International Journal of Signal Processing, Image Processing and Pattern Recognition
Vol.9, No.6 (2016), pp.55-70
http://dx.doi.org/10.14257/ijsip.2016.9.6.06

Corrosion and Deformity Recognition for Current Coin

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Abstract

Current coins often get damaged in the current environment, such as smudginess, discoloration, corrosion, mutilation and attrition. When the damage comes to a certain degree, the continuous use of coins will be impacted. In this paper, relevant identification technologies to mutilation and corrosion which are two common defects in circulation are investigated. At first, an auto identification and quantization algorithm about mutilation area of coin surface, based on Freeman boundary tracing is designed. On the basis of binarization, the algorithm accomplishes boundary tracing and extraction and area calculation automatically after the seed point is determined which is an arbitrary point in extracting mutilation area. Secondly, a clustering method based on HIS color model is developed for auto identification of corrosion area and calculation of corrosion area and average corrosion degree. At last, the validity and practicability of the algorithms are proved by a large number of experimental results.

***Keywords**: Coin, Deformity, Corrosion, Recognition*

1. Introduction

Metal coins can be divided into circulation coins and collection coins. The circulation coins have lots of merits such as abrasion resistance which makes the circulation lifetime as long as 20 years or mora, lower cost than paper money, easy to use and suitable for vending and automatic ticketing services and so on. So, circulation coins have been active in the currency area. At present, at home and abroad, the grading of coins is often determined by a few experts with human eye. But, for circulation coins which have large circulation, it is impossible that each circulation coin is determined by experts. Besides, different expert will give different position for same coin because of subjectivity of human. For the above situation, it is meaningful to research image processing technologies to detect the surface quality of circulation coins for the coin judgment.

Currently, the research about coins is mainly in the counting, recognition and authenticity of coins at home and abroad. For instance, coin counting machine [1-4] uses eddy current sensor to accomplish counting with physical characteristics such as weight, area and material and so on. It not only has the ability to recognize and discriminate coins, but also to count the total face value of coins and the face value of each kind of coins. But, most coin counting machines do not use image processing technology and those who adopt image processing technology mainly recognize coins [5-10]. In China, data of input images are classified by clustering ability of ant colony algorithm which is used by Bi Xiaojun, *etc*, so as to recognize coins [11]. The improved BP neural network is used to recognize coins with different face value by Liu Meijia, *etc.*, [12]. Image processing technologies are used to detect the patterns of coins which are useful to discriminate coins by Zhang Chi, *etc.*, [13]. At abroad, coins are recognized by the research based on some characteristic parameters of rotation invariance of coins images. For example, coins can

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ISSN: 2005-4254 IJSIP

be recognized by the algorithm combined with neural network or genetic algorithm [14-17].

The research which use image processing technologies to detect surface quality of coins is still in initial stage in the world, for instance, the design of synthetic evaluating system of coins surface quality which is proposed by Zhou Guangfu, *etc* [18]. First of all, use image processing technology and get the data of defect degree of coins surface. Then, coins should be given stage treatment by using analytic hierarchy process and fuzzy comprehensive evaluation. In Shanghai coinage Co., LTD, an online detection system about surface quality of finished products is invented to detect the surface quality of coins on product line. In a word, the technology and theory of quality detection of coins surface based on image processing technology are still not perfect and mature. So the research of this area still has extensive prospect and important meaning.

Because the circulation of coins is ever-present, it is inevitable that coins surface will get damage from outside environment (including man-caused and non man-caused). The damage often includes smudginess, corrosion, mutilation and attrition and so on. If the surface of circulation coins are damaged, the condition of coins will become poor. The condition of coins is inversely proportional to the damage degree of coins surface. This means that the bigger the damage is, the poorer the condition is. And the damage degree of coins surface depends on some factors such as area of surface defect. Therefore, this paper aims to develop a quality detection system of coins surface. This system will use knowledge of many disciplines which includes image processing, pattern recognition, computer language and applied mathematics to solve the problems about recognition and segmentation of coins surface defect. So, the data of all kinds of defect on coins surface are useful for the assessment of damage degree and coins grade.

2. Treatment Technology of Coins Surface Defect

The steps of auto identification algorithm of mutilation area are as follows.

Step 1 Preprocessing. The images should be done preprocessing before defect extraction. It means that the area outside coins area need to be changed to white color(because of complex background color), which is conducive to the extraction of defect part.

Step 2 Image binarization. The gray value of defect area is least after preprocessing. So, it is easy to do segmentation on defect area.

Step 3 Boundary extraction of defect area. After step 2, look arbitrary point in extracted defect area as a seed point. The program automatically track and extract boundary.

Step 4 Calculation of area. Calculate the defect area with the boundary points extracted in step 3.

In the above process, the images need to be done gray processing and binarization processing. The so-called gray processing is that change the 24 bits true color image into gray image. Because the color value scope is [0,255], the grade of gray only has 256 kinds. That gray image can only show 256 kinds of gray color. There are three treatment methods.

Maximum: $R=G=B=Max(R,G,B)$

Average: $R=G=B=(R+G+B)/3$

Weighted average: $R=G=B=w_r \times R + w_g \times G + w_b \times B$

The weight values of R、G、B are w_r、w_g、w_b.

In this paper, the weighted average would be used. The transfer formula is as follows.

$$R=G=B=(9798 \times R + 19235 \times G + 3725 \times B)/32768 \quad (1)$$

Binarization processing formula is:

$$R = G = B = \begin{cases} 0 & Th_{r,g,b} < 200 \\ 255 & Th_{r,g,b} \geq 200 \end{cases}$$

$Th_{r,g,b}$ is gray threshold.

Boundary tracing is one of basic image processing. Chain code, proposed by Freeman in 1961, has widespread application in target analysis, image compression and computer graphics. According to the 4 connected or 8 connected relationship, the boundary tracking is from a starting point and it will not stop tacking along the boundary until come to the starting point. Through the boundary tracking, coordinate sequence and chain code of boundary points can be got.

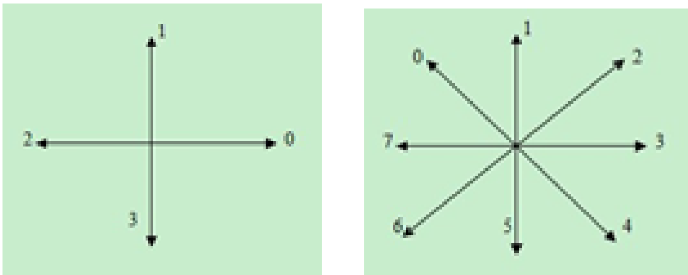

Figure 1. Code of 4-Direction and 8-Direction

In this paper, 8-direction boundary tracking algorithm based on Freeman is adopted to extract boundary points and boundary chain code clockwise [20-21]. And, artificial selection seed point is chosen to select boundary starting point. The specific algorithm is as follows: the image is a binary image (the target area area is white and pixel value is 255; background is black and pixel value is 0) after segmentation of defect area. Select a point randomly in defect area and the first white boundary on it left is the starting point. Begin with the 0 direction of starting point, pixel values of points in the eight directions of the starting point should be judged clockwise. It is not until the point whose pixel value is 255 have been found that the judgment should be carried on. Write down current direction and mark coordinate of the point as Point [i]. Then, make the point as a new target point. Rotating the current direction 90 degrees and that is the new starting direction. After this, pixel values of points in the eight directions of the new target point are judged. So, do circulation until come back to the boundary starting point. The algorithm flowchart is shown in Figure 2.

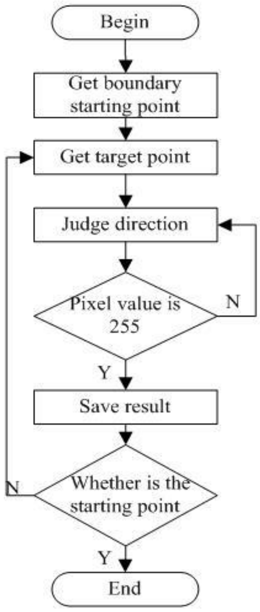

Figure 2. Flowchart of Boundary Tracing Algorithm

Write down the coordinate and chain code direction of boundary points while tracking boundary. Then, combined with Table 1, the type of the point should be judged and marked. The mark way is as follows.

$$nick[i] = \begin{cases} 1 & left \\ 0 & \text{points with nothing} \\ -1 & \text{left boundary point} \end{cases} \tag{2}$$

At last, the area of defect area is calculated by the weighted sum algorithm of abscissas of boundary points. The area formula is shown.

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$$Area = \sum_{i=0}^{n} Po\text{int}[i].X \times nick[i] \tag{3}$$

Corrosion refers to the damage generated by the coins suffered to the external environment in circulation (often refers to a chemical change). Corrosion includes slight corrosion and severe corrosion. The surface of the coins shows incomplete region or extra attachments due to chemical changes. Slight corrosion and severe corrosion can be distinguished by colors usually.

The brightness and saturation of the slight corrosion compared different to the severe corrosion. Typically, the overall brightness of the slight corrosion looks more bright and the colors looks more colorful. The region of the severe corrosion tends to show a darker color such as black, dark red, green, at the same time, the coins of different materials are different.

Table 1. Contrast Table of Left and Right Boundaries Based on Freeman Chain Code

Entered	Out direction							
direction	0	1	2	3	4	5	6	7
0	L	L	L	L	LR	*	*	*
1	L	L	L	L	LR	LR	*	*
2	L	L	L	L	LR	LR	LR	*
3	*	*	*	*	R	R	R	R
4	LR	*	*	*	R	R	R	R
5	LR	LR	*	*	R	R	R	R
6	LR	LR	LR	*	R	R	R	R
7	L	L	L	L	*	*	*	*

For the corrosion of coins, the corroded area maybe similar but their corrosion is large difference because of different chemical changes or chemical changes in different levels (Referred to Figure 3).It would be inaccurate if measure the extent of corrosion only by corrosion area of the surface of the coin. Then, we use the corrosion area and the average degree of corrosion to measure the influence of corrosion on the coin. Among them, the average degree of corrosion using the brightness I of the HSI space to measure and the corrosion area refers to the size of the corrosion area on the surface of coins.

For coins in circulation, the surface of the coins will show different colors due to the different chemical changes or chemical changes in varying degrees. Different colors of corrosion in the entire coin corrosion play different role in the degree of severity. Therefore, the method of corrosion detection for the coins as follows: First of all, conduct 256 colors (or 729 colors) quantization processing for the whole coin image. Secondly, add up the number of corrosion colors on the coin surface. Then, add up the area of different colors. Finally, calculate the average degree of corrosion of all kinds of corrosion.

Figure 3. Corrosion Coins

Due to the number of colors in the color space is too much, processing and storage color occupy massive resources. In order to reduce the dimension of color features, we usually process the color quantization before extracting color features. That is, we choose n colors as little as possible from the colorful original image and close to the original image as realistically as possible according to the reconstructed image obtained by the n kinds of color. The basic idea of color quantization is set the quantization points as the axis; classify the color similar to it as a class, cluster the minimum number of colors in the lowest average variance. At present, the color quantization algorithm is divided into two directions: one is quantization algorithm based on the color frequency, the other quantization algorithm based on the color space. Such as frequency sequence method, the Octrees algorithm can be viewed as algorithms based on color frequency, while uniform quantization algorithm, the median cut algorithm, the clustering algorithm can be viewed as algorithms based on color space.

This project mainly used the uniform quantization algorithm. This method is to divide the color space, select a group of uniform distribution of red, blue and green components of the color table color. The easiest method is: separate the RGB space first, so that each dimension is divided into equal pieces, use intersection bodies for each primary color layer to produce a variety of basic colors, so we can select a group of widely used color. The most typical situation is that K is 256, the monitor has 8-bit plane. Taking the sensitivity of the human eye to different colors into account, divide the red axis in space and the green axis in three planes each, divide blue axis in two planes, so that 8 kinds of red and green, 4 kinds of blue, species combination to get the $8 \times 8 \times 4 = 256$ colors. With this unified quantitative methods, an image color value by rounding some elements to get approximate representation. This method uses a fixed definition of the color palette, rather than according to the image content to select color palette makes the limited value of colors in the color table unrelated to the display image colors. This method is simple and fast.

Corrosion area calculation is relatively simple, only need to add up the total area of the coin surface corrosion. In order to estimate the corrosion area, we divide corroded areas to segment according to the large difference of the corrosion color. The classifier is designed according to different materials in the concrete realization of split. Copper coin classifier conditions are as follows:

(a) R < 100 && G < 100 && B < 100；

(b) R > G && G >= B；

(c) G > R && G > B。

The classifier of non-copper coins conditions are as follows:

(a) R < 100 && G < 100 && B < 100；

(b) R > G && G >= B。

If segmentation effect is not very good, you can manually segmentation processing. Concrete processing methods are detailed in the operating instructions section.

The calculation of average corrosion degree is complicated, and it is related to the brightness of the HSI space and the size of each corrosion area. HSI color space is created from the person's psychological perception point of view. H (Hue) is the most important attribute of color, to determine the nature of the color and determined by the dominant wavelength of light reflected from objects, different wavelengths produce different colors feel. S (Saturation) is the depth of color and shades, the higher the saturation, the deeper the color. I (Brightness) is a uniform amount of feeling, refers to the human eye's feeling light shade. The greater the light energy, the greater the brightness. HSI color space and RGB color space can be conversed though some algorithm. The following is color model conversion equation:

$$I = \frac{1}{\sqrt{3}}(R + G + B) \tag{4}$$

$$S = 1 - \frac{3\min(R, G, B)}{R + G + B} \tag{5}$$

$$H = \begin{cases} \theta & G \geq B \\ 2\pi - \theta & G < B \end{cases} \tag{6}$$

$$\theta = \cos^{-1}[\frac{\frac{1}{2}[(R-G)+(R-B)]}{\sqrt{(R-G)^2+(R-G)(G-B)}}] \tag{7}$$

For the calculation of average degree of corrosion indicators require a combination of each kind of the corrosion area. If you just calculate the average brightness of all kinds of colors, the same average degree of corrosion occurs, the actual corrosion degree of difference is larger or corrosion area is quite different. Therefore, in the calculation process to consider the impact of a variety of corrosion area. Statistics and analysis of a large number of corrosion coins come to the coin surface corrosion of the more serious color, the brightness of the color, the smaller (Brightness I up to 255). Thus the average degree of corrosion is calculated as follows:

$$D = \frac{\sum_{i=0}^{n} S_i \times (255 - I_i)}{S} \tag{8}$$

S_i Indicates the area of a corrosion color;

I_i Indicates the average brightness of a corrosion color;

S is the total area of corrosion.

Through a lot of statistics and analysis, the average degree of corrosion is generally in the range of 50 to 200. Which the average degree of corrosion normalized formula:

$$D = (D-50)/150 \tag{9}$$

The basic idea of the proposed algorithm: First, convert the original image to the HSI color space. Coarse classification the color of the original image in the HSI color space use hue H. That is, the color with similar shades is clustered into a subclass. Secondly, determine the number of initial cluster centers each sub-class should have depending on the size of the subclass. Then, use the combination of the luminance component of the HSI color space and the color saturation to determine the initial cluster centers for each subclass. Then convert the color space to the corresponding RGB color space, and though the merge algorithm, the splitting algorithm and the iterative algorithm and some auxiliary algorithms to strike the final cluster centers. Finally, reconstruct the new color palette and the original image.

The specific implementation steps of the algorithm are as follows:

Step 1 convert the original image from the RGB color space to HSI color space.

Step 2 coarsely classifies the image pixels according to the hue component. For the hue H of HSI color space, its transformation range of 0 to 360 °. Different degrees represent not kinds of shades of color. When use hue to initial cluster the color of original image should not be divided too small. Here hue of the finer points and details of the image to keep the better, but for the layering of images will be weakened. In this article, the original image roughly divided into 12 categories combined with color hue, each 30° belong a subclass.

Steps 3 add up the number of pixels contained in each subclass. Denoted by Ni.

Step 4 strike the number of the subclass should be included in the initial cluster centers according to the number of pixels in each subclass. In order to ensure that the reconstructed image has good detail, as long as the number of image pixels contained in the subclass is greater than 0 and will be assigned initial cluster centers.

The concrete allocation method as follows: First, check the image pixels contained in each subclass. Add up the number of subclasses which pixels is greater than 0, denoted as n. Then allocated to each of the sub-class, which the number of pixels is greater than 0, an initial cluster centers. Then, here left K-n initial cluster centers. Finally, distribute the remaining initial cluster centers combined (10).

$$ClusterNum\,[i] = (K - n) \times N_i / N \tag{10}$$

The entire allocation process can be expressed as:

$$ClusterNum[i] = \begin{cases} (K-n) \times N_i / N + 1 & N_i > 0 \\ 0 & N_i = 0 \end{cases} \tag{11}$$

Steps 5 add up the brightness I and the saturation of each pixel in each sub-class.

Step 6 combined with the number ClusterNum[i] of initial cluster centers, the brightness I and the saturation S distribute the initial cluster centers for each subclass.

Step 7 combined with a principle of color similarity and initial cluster centers of each subclass, process cluster pixels of each subclass. Then form a subclass of the sub-cluster family and the initial cluster centers. This article uses the Euclidean distance to cluster pixels, calculated equation as follows:

$$D = \sqrt{(I_i - I_j)^2 + (S_i - S_j)^2} \tag{12}$$

Strike Euclidean distance D of each pixel to all the initial cluster centers. For any pixel, it will be clustered to the initial cluster center which has the minimum Euclidean distance. Finally, calculate the mean of all pixels' R, G and B component in each sub-cluster family as the initial cluster centers of the sub-cluster family.

Step 8 merges the cluster center. The values of x in Step 6 is round $\sqrt{\text{ClusterNum[i]}}$ and plus 1, so the number of each sub-cluster center may greater than or equal to the Ki. Repeat this until the number of cluster centers in each sub-class is equal to the number originally assigned.

Step 9 split the cluster center. First, check the volatility of the sub-cluster family of each subclass. Here the measure of volatility is defined by the standard deviation of sub-cluster family. Calculated as follows:

$$S = \sqrt{\frac{1}{n}\sum_{i=0}^{n}(G_i - \overline{G})^2} \tag{13}$$

G_i Indicates each color's gray degree. Calculate the sub-cluster family which has the maximum volatility, and then divided the sub-cluster family is into two. Then get two new cluster centers, the new cluster center can be expressed as follows:

$$(R_1, G_1, B_1) = (\overline{R} + S_r, \overline{G} + S_g, \overline{B} + S_b) \tag{14}$$

And

$$(R_2, G_2, B_2) = (\overline{R} - S_r, \overline{G} - S_g, \overline{B} - S_b) \tag{15}$$

Among them, $\overline{R}$, $\overline{G}$, $\overline{B}$ is the mean of R, G, B in the sub-cluster family, S_r, s_g, s_b is the standard differential R, G, B in the sub-cluster family.

Step 10 re-clustering and calculate the new cluster center of each sub-cluster family according to the cluster center, and then compared with the original cluster center. Repeat this until the new cluster centers no longer change.

Step 11 take out the final cluster centers R, G and B values, and form a new palette, then reconstruct a new image.

The above algorithm is mainly included two parts, namely get the initial cluster centers in the HSI color space and determine the final cluster centers in the RGB color space. Finally, form the color palette according to the cluster center, and then reconstruct a new image. The detailed algorithm flow chart is as follows.

3. Experimental Results and Analysis

In order to verify the validity and robustness of the algorithm, systematically repeated test is tested, first of all, rotated on coins of different types of defects. Then process the variety of rotated coin images. Finally, the results are analyzed. Here the main validation on the torn, dirty and discolored coins, for various defects for pictures of rotating 0 degrees respectively, 120 degrees, 240 degrees, and then analysis of the rotated picture.

Incomplete processing module is designed combines the types of incomplete. There are two main defects for the circulation defects coin, that is, torn area completely missing, and part of the area that is missing. According to different defects, design a variety of processing methods. Specific treatment is as follows:

Defect incomplete test mainly uses the 1yuan and 1jiao coins, the artwork and the image after rotate are shown in Figure 5-7, obvious missing zones are existed in the coins.

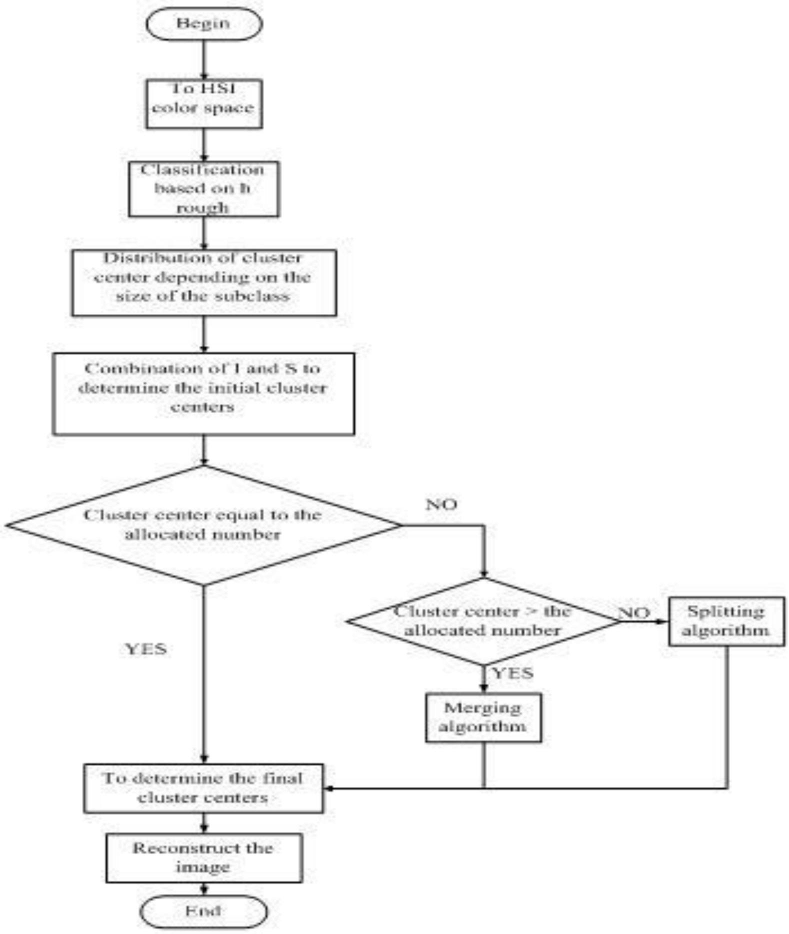


Figure 4. Algorithm Flowchart

(a)Incomplete of 1yuan (b) Incomplete of 1jiao

Figure 5. The Graph of 0 Degree Rotation Process Results

(a)Incomplete of 1yuan (b) Incomplete of 1jiao

Figure 6. The graph of 120 Degree Rotation Process Results

(a)Incomplete of 1yuan (b) Incomplete of 1jiao

Figure 7. The Graph of 240 Degree Rotation Process Results

Incomplete duplication of test results are shown in Table 2, for 1yuan torn area in Figure 7 (a), the processing results are stably in the 6-7 pixels in different Angle image. The torn areas are between 58-59 pixels in Figure 7 (b) of 1jiao torn areas. The standard deviation of 1jiao is slightly larger, which associated with the missing areas on the coins are too large. Visible for shooting at different angles of the same coins measured difference between the dirty areas are not large, and the standard deviation is also to meet the requirements, so the defect identification and the quantitative methods are proved valid for the incomplete recognition of the two materials coins.

Table 2. The Results of Incomplete Duplication Test

The name \ Angle		Angle of rotation 0	120	240	Standard deviation
Incomplete area	(a)Attenuation of 1yuan	6.6240	6.6069	6.6262	0.0106
	(b)Attenuation of 1jiao	58.4528	59.5139	58.0811	0.7435

The result of defect detection are shown in Figure 8-10, grey and black pixels in the diagram represents the detected dirty region, visible for shooting at different angles of the same coin, compared with the naked eye to the original image, the torn place is the same.

(a)Incomplete of 1yuan (b) Incomplete of 1jiao

Figure 8. The Result of 0 Degree Rotation Process Results

(a)Incomplete of 1yuan (b) Incomplete of 1jiao

Figure 9. The Result of 120 Degree Rotation Process Results

(a)Incomplete of 1yuan (b) Incomplete of 1jiao

Figure 10. The Result of 240 Degree Rotation Process Results

Corrosion process in a similar way of dirty, the algorithm's design is depending on the material to the circulation coin. Because of its material decisions, normal circulation coins in aluminum-magnesium, just missing the original metal luster on the surface after corroded, there was too much change in color. Nickel plated coins like aluminum and magnesium coins, due to the nature of nickel, Normal circulation coins are difficult to corrode, but when the surface of the coin after nickel plating wear, the internal steel materials are easy to corrosion. The corrosion of colors is such as red and black est. Different corrosion and processing results are listed below.

The corrosion defects tests are mainly used the coin of 1jiao and 1yuan. The original images and the images after rotating are shown in Figure 11-13.

(a)Incomplete of 1jiao (b) Incomplete of 1yuan

Figure 11. The Result of 240 Degree Rotation Process Results

(a)Incomplete of 1jiao (b) Incomplete of 1yuan

Figure 12. The Result of 120 Degree Rotation

(a)Incomplete of 1jiao (b) Incomplete of 1yuan

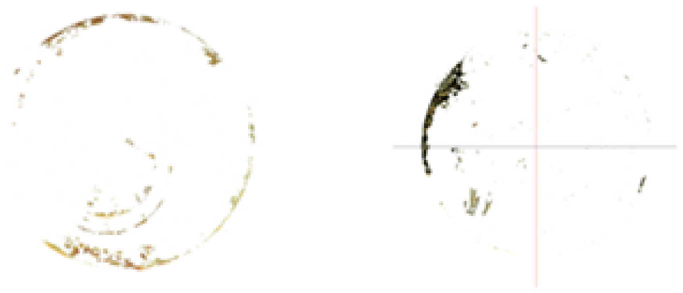
Figure 13. The Result of 120 Degree Rotation

The results in detection of corrosion index are show in table 3, for the corrosion areas of 1jiao in Figure 13 (a), the processing results stability between the 9.7-9.8 pixels at different angles image, and the processing results stability between the 18.5-18.8 pixels, for the corrosion areas of 1yuan in Figure 13 (b). The standard deviation of 1yuan is slightly larger, and is associated with the small contrast of the corrosion and the background of 1yuan. And a little difference from the standard deviation of corrosion degrees after the normalization. Visible for shooting at different angles of the same coins measured difference between the area of corrosion and the degree of corrosion are not large, and the standard deviation is also to meet the requirements, so based on color clustering for corrosion identification and quantification methods are proved valid for the smudgy recognition of the two materials coins.

Table 3. Corrosion Duplicative Testing Results

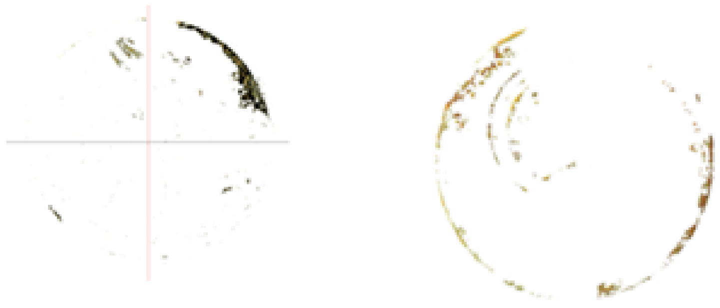
Name \ Angle		Angle of rotation			Standard deviation
		0	120	240	
Corrosion area	(a) Corrosion of 1 jiao	9.8003	9.7668	9.7623	0.0225
	(b) Corrosion of 1 yuan	18.8411	18.7705	18.5802	0.1349
Average degree of corrosion	(c) Corrosion of 1 jiao	0.6088	0.6108	0.6121	0.0017
	(d) Corrosion of 1 yuan	0.4537	0.4517	0.4502	0.0018

Figure 14-16 shows the result of defect detection, the remaining pixel after image registration representative of the detect corrosion areas, visible for shooting at different angles of the same coin, Whether nickel plating coins or aluminum and magnesium are marked the location of the coins out much fewer, and are basically the same corrosion location of the naked eye distinguish the original image.



(a)Incomplete of 1jiao (b) Incomplete of 1yuan

Figure 14. The Result of 0 Degree Rotation Process Results



(a)Incomplete of 1jiao (b) Incomplete of 1yuan

Figure 15. The Result of 120 Degree Rotation Process Results

(a)Incomplete of 1jiao (b) Incomplete of 1yuan

Figure 16. The Result of 240 Degree Rotation Process Results

To sum up, for the same coin can be seen rotating different angles measured results changed little, and also contains rotating error in this error. Therefore, it can be concluded that the actual error is less than or equal to the above error in the system. Errors are within the allowed range, so it can be found that this algorithm has good repeatability and robustness.

4. Conclusion

Circulation currency in the exists of torn and corrosion are in-depth researched, and based on border track law of torn automatically recognition and quantitative algorithm principle, and based on color poly class of corrosion recognition and quantitative algorithm of principle are detailed elaborated, this two species defects of the circulation coins surface are extracted out through the experiments, and the repeatability and robustness test of the algorithm are finished, the work in this paper can provide the data support for coins surface damage degree and coins grade of further assessment.

Acknowledgments

This work is partly supported by China Postdoctoral Science Foundation Funded Project (Grant No.2013M530954), the State Key Laboratory of Robotics Foundation (Grant No. 2012017), Program for Liaoning Excellent Talents in University(Grant No.LJQ2014021), the Natural Science Foundation of Liaoning Province (Grant No.2014020093), Liaoning Million Talents Project (Grant No. 2013921032), Chair Professor Project in Liaoning Province, and Shenyang Ligong University Computer Application Key Discipline Foundation (Grant No.4771004kfx09).

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