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3—15 Automatic Seal Verification by Calculating Distance between 2D and 3D Patterns

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Abstract

This paper describes an efficient matching approach for automatic seal verification. Most of the conventional approaches to this problem used a reference seal impression registered as a 2D image. However, it was difficult to absorb various input seal patterns by only one reference pattern. In our previous study, one of the authors has been proposed a new algorithm in which the reference seal was measured as a 3D range image. The verification rate was improved from that by using the 2D reference image. But, in the previous algorithm, as the seal verification was performed in 2D pattern space by generating the optimum 2D reference seal impression for the input pattern from the 3D reference image, this way still cannot verify random dot-patterns of the seal-ink. In this paper, our approach uses 3D shape information directly in the matching process. The input seal is verified by calculating Euclidean distance from the 3D reference seal. The excellent recognition rate achieved in all the performed experiments indicate that the proposed matching is well-suited for seal verification. Moreover, the verification speed was improved remarkably.

1 Introduction

In Japanese society, seal verification have been widely used for verifying a person. Recently, attending with the complex social structure, seal verification by human-eyes has become too hard, and an automatic verification system is required as a labor-saving device. Figure 1 shows examples of seal impressions. Over the past years, many studies have been made on automatic seal verification. Most of the methods performed one-to-one matching between the reference impression and the input one which were measured as 2D images. However,

True seal impressions.

Forgery seal impressions for the above *true* them.

Figure 1: Examples of seal impressions.

those automatic methods have not turned out to be practical. As one of the reasons, we consider that the conventional methods could not absorb the various quality by only matching techniques. In fact, most of the papers limited materials with high quality in the experiment. In the actual work of seal verification, there are almost no limits on the size and the shape; moreover, there are various impression qualities. Therefore, it needs dealing with, not only clear impressions but also unclear impressions for realizing a practical automatic verification system. The variety of the impression quality is mainly caused by the changes of affixing conditions.

One of the authors has been proposed a new approach in which a reference seal is measured as a 3D range image instead of a 2D image for absorbing the various quality conditions [1]-[5]. In that system, stamping conditions of an input seal are extracted. By using them, its optimum 2D reference pattern for the input pattern is generated from the 3D reference seal by virtual stamping process. Then the verification is performed in the 2D pattern matching space between the input pattern and the generated 2D reference pattern. By using the previous system, the

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Figure 2: An example of 3D reference seal

correct rate was improved from 93.2% to 97.0% for 1,000 test data. However, the 2D matching process still includes a serious problem that many random dot-patterns exist around boundaries of seal-ink. It is difficult to verify this part by using the 2D pattern matching techniques. In order to solve the problem, this paper proposes a matching process by using 3D shape information of the reference seal directly.

2 Previous Algorithm using 3D Reference Seals

In our system, the reference seal is fixed with the surface faced to the sensor of a range finder system, and the range from the sensor to the uneven seal surface is measured. Fig.2 shows an example of measured reference seal.

An input seal is measured as a 2D binary image. The input pattern can be changed innumerably by stamping conditions. In the previous study, the stamping conditions are expressed as six parameters, such as position, rotation, slant and pressure. By changing the parameters, the most similar 2D reference pattern to the input pattern is generated in the virtual stamping process. After that, the seal verification is performed by an overlapping method in 2D pattern space.

By using that approach, the correct rate was improved from 93.2% to 97.0%. However, the correct rate is not enough to the practical use. We consider that the rate is the limit of property for 2D matching. Random dot-patterns around boundaries of seal-ink cannot be absorbed by 2D matching. In order to break down this stone wall, a novel matching approach is needed.

3 Proposed Algorithm by Calculating Distance between 2D and 3D Patterns

3.1 Policy

In the previous approach based on 2D matching, random-dot patterns around boundaries of the seal-ink could not be verified. In order to solve the problem, we use the 3D shape information of a reference seal directly. This approach is constructed based on the following concept: if an input seal impression is stamped by *true* seal, there should be a corresponding part on the convex surface of the 3D reference image for each ink-dot on the input seal impression. So the distance between the input seal impression and the reference seal is calculated as the mean of Euclidean distance for each seal-ink between the stamped paper and the corresponding surface of the reference seal. If the input seal is stamped by *true* seal, the distance will be small. Since this method verifies only the part of the seal-ink, the random-dot problem can be solved.

3.2 Definition of distance

By using Hough Transform in 3D parameter space, a plane of the reference seal can be extracted as

$$\rho_0 = x\cos\phi_0\cos\theta_0 + y\cos\phi_0\sin\theta_0 + z\sin\phi_0, \quad (1)$$

(see in Refs.[4] and [5]). So, the reference seal has its own peculiar three parameters $(\theta_0, \phi_0, \rho_0)$. Let $z_m(x, y)$ be the range values of the reference seal. Then, a revised range $z_r(x, y)$ will be defined as

$$z_r(x, y) = ax + by + c - z_m(x, y), \quad (2)$$

where

$$\begin{aligned} a &= -\frac{\cos\phi_0\cos\theta_0}{\sin\phi_0}, \\ b &= -\frac{\cos\phi_0\sin\theta_0}{\sin\phi_0}, \\ c &= \frac{\rho_0}{\sin\phi_0}. \end{aligned}$$

Next, the normalized range $z_R(x, y) \in [0, 1]$ shall be derived as

$$z_R(x, y) = \frac{z_r(x, y) - \min z_r}{\max z_r - \min z_r}. \quad (3)$$

Figure 3 schematizes the normalized range for each seal-ink.

Then the distance between the input seal impression and the 3D reference seal, which is essential in this paper, will be defined as

$$D = \frac{\sum_{(x^*, y^*)} z_R(x^*, y^*)}{\sum_{(x^*, y^*)} 1}, \quad (4)$$

where (x^*, y^*) means coordinate points of the input seal impression with seal-ink.

By the way, z_r in Eq.(2) can be include quantization error by Hough transform, and the reference

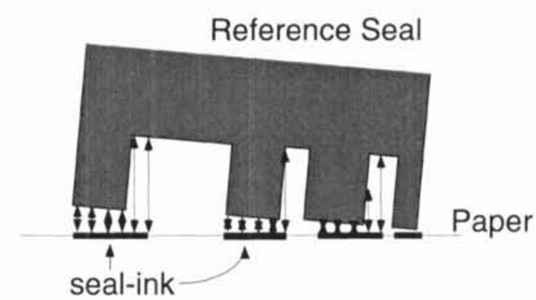

Figure 3: Definition of the normalized range . (Arrays show the range.)

seal has a slope. This slope has an bad influence on the distance D. We revise the distance as follows:

$$D^* = D - M, \qquad (5)$$

where M is the average of the revised range on only convex surface of the reference seal.

3.3 Calculation of distance

In order to calculate the distance, we have to fit parameters for position and rotation between the reference and the input images. By changing the parameters, the minimum distance is decided as the result.

3.3.1 Initialization of position parameters

First, the parameters fot the position of the seal are initialized. The algorithm is the same way of the previous studies [4],[5]. The difference in positioning seal impressions is represented by the center of both the 3D reference image and the input image. The initial values of the parameters are determined as the center of the circumscribed rectangle. However, the center of the input seal impression may not be same to the center of this circumscribed rectangle in the case of noisy input image. For such case, the circumscribed rectangle rotated by 45 degree is also estimated. When the distance between the centers of two circumscribed rectangles is more than ε, both centers are determined as initial values and the following search is processed in parallel. In this paper, ε is set as $\varepsilon = 1$.

3.3.2 Initialization of rotation parameters

Second, the parameter for the rotation of the seal is initialized. The algorithm is also the same way of the previous studies [4],[5]. The surface of the range image $z_R(x, y)$ in Eq.(3) is binarized. So the binarized image can be regarded as a standard seal impression. Then the marginal densities of the binarized image and the input image are calculated. The marginal densities are defined as follows. The binary images is divided equally to N sectors around the center, and the number of the dots in each sector is the marginal density. Let the marginal densities for the binarized image from 3D data and for the input images be $\{f_r(n)\}_{n=0}^{N-1}$ and $\{f_b(n)\}_{n=0}^{N-1}$ respectively, the correlation function of them is given as

$$R(k) = \sum_{n=0}^{N-1} f_r(n) f_b((n+k)_{modN}) \qquad (6)$$
$$(k = 0, 1, \ldots, N-1)$$

When $k = k_0$ maximizes $R(k)$, the initial parameter for rotation is determined as k_0. The angle of rotation is $2\pi k_0/N$ degree. However, the degree may be determined in different about 180 degree in the case that the distribution of the marginal densities is almost symmetric with respect to a point, which is made when the pattern of the seal is nearly symmetric with respect to a point such as "山下". Therefore we also select second local maximum as another initial parameter and the following search is processed in parallel. In this paper, N is set as $N = 360$.

3.3.3 Iterative fitting of parameters

The optimum value of the parameters are found by an iterative searching.

[STEP 1] Eight-neighbor connection points and the present point of the parameters for the position are estimated. We select candidate points of position which has the distance between $D^*_{\min}$ and $D^*_{\min} + T$, where T means a threshold value. For the candidates, and next search is performed.

[STEP 2] The before, present and after points of the rotation parameter is estimated. We select candidate degrees of rotation which has also the distance between $D^*_{\min}$ and $D^*_{\min} + T$.

After [STEP 2], the calculated distance is compared with one of the previous iteration. When the distance is improved, the procedure goes back to [STEP 1] with $T_{new} = T_{old}/10$ in order to get better distance. When the distance not improved, the procedure stops. In this paper, we set $T = 0.0001$.

4 Experiments

Proposed algorithm has been developed using C language on SUN Sparc Station 20. The same data sets in Ref.[5] were used for evaluation. Five seals were used as materials. *Forgery* seals for each seal

Table 1: Verification rate.

	2D	3D [5]	Proposed
Correct rate	93.2%	97.0%	99.2%
Error rate	6.8%	3.0%	0.8%

True seal impressions.

Forgery seal impressions.

Figure 4: Partial set of low-quality input seal impressions.

were also prepared (see in Fig.1). 3D reference seals were measured with a range finder system. The sampling space of $x - y$ axis is set as 0.05mm in order to measure a seal in 256×256 pixels and the accuracy of z axis is set as 0.005mm. 100 patterns of 2D input seals for each seal were affixed in random conditions, then the seal impressions were of uneven quality. Therefore, there were 1,000 patterns for input data.

Table 1 shows the experimental result of the verification rate. Since we used the same test data in Ref.[5], the conventional rates are also indicated. Let the threshold for decision making (*true* or *forgery*) be set as to minimize the error rate. In this experiment, the threshold was 0.046. The result shows that the verification rate was improved.

Figure 4 shows a partial set of low-quality input seal impressions. The proposed method could also perform correct decision. This means that the method can absorb the loss part of seal-ink, and it solves the random-dot problem.

There are eight mis-verifications in 1,000 test data in this experiment. All mis-verified input data is shown in Fig.5. It is difficult to verify those patterns correctly by even human-eyes. Those data were stamped by *true* seals. This means that all *forgery* seals were verified correctly as *forgery*.

It was brought to light that the maximum area of seal-ink for each eight data was 58.3% of the area of ideal seal impressions which was stamped politely. Therefore, it is confirmed experimentally, if we set a reject option for input seal impressions which do not have 60% or high area of seal-ink, the error rate becomes zero.

Figure 5: Eight mis-verified seal impressions.

The verification speed was also improved remarkably from 1 [hour/char.] (in Ref.[5]) to 20 [sec./char.] on the same computer.

5 Conclusions

We have presented an algorithm and a system to verify seal impressions. The system calculates the distance between a 2D input seal and a 3D reference seal. By using the shape of the reference seal as matching process, variety of input patterns can be absorbed and seals can be verified physically. Experimental results showed that both correct rate and verification speed were improved. Especially, *forgery* seals were never verified as *true* ones. By setting a reject option, the error rate became zero.

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