, in essentially, the process that except for the adjustment of wavelet neural weight, the construction of suitable wavelet base in the feature space of wavelet and the minimization of network output error by iterating the contraction-expansion factor and displacement factor. Since the coloration of citrus was irregular, the fractal dimensions of the colors of the stem surfaces, calyx surfaces and opposite profile surfaces should be computed simultaneously. In this paper, the wavelet neural construction was 22×25×1, the hidden layer and output layer neurons was

$$\Psi(t) = \exp(-0.5t^2)\cos(1.75t)$$

And

$\phi(t) = 1/[1+\exp(-t)]$. To improve the training speed, the momentum terms were introduced. The training would be terminated when the training error reached 10-4 or the training paces were 105.

V. RESULTS AND DISCUSSION

A. Test results

The well trained citrus color and shape grade trainer of wavelet neutral net above were used to test the classification performance with 30 the finest grade, first grade, the second grade and the substandard respectively, and all of which were selected manually. By this model, 5 were misjudged in total: 1 the finest grade was misjudged for the first grade, 2 the first grade for second grade, 1 the second grade for the first grade, and 1 substandard for the second grade. The accuracy of the finest grade, first grade, the second grade, the substandard and the mean one was 96.7%、93.3%、96.7%、96.7% and 95.83% respectively.

B. Analysis and discussion

The fractal dimensions of hue domain, which were applied to describe the color characters, contain not only the cumulative character of the same hue, but also the distribution character of the hue. Furthermore, the quantities of characteristic values obtained by this method were far less than those of hue cumulative method's, also it presented less information and higher classifying speeds, which was different from the methods presented in [1-6], and the accuracy were higher than those of presented in [2,4].

The citrus shape characters which were denoted by the fractal dimensions could described the total contour, and were more accurate than those of geometry method, furthermore, this method avoided losing the fineness part of citrus as select the contour characters, which was different from the method presented in [11-13, 15, 16]. On the other hand, the training collection of several of citrus imagines was not needed to establish beforehand, but a direct test in this paper, which was different from that of [14].

Citrus unshiu Marc.cv.unbergii Nakai are picked in the middle of October, when most of the fruits are mature, and the peels are orange yellow, but for the minority covered by leaves, the peels present yellow green or green small patches, and cannot be accurately classified manually, which is one of the reasons that the classifier causes errors. On the other hand, for the adjacent grades, especially the finest grade & the first rate and the first rank & the second rank, it was less accurate to classify shapes manually, which was the second reasons that causes classification errors. Finally, for individual green-yellow citrus, the edge brightness values and the dark background brightness of the light box were quiet close, which was the third reason for the errors.

VI. RESULTS

- 1）For the synthetic grading of citrus colors and shapes, the grading indexes was unified by the fractal dimensions.
- 2）The color characters, which were described by the fractal dimensions of the hue region 0o～100o, bind with the cumulative characters and the space distribution characters of the same hue, which reduced the quantity of the cumulative character values and a method of well grounded basis, high speed and accuracy was presented.
- 3）By extracting the box-counting dimensions of edge contour and describing the describing the cubic shapes of citrus with the fractal dimensions of the fruit stem surface and the profile one, the shapes were descript more accurately. And since the pixels in the citrus were not considered, the grading speed and accuracy were high.

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