Identification and Grading of Tea Using Computer Vision

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Abstract. *In order to objectively evaluate the tea's quality, this article uses the computer vision to classify and grade the tea based on the parameters of the tea's color and shape. Images of tea leaves were directly acquired by digital devices (e.g. digital camera), and then the color feature parameters were extracted on the basis of the HSI model and shape feature parameters were extracted on the basis of binary images after being converted and pre-processed. The automatic identification of tea was achieved by using the genetic neural-network. According to the experimental results, this method could achieve a better effect of identification with eight parameters of color and shape, and the results of computer-based tests were highly consistent with those of manual tests.*

Keywords. *Tea, Color, Shape, Image processing, Genetic-algorithm, Neural-network, Identification.*

The quality grading of tea is carried out in the aspects of color, tenderness, shape, cleanliness, etc. Therefore, testing color plays an important role in the quality grading of tea (Liang and Zhang, 2005). Until now, the quality of tea, to a large extent, has been judged by sensory evaluation. However, the sensory evaluation is often affected by personal or environmental factors, and different people have different comments on the same tea because of individual preference, while the tea color would also be affected by the outside lighting, so the test results are not objective or accurate enough, resulting in some subjectivity in the quality grading of tea. With the increasingly wide application of computer vision in modern agriculture (Shimizu and Heins, 1995; Bosnat and Sun, 2002; John, 2002), the computer-based automatic identification technology is promoting the standardization of grading tea (Borah et al., 2007) thus enhancing the objectivity and consistency of the results of classification. By using the computer-based vision technology to quantitatively describe the related feature parameters, the color of tea leaves can be identified more objectively and accurately, which makes it possible to achieve quantitative grading of the tea.

Recently, tea identification with computer vision technology has mainly been used in the research on color change during its process and storage. There are few tea classification researches using computer vision technology on the basis of tea leaf color and shape feature parameters. Cai (2000) made the research with computer vision system and tea leaves color-model description. Borah and Bhuyan (2003) and Gejima and Nagata (2000) also researched tea leaf color with computer vision technology to identify tea quality. The previous research usually ground the tea into powder or immersed them in water to get the color to identify its quality. In this study, a new way was explored to test tea leaves by computer system without harming them. During the production process, the newly processed tea leaves were taken as the research object, and the quality was evaluated by computer vision and image processing technology.

Materials and Methods

Composition of Tea Image Acquisition and Processing System

In our research, tea leaf images acquired by digital cameras are more real-time and practical than those acquired by scanners and it is better for the identification with the system. A Sony CCD(charge coupled device) video camera (Japan) was used to take dynamic images with definition of 540 lines and a Canon S80 of 8 million pixels was used to take static images. All computer vision and processing systems are explained in figure 1. The tea leaves were photographed in a hemispherical light room whose interior wall was painted white to achieve a uniform diffuse reflection. The lighting system consisted of three tri-phosphor fluorescent lamps which were put away symmetrically to form symmetrical irradiation. This was done to provide better tea leaf images without shadows. Digital cameras and digital CCD video cameras were fixed atop the windows. Digital cameras were adjusted to macro mode and its flash was shut. The static images acquired from digital cameras can be directly imported into the computer, but the dynamic images acquired from CCD video cameras were acquired and stored by an image-grabbing card in the computer. In order to acquire images for extraction of color features, the tea leaves should be overspread on the window evenly, but when getting images for extraction of shape features, all tea leaves should be spread on the window sparsely without overlapping.

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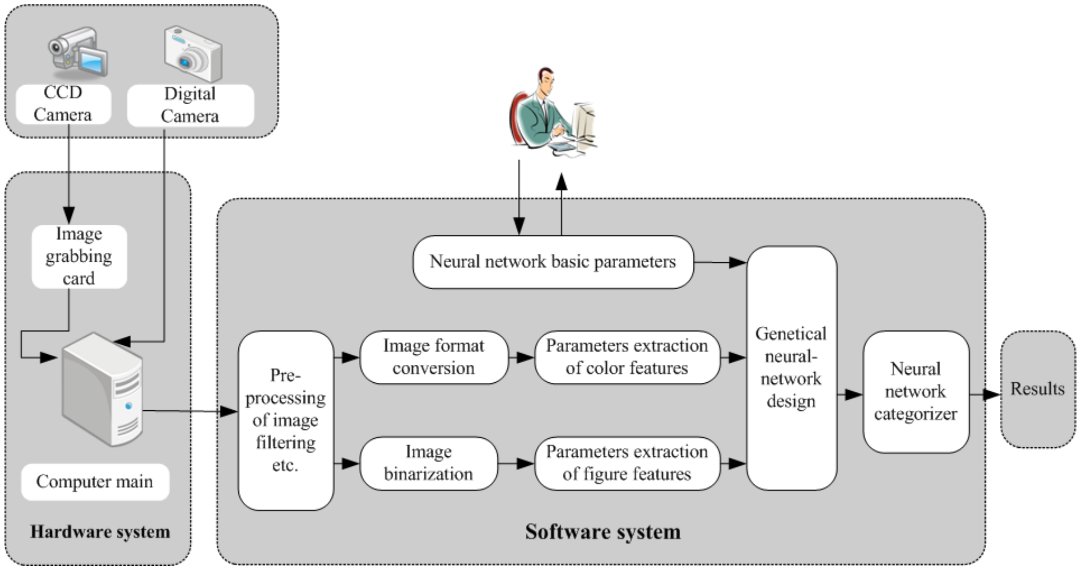

Figure 1. Composition of computer vision and processing system.

Tea Leaf Image Processing

In the analysis of tea leaves, the directly acquired images should be given a digital processing first, because the original images contain noise due to the impacts from various factors (e.g. light, hardware, etc.) during photographing and transmission. At the same time, in the early processing of image treatment, the images should be normalized. The formats of acquired images should be unified. The resolution and focal length of digital equipment should be fixed. The images must be de-noised by using a median filtering algorithm (Gallagher and Wise, 1981) and pre-processed by the way of histogram equalization to improve its definition and accuracy of the analysis and processing of the images. First, we used the histogram to extract the color parameters from the acquired HSI images by converting the image formats. Next, through threshold binarization of processed tea leaf images, we got tea leaf shape and contour images, and acquired the parameters of their perimeter, area, axis, etc. Then we input these parameters to neural-network systems trained by the way of a genetic algorithm. Finally, we completed the tea leaf auto-identification. A P4/3.0G computer with 1G memory was used with programs written utilizing Visual C++ 6.0.

Extraction of Color and Shape Features of Tea Leaves

Analysis and Conversion of Color Model

The color of tea leaves depends on the light source and physical properties of the tea leaf surface. People have built many color models to correctly measure, describe, and evaluate the color, and each model has its own features. In this research, we used the HSI color model (Kim and Park, 1996). It is more suitable for color observation and better indicates our color understanding during the experiments. Hue (H) describes color features and indicates the nearest spectral wavelength. Saturation (S), or the measurement of pure color level, reflects the color shade. Intensity (I), shows the glare level of the visible light to our eyes, measuring the whole energy of different multicolor wavelength and reflecting the entire pixel lighting degree, namely luminous intensity or light magnitude. In the HSI model, color information of the image is displayed by H and S, so when the information is acquired it is scarcely affected by the light magnitude.

When we visually test tea leaves, the difference in color is an important foundation for identification. Tests using computer vision system simulates the identification mechanism of the human eye and chooses color as a main feature parameter (Helman and Efros, 2005; Liang and Zhang, 2005; Lian et al., 2006). However, the difference in color of tea leaves is small, making the acquisition of parameters to identify the tea leaves effectively a difficult research problem. Usually image information by video cameras is shown in red, green, and blue (RGB). After analysis, we found that there are no rules complying with the RGB spread on the tea leaf image, so we could not get the needed results directly using this information. But HSI space has the advantage that it separates intensity from the other two parameters, hue and saturation, which reflect the color features. The RGB information needs to be transformed into HSI information in the research (Tao et al., 1995), as we don't need to process the information of RGB one by one, and we only have to analyze and process the images with hue and saturation. It shortens the processing time of multi-color images, and is suitable for the real-time tests. In practical tests, RGB can be converted to HSI by using the following equations (Plataniontis and Venetsanopoulos, 2000):

H equals:

$$\begin{cases} H = 2\pi - \theta & B > G \\ H = \theta & B \le G \end{cases} \tag{1}$$

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

$$I = \frac{R+G+B}{3} \tag{3}$$

In which

$$\theta = \arccos\left[\frac{2R-G-B}{2\sqrt{(R-G)^2+(R-B)(G-B)}}\right] \quad (4)$$

Image Pre-Processing

When obtained and transformed, the images will be affected by many noises due to outside and inside influences which lower the image quality and prevent them from the later proceeding. So the quality is expected to be enhanced. Thus, it is necessary to strengthen the image information, improve the image effect, underline the useful information for later analysis, and reduce or delete useless information through image processing technology.

Image median filtering was a main pre-processing task. We used it to eliminate the random white noise of the image transmission using the video camera and the capture card, and it scarcely affected the image vision quality. During the research, we used a 3×3 median filtering template. After median filtering, noise was deleted and the image edge was protected.

Median filtering in the images is defined as (Gonzalez and Woods, 2008):

$$Y_{ij} = Med\{X_{ij}\} = Med\{X_{(i+r),(j+s)}, (r,s)\in A, (i,j)\in P\} \quad (5)$$

In which, X_{ij} refers the pixel value of the tea image, Y_{ij} is the output value of the median filtering, and P refers to the plane window.

Extraction of Image Color Features

In the HSI color model, the intensity difference is small for the images which were taken under the same lighting condition. In this experiment, we chose color-relating H and S information as the feature parameters. Their histogram is calculated as:

Define $Sum(P, x_i)$ as an eigenvalue in the image (e.g. hue), which is the number of pixels of x_i. Define N as the number of the total pixels. The histogram of P feature is:

$$H(P) = (h_{x\,1}, h_{x\,2}, \ldots h_{xi} \ldots h_{xn})$$

$$\text{In which } h_{xi} = Sum(p, x_i)/N \quad (6)$$

At the same time we calculate the standard deviation of H.

$$\bar{S}_H = \frac{1}{N}\sqrt{\sum_{i=1}^{N}(H_i - \bar{H})^2} \quad (7)$$

In which, $\bar{H}$ is the hue average, H_i is the hue of one random pixel in the image

In a similar way, $S(P) = (S_{x\,1}, S_{x\,2}, \ldots S_{xi} \ldots S_{xn})$,

$$\bar{S}_S = \frac{1}{N}\sqrt{\sum_{i=1}^{N}(S_i - \bar{S})^2} \quad (8)$$

Extraction of Tea Leaf Shape Features

Tea leaf shape is one of the important factors that determine tea quality. Qualified tea has tight stripes. To acquire the shape features parameters of tea leaves, we need to binarize the tea leaf images. In order to make the tea leaf contour image easier to get, we had to reduce the overlap of tea leaves as much as possible when acquiring tea leaf images. Tea leaves have many shape features which can be used to distinguish them from other categories of tea. We can better complete the identification with the following feature parameters:

- Perimeter: Length of the contour line of the tested tea leaves.
- Area: Area of the tea leaves image, namely the number of pixels it contains.
- Length of axis: The center line length calculated by thinning algorithm through the mass center of tea leaves.
- Maximal Distance: The distance between the two top points of axis.
- Average Width: Parameters showing the proportion of the tea leaf size.
- Curvature Parameters: The curving degree of the tea leaf shape.

$$K = \frac{S}{I} \quad (9)$$

S is the actual length of the curving tea leaves, I is the distance between two top points of the curve.

The six shape parameters influence tea quality differently. Their specific values can reflect that the high-grade tea leaves are tender, tight, slender, and uniform, while the low-grade tea leaves have rough and loose stripes.

Neural-Network Model Based on Genetic Arithmetic

Genetic Neural-Network Arithmetic Model

The genetic algorithm, which is an overall search algorithm, displays the high parallel and auto-accommodation of biological natural selection and population genetic mechanism. Since the convergence rate of normal back propagation (BP) neural-network algorithm is slow, it is easy to entrap into local minimal value with inferior full searchability. We adopted the combination of genetic algorithms with neural-network for the tea leaves identification which is to train the neural-network by genetic algorithms (Sexton et al., 1999; Sung-Kwun Oh et al., 2006). It overcomes the shorts of the easy entrapping of local minimal value in BP neural-network model and has better results (Kavdir and Guyer, 2002; Kilic et al., 2007).

Genetic algorithms use biological natural selection and population genetic mechanism for reference and match the phenomena of breeding, amphimixis, and variation in natural selection and natural genetics. It uses the advantage of quick optimization of neural-network original weights and threshold values by genetic algorithms to position a better research space in the solution space; then we take it as the later neural-network original weights and threshold values. So we can search the optimal solution with neural-network strong searchability in local area. It shows a fitness value according to each evaluation of predetermined objective functions. The three basic operators in genetic algorithms are selection, amphimixis, and variation operators.

Confirmation of Genetic Neural-Network Coding and Fitness Functions

In this research we used genetic algorithms to complete the study and design of three-level neural-network in practical application.

(1) Individual variables in genetic algorithms are neural-network weights in decimal code. Dimension for each individual variable is M(N+I), in which M, N, I are the neuron numbers of the hidden layer, input layer, and output layer, respectively.

(2) To confirm network weight and initialized population, if $W = (w_1, w_2, \ldots, w_n)$, in which n is the population number, the objective function is:

$$E = \frac{1}{2P} \sum_{p=1}^{p} \sum_{i=1}^{m} [f(i) - y(i)]^2$$

Fitness function is:

$$f = \frac{1}{1+E} \tag{10}$$

In which P is the total number of training samples, m is the number of output nodes, $y(i)$ is the expected network output value of the i-th training sample, and $f(i)$ is the network output value of the i-th sample.

(3) During population replication, the population size was consistent, ranked the fit value from big to small, and held the optimal individuals without amphimixis and variation. Left individuals were to have amphimixis and variation by the amphimixis operator, P_c and variation operator, P_m, and reiterate until shaping a new population.

(4) The setting of control parameters.

The first step of the application of genetic algorithms that find the solutions is to represent each possible node in problematic search space as the confirmative feature strings. As per the real practical requirements, the node number of captured identification network is 8, the hidden layer number is 6, and the node number of output layer is 4, corresponding to 1 category and 3 ranks. By application, genetic control parameters are chosen as follows: population size N is 100, amphimixis operator P_c is 0.75, variation operator P_m is 0.037.

Results and Discussion

In the classification and identification of tea categories, Zhuyeqing and Huangya tea have very similar shapes. Both of them are flat and slender with two tapers, which are similar to the bamboo leaf. However, these two teas are different in color. As Zhuyeqing tea is fried under low temperature, the color is much lighter than Huangya. Whereas, Huangya's color is dull yellow. Ganlu tea, due to the additional hand-kneading process in the frying production, has a compressed form with curve. In the color aspect, Ganlu tea shows the green color with faint whiteness. Yinzhen tea is picked from the tea bud tips, so its shape is much smaller than other teas and is as slender and straight as a needle.

The definition and requirements for the tea classification are: first-grade tea, the appearance is even and symmetrical, the color is light green and unified; second-grade tea, the appearance has small branches and the color is unified; third-class tea, some parts of the appearance are defective, the leaf shape is slightly large, the color is dark with poor uniformity.

The testing materials were teas produced in 2009. We took green and cyan tea from Ya'an Meng Moutain as samples which were processed by different cyan-deleting and roasting methods. The category of tea can be divided into three grades, four categories have a total of 12 types, to choose two samples for each type, so there are a total of 24 types, We chose 24 types of different green and cyans tea in four categories as training samples, among which the first eight types were defined as first grade, the second eight types were defined as second grade, and the third eight types were defined as the third grade. The values obtained through the training of the training samples, by using the genetic algorithm and through repeated evolution of replication, amphimixis, and variation, at last the effective neural network identification weights can be finally obtained.

Figure 2 is the original image of Huangya and Ganlu tea from Meng Moutain and their binary image, together with the contour image and the feature images of the center thinning.

The identification of different types of tea is mainly based on the shape of tea leaves, while the classification of quality largely depends on color parameter with the difference in shape as a supplementary parameter. Since the roles of different parameters in tea grading are different from each other, each of which is given a weight coefficient. We have set two weighted values for the color and shape, for color parameter, the weight of H is 0.6, while that of S is 0.4; for shape parameter, the weight of curvature parameter is 0.25, the weight of area and average width is 0.2, the weight of length of axis is 0.15, and the weight of perimeter and maximal distance is 0.1, respectively. The scope of parameter values in evaluating three grading of four categories of tea are shown in table 1.

For the training neural network parameters, we have carried out many tests for each category of tea and have selected six groups of measured values of color and shape feature parameters and the variance analysis of all test data for tables 2, 3, 4, and 5. The unit of shape feature parameter is pixels.

We chose 24 types of green and cyan tea samples in the test set and used an auto-testing system described in this article for experiments. Experiments show that the average accuracy of the test in table 7.

Gejima, Yoshinori, and others on have monitored the changes of tea color in the drying process based on the RGB model by using computer vision technology. Borah and Bhuyan (2003) have monitored the changes of the liquor color of black tea in the process of fermentation based on HSI model by applying the image recognition technology, and Cai (2000) has carried out the measurement and comparison of the tea colors and tea liquor colors of Longjing Tea produced in different years based on the HSI model. In addition to the color measurement of tea leaves, we also introduced the shape parameter to enhance the accuracy of identification on the categories and grade of tea leaves.

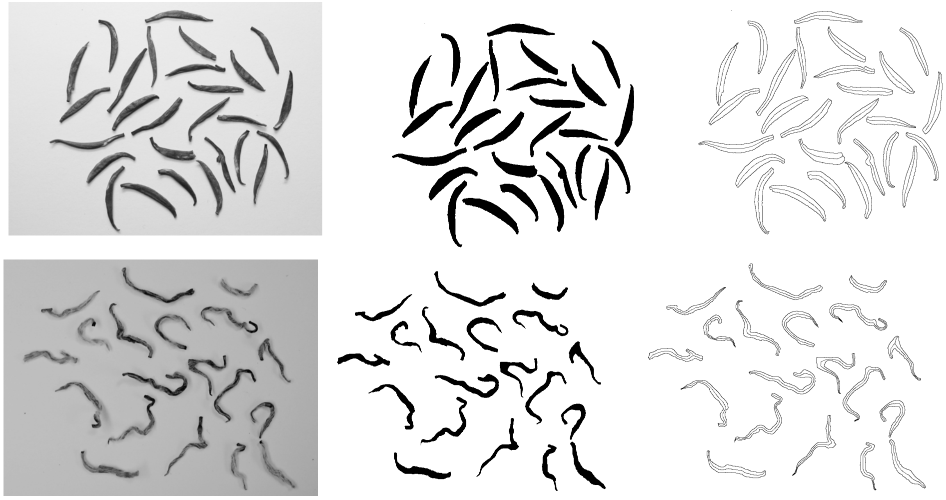

Figure 2. Original, binary, and contour images of Huangya tea and Ganlu tea.

The digital camera and video camera are not used at the same time in the application. In the laboratory's measurement, the digital camera is often used as it brings less noise. However, in the application of actual production, in order to achieve the real-time calculation and identification, the video camera should be used to acquire the tea image through the video capture card.

The above tests are still in laboratory stage and are not used in the practical production, the images adopted have high resolution and pixels, so the calculation time is relatively long in the abovementioned conditions of the computer, it take around 2 s to complete the calculation of a image. Therefore, the color video camera for production should be used in the future practical applications, although the accuracy and imaging resolution will be relatively low, but could speed up the computing time.

In the tests, the hemispherical light room is sealed, without the interference of external light, so it ensures the consistency of the conditions of acquiring images, the radius of the light room is 0.3 m, and the digital camera used is Canon S80 (Japan), its imaging resolution adopt 2592 × 1944, the video

Table 1. The scope of parameter values.

Sample Name	Grade	Average of H	Average of S	Perimeter	Area	Length of Axis	Maximal Distance	Average Width	Curvature Parameter
Huangya tea	1	68 ±3	0.32 ±0.02	907 ±5	17630 ±40	467 ±4	434 ±2	36.3 ±0.3	1.09 ±0.01
	2	72 ±3	0.36 ±0.03	910 ±5	17640 ±50	470 ±4	436 ±2	36.5 ±0.5	1.09 ±0.01
	3	78 ±3	0.37 ±0.03	915 ±7	17660 ±50	475 ±5	438 ±2	37.5 ±0.6	1.09 ±0.01
Ganlu tea	1	60 ±3	0.26 ±0.02	865 ±6	11700 ±100	496 ±4	313 ±5	24.5 ±1.0	1.55 ±0.01
	2	65 ±4	0.28 ±0.02	870 ±7	11800 ±150	500 ±5	315 ±5	25.0 ±1.3	1.57 ±0.02
	3	69 ±5	0.29 ±0.02	875 ±7	11900 ±200	505 ±5	318 ±7	27.3 ±1.5	1.58 ±0.03
Zhuyeqing tea	1	78 ±2	0.38 ±0.01	1070 ±5	18700 ±80	476 ±4	435 ±2	38.0 ±1.0	1.09 ±0.01
	2	81 ±2	0.39 ±0.01	1073 ±6	18720 ±100	480 ±4	437 ±2	39.0 ±1.0	1.09 ±0.01
	3	85 ±3	0.41 ±0.01	1078 ±6	18750 ±130	485 ±5	439 ±3	40.5 ±1.2	1.10 ±0.01
Yinzhen tea	1	82 ±2	0.40 ±0.01	757 ±4	9250 ±30	475 ±3	448 ±2	17.8 ±0.5	1.06 ±0.01
	2	84 ±2	0.42 ±0.02	760 ±4	9270 ±35	477 ±3	450 ±3	18.5 ±0.6	1.06 ±0.01
	3	87 ±4	0.43 ±0.02	763 ±5	9300 ±35	480 ±4	452 ±3	19.0 ±0.7	1.06 ±0.02

Table 2. Feature parameters of Huangya tea.

Sample Name	Test Times	Average of H	Average of S	Perimeter	Area	Length of Axis	Maximal Distance	Average Width	Curvature Parameter
Huangya tea	1	77.71	0.376	921.36	17757	482.31	439.55	37.18	1.097
	2	79.89	0.385	908.45	17533	472.15	434.61	36.70	1.086
	3	73.37	0.341	917.34	17713	476.47	436.10	37.18	1.093
	4	76.96	0.373	915.53	17685	478.81	438.59	36.54	1.092
	5	75.57	0.363	898.47	17513	466.91	430.35	37.43	1.085
	6	74.50	0.356	903.87	17589	474.82	435.45	36.01	1.090
Average	$\bar{x} \pm \Delta x$	74.08±3.80	0.351±0.025	912.55±6.77	17645±66	474.83±3.70	435.16±2.49	36.89±0.56	1.091±0.004
ANOVA		21.65	0.001	65.47	6593.8	23.03	9.38	0.48	2.41×10^{-5}

Table 3. Feature parameters of Ganlu tea.

Sample Name	Test Times	Average of H	Average of S	Perimeter	Area	Length of Axis	Maximal Distance	Average Width	Curvature Parameter
Ganlu tea	1	72.65	0.317	875.55	11708	493.31	317.15	28.18	1.555
	2	56.50	0.215	881.93	11813	496.58	322.25	24.77	1.541
	3	58.75	0.246	882.72	12195	498.64	315.57	25.38	1.580
	4	71.43	0.312	868.54	11448	493.20	318.26	23.86	1.550
	5	62.47	0.257	893.36	12155	507.51	324.16	27.17	1.566
	6	67.12	0.275	871.12	11697	495.82	307.59	23.45	1.612
Average	$\bar{x} \pm \Delta x$	66.52±4.60	0.280±0.028	873.58±8.65	11808±218	497.87±4.89	317.06±4.00	25.22±1.36	1.571±0.019
ANOVA		34.16	0.001	121.45	68698.1	38.16	30.27	3.06	5.15×10^{-4}

Table 4. Feature parameters of Zhuyeqing tea.

Sample Name	Test Times	Average of H	Average of S	Perimeter	Area	Length of Axis	Maximal Distance	Average Width	Curvature Parameter
Zhuyeqing tea	1	77.62	0.378	1071.39	18812	478.05	437.19	40.35	1.093
	2	78.85	0.384	1065.39	18501	472.22	433.23	37.75	1.090
	3	84.65	0.411	1073.78	18734	477.52	435.52	38.37	1.096
	4	74.57	0.354	1064.13	18652	486.21	438.87	38.24	1.108
	5	78.11	0.382	1085.29	18545	475.53	439.67	40.46	1.082
	6	76.93	0.380	1082.26	18938	488.81	441.26	41.75	1.108
Average	$\bar{x} \pm \Delta x$	79.10±2.46	0.388±0.016	1073.37±7.23	18723±105	479.08±4.53	437.60±2.21	39.12±1.08	1.096±0.007
ANOVA		12.26	0.0004	74.90	18247.7	31.14	7.22	1.81	8.02×10^{-5}

Table 5. Feature parameters of Yinzhen tea.

Sample Name	Test Times	Average of H	Average of S	Perimeter	Area	Length of Axis	Maximal Distance	Average Width	Curvature Parameter
Yinzhen tea	1	83.75	0.423	763.38	9312	482.11	452.53	19.54	1.065
	2	81.78	0.401	757.10	9269	473.07	450.21	18.40	1.051
	3	79.47	0.381	752.63	9236	476.56	449.56	19.12	1.060
	4	81.23	0.407	772.86	9315	480.73	448.61	19.25	1.072
	5	85.97	0.433	753.92	9347	478.61	451.35	18.71	1.060
	6	80.36	0.393	769.08	9255	473.84	445.27	17.42	1.064
Average	$\bar{x} \pm \Delta x$	83.86±2.68	0.420±0.019	761.07±6.20	9286±35	477.07±3.15	449.51±2.52	18.64±0.64	1.061±0.005
ANOVA		10.18	0.0006	54.96	1871.8	14.06	10.65	0.70	4.42×10^{-5}

Table 7. The average accuracy of the test.

Sample Name	Huangya Tea			Ganlu Tea			Zhuyeqing Tea			Yinzhen Tea		
Grade	1	2	3	1	2	3	1	2	3	1	2	3
Accuracy	93.1%	91.2%	92.5%	87.6%	88.3%	86.5%	92.2%	91.6%	91.7%	93.3%	92.1%	92.6%

camera is Sony XR100E (Japan), and the capture resolution is 2304 × 1728.

CONCLUSION

This research discusses the application of image processing and analysis for quantitative grading and identification of different qualities of tea based on color (HSI model) and geometrical information extracted from segmented tea images. The automatic identification of the samples was then performed using a combined neural-network/genetic algorithm approach. We also probe into a new way to choose parameters as identification indexes in genetic neural-network algorithm with the model of tea leaves HSI images and binary tea leaves shape to identify tea leaves images effectively. The established parameters and methods for identification were used to test the tea leaves undergoing different roasting techniques. That means it is feasible to substitute computer vision processing system for human senses in tea identification. It provides a new testing method for sensory test of tea quality, so it has a big and wide application prospect. But there are still many aspects that need to be improved and discussed, such as the choices of feature parameters in modeled identification and the quantitative description of tea quality.

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