A Robust Coin Recognition Method with Rotation Invariance

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Abstract— **This paper presents a robust coin recognition method with rotation invariance. The rotation invariance feature is represented by the absolute value of Fourier coefficients of polar image of coin on circles with different radii. The absolute value of Fourier coefficients is considered as the individual feature of the particular coin. Moreover, in this paper, the variations on surface of coin such as light reflection effect, are taken into account. Such variations effect can be reduced using the Fourier approximation of the coin image. Finally, coin can be recognized by the distance between the absolute value of Fourier coefficients obtained from the reference coin and the coin to be recognized. The coin recognition experiments are given to show the effectiveness of the proposed method.**

I. Introduction

There are many coin operated equipments in the world [1] such as an automatic machine for payment especially vending machine. Coins used in many countries have various patterns such as shape, size, surface design, weight and so on. Some coins used in different countries have similarity in size, weight and surface design but different value. In Thailand also, some patterns of Thai coins are similar to that of coin in other countries. It is difficult for an automatic system to recognize coins with a similar pattern. Moreover, amulet coin is popular in Thailand. There are various patterns for Thai amulet coins and some patterns are very high value. Fig.1 (a) and (b) show various patterns of amulet coins and baht coins used in Thailand, respectively. To recognize such amulet coins, the expert in coin is needed. However, it usually takes long time for operation and there are occasions for the examiners to make some mistakes by visual examination. In this paper we propose a method for realizing a simple automatic coin recognition system to recognize coins effectively.

Coin recognition methods have been reported in [2][3]. However, the calculation procedures in those methods are quite complicate. In this paper, we propose a robust coin recognition method with rotation invariance. The rotation invariance feature is represented by the absolute value of Fourier coefficients of polar image of coin on circles with different radii. The effectiveness of rotation invariance feature for seal imprint verification was shown in the work [4]. Moreover, the variations in images obtained from new and used coins are also discussed in this paper. The coin images obtained from new and used coins are very different especially for Thai amulet coins because most of Thai amulet coins have been treated by enamel process. In this paper, such variation can be reduced by the Fourier approximation of the coin image. The obtained absolute value of the Fourier coefficients of polar image of coin on circles with different radii is used as the feature for coin recognition. Finally, coin can be recognized by the distance between the above features obtained from the reference and the coin to be recognized.

Fig. 1. (a) Thai amulet coins (b) Thai baht coins

II. Feature Extraction

The coin images with 256 gray level are collected by using digital camera with the same light condition and same position. Therefore there is no variation in size of coin and light. Then the coin image is represented by 2D continuous function in

Cartesian coordinates as

$$f(x,y)=\sum_{n=0}^{Q}\sum_{m=0}^{Q}F(n,m)\phi(x-n,y-m) \tag{1}$$

where

$$\phi(x-n,y-m)==\frac{sin\pi x}{\pi x}.\frac{sin\pi y}{\pi y} \tag{2}$$

and Q is an integer related to the image size. $F(n,m)$ is gray level at a pixel (n,m) Then the following function is defined by letting $x=rcos\theta, y=rsin\theta$ in (1) as

$$\hat{f}(r,\theta)=f(rcos\theta,rsin\theta) \tag{3}$$

where $0\le r\le R, 0\le\theta\le 2\pi$ and $\hat{f}(r,\theta)$ is defined inside the circle of radius R. An example of the polar image of coin is shown in Fig.2

For coin recognition, in case the coins are of the same size, the design of coin surface is one of the important features of coin image. However, the coin image can be rotated by any random number of degrees. In order to extract the rotation invariance feature of the coin image, it is assumed here that without the loss of generality, $\hat{f}(r,\theta)$ as

$$\hat{f}(r,\theta)=\hat{f}(r,\theta+2m\pi) \tag{4}$$

where m is any integer and $\hat{f}(r,\theta)$ is expanded into Fourier series by letting $r=r_k$(constant) as

$$\hat{f}(r_k,\theta)=\sum_{m=-M}^{M}a_m^{(k)}e^{jm\theta} \tag{5}$$

where

$$a_m^{(k)}=\frac{1}{2\pi}\int_0^{2\pi}\hat{f}(r_k,\theta)e^{-jm\theta}d\theta, \tag{6}$$

and k is number of radius of coin images. Let $\hat{g}(r_k,\theta)=\hat{f}(r_k,\theta+\alpha)$ be the rotated seal imprint of $\hat{f}(r_k,\theta)$ by angle α about its origin. Then it can be seen that the Fourier coefficients b_m^k of $\hat{g}(r_k,\theta)$ is given as

$$b_m^k=a_m^{(k)}e^{-jm\alpha} \tag{7}$$

Thus we have the following relation:

$$u_m^k\equiv\mid b_m^k\mid=\mid a_m^{(k)}\mid \tag{8}$$

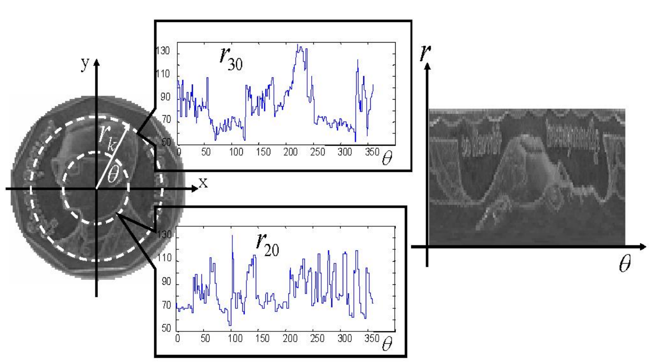

Fig. 2. polar image of coin on circles with different radii

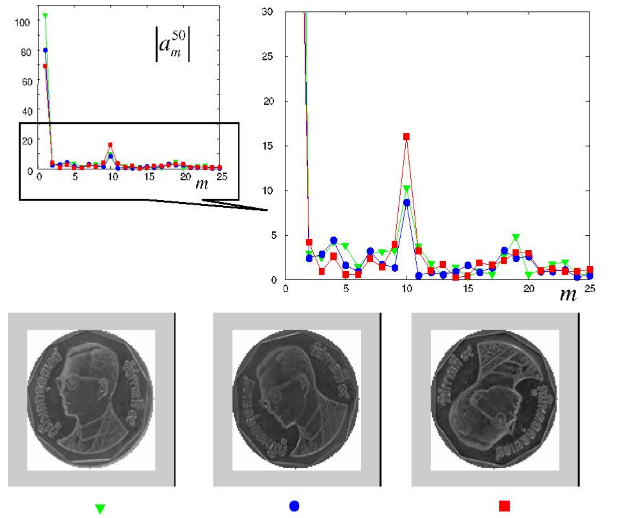

Fig. 3. $\mid a_m^{(k)}\mid$ obtained from three Thai coins which have the same surface design and rotated by different degrees.

It can be seen from Eq. (8) that the absolute value of Fourier coefficients, u_m^k, of coin on circles with different radii are rotation invariant.

Fig.3 shows $\mid a_m^{(k)}\mid$ obtained from three Thai coins which were rotated by different degrees. It can be seen from Fig.3 that $\mid a_m^{(k)}\mid$ obtained from three Thai coins are quite similar.

Fig. 4. (a),(b) Thai 5 baht coins which have the same surface, (c),(d)Thai amulet coins which have the same surface design.

Fig.4(a),(b) show Thai 5 baht coins which have the same surface design and Fig.4(c),(d) show Thai amulet coins which have the same surface design. It can be seen from Fig. 4 that the images obtained from the two coins which have the same surface design are quite different because of the effect of light reflection for new and used coins. And some Thai amulet coins have been treated by enamel process and enamel coating on the surface of the amulet coin will become fade for a long time use. In order to recognize such those images, the variation in surface of coin should be reduced. In this paper, such a variation in surface of coin can be reduced

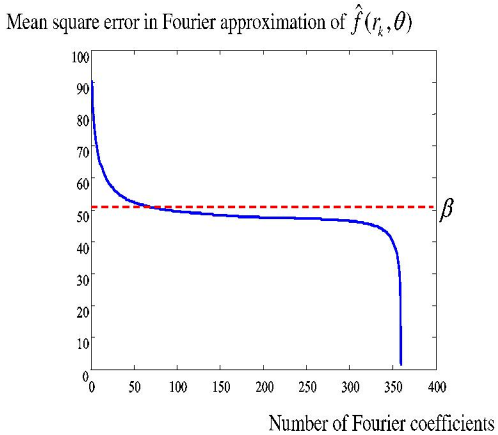

Fig. 5. mean square error in Fourier approximation of $\hat{f}(r_k, \theta)$.

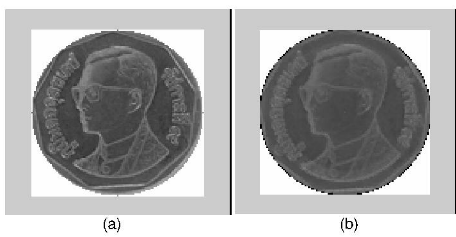

Fig. 6. (a) original coin image,(b) Fourier approximation of the coin image in (a) $(M = 60)$

by Fourier series with a suitable number of coefficients. The suitable number of Fourier coefficients is determined by minimizing the mean square error in the Fourier approximation of $\hat{f}(r_k, \theta)$. Fig. 5 shows the plot of mean square error in Fourier approximation of $\hat{f}(r_k, \theta)$ and the threshold β for selecting the suitable number of Fourier coefficients. The suitable number of Fourier coefficients is determined so that the mean square error of the Fourier approximation may be less than the threshold value β, where the threshold value β is determined from training data. The obtained Fourier coefficients are considered as the individual feature of the particular coin. Fig. 6 (a) and (b) show original coin image and its Fourier approximation, respectively. And Fig. 7 shows the absolute value of Fourier coefficients obtained from the new and used coins with same surface design and the absolute value of Fourier coefficients obtained from other coin with different surface design, respectively. It can be seen from Fig.7 that the absolute value of Fourier coefficients obtained from the coins with same surface design are quite similar but the absolute value of Fourier coefficients obtained from the other coin is different.

Moreover, to reduce the above variation, it is desirable to normalize the total sum of the gray level. Therefore in our method u_0^k is normalized as 1. Then the feature vector of coin image is defined by the Fourier coefficients as

$$\mathbf{u}_k^T = [1, \hat{u}_1^k ..., \hat{u}_M^k], (k = 1, ..., K) \tag{9}$$

where

$$\hat{u}_m^k = \frac{u_m^k}{u_0^k}$$

and $\mathbf{u}_k^T$ is the transposition of $\mathbf{u}_k$ and used as the feature for coin recognition.

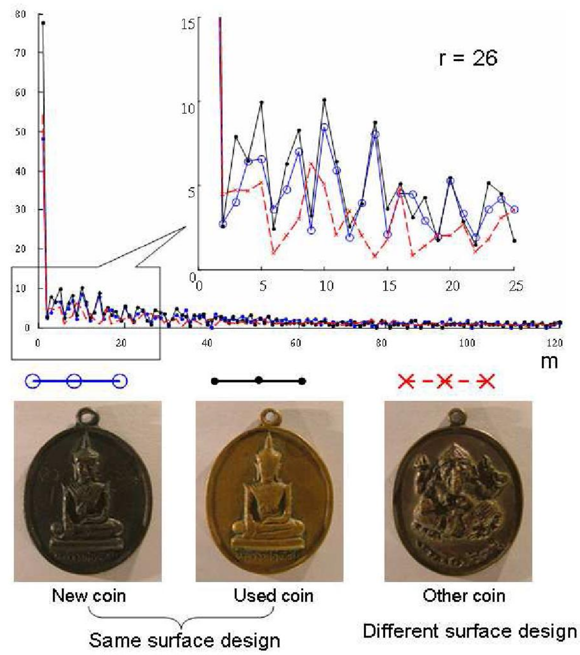

Fig. 7. absolute value of Fourier coefficients obtained from the new coin, used coin and other coin, respectively

III. Coin Recognition Algorithm

In this section, the feature vector $\mathbf{u}_k$ obtained in the preceding section is used to recognize coin. The coin recognition procedures are given below.

1) Represent a coin image as 2D continuous function

$$f(x, y) = \sum_{n=0}^{Q} \sum_{m=0}^{Q} F(n, m)\phi(x - n, y - m) \tag{10}$$

and define $\hat{f}(r, \theta) = f(rcos\theta, rsin\theta)$

2) Compute the Fourier coefficients $b_m^{(k)}$ of the polar image $\hat{f}(r, \theta)$

$$b_m^{(k)} = \frac{1}{2\pi} \int_0^{2\pi} \hat{f}(r_k, \theta)e^{-jm\theta} d\theta, (m = 0, ..., M) \tag{11}$$

3) Define the feature vector

$$\mathbf{v}_k^T = [1, \hat{v}_1^k ..., \hat{v}_M^k], (k = 1, ..., K) \tag{12}$$

where

$$\hat{v}_m^k = \frac{v_m^k}{v_0^k},$$
$$v_m^k \equiv |b_m^{(k)}|$$

Fig. 8. US 25 cent coin and Thai 5 baht coin

4) The coin is recognized as

$$\left.\begin{array}{ll} true & if \;\; \|\mathbf{u}_k - \mathbf{v}_k\| < \eta, \\ false & \text{otherwise,} \end{array}\right\} \tag{13}$$

where $\|.\|$ is Euclidean norm, $\mathbf{u}_k$ is feature vector obtained from reference data for a particular coin and η is a predetermined threshold value for a particular coin determined by using reference data.

IV. Experiments

In our experiments, coin images were collected by using digital camera. Two experiments are given to show the effectiveness of the proposed method. In the first experiment, Thai 5 baht coin and US 25 cent coin having the similar size(Fig.8) were used for coin recognition. In the second experiment, Thai amulet coins with the similar size were used for coin recognition. The coins used in both experiments have various variations such as stains, blur and so on. The experimental results of the first and second experiments are shown in Fig.9 and Fig.10, respectively. In the both experiments, to show the generalization error rates, we use the threshold value at the point where the Type I(false rejection) and Type II(false acceptance) error rates are nearly equal for coin recognition for a particular coin.

V. Conclusion

We proposed a robust coin recognition method with rotation invariance. First, the polar image obtained from coin represented as 2D continuous function in Cartesian coordinates was expanded into Fourier series.The rotation invariance feature is represented by the absolute value of Fourier coefficients of polar image of coin on circles with different radii. Finally, coin can be recognized by the distance between the absolute values of Fourier coefficients obtained from the reference coin and the coin to be recognized. It was found from the experimental results that the proposed method is robust for coin recognition.

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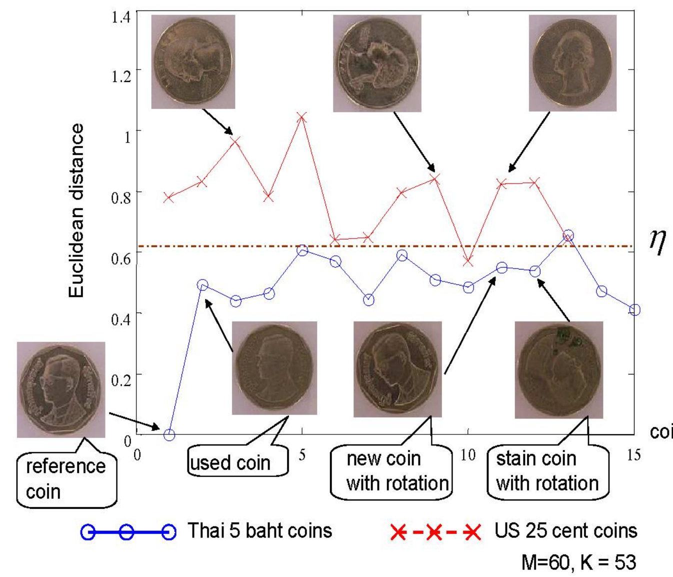

Fig. 9. First experiment: Euclidean distance obtained from Thai 5 baht coins and US 25 cent coins (Type I(false rejection) and Type II(false acceptance) error rates were 7.14% and 7.69%, respectively)

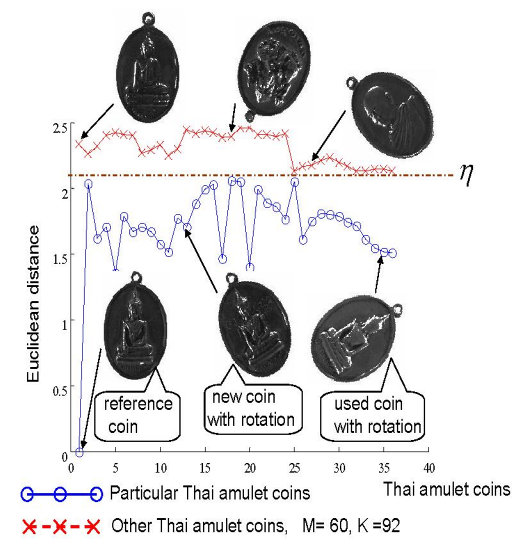

Fig. 10. Second experiment: Euclidean distance obtained from particular Thai amulet coins and other Thai amulet coins(Type I and Type II error rates were 0.00% and 0.00%, respectively)