PERSONAL IDENTIFICATION BY EXTRACTING SIFT FEATURES FROM LASER SPECKLE PATTERNS

[1]Chih-Ming Liao, [2]Ping S. Huang, [3]Chung-Cheng Chiu, and [1]Yi-Yuh Hwang

[1]Chung-Shan Institute of Science and Technology, Taoyuan 335, Taiwan, R.O.C.
[2]Department of Electronic Engineering, Ming Chuan University, Taoyuan 333, Taiwan, R.O.C.
[3]Department of Electrical and Electronic Engineering, Chung Cheng Institute of Technology, National Defense University, Taoyuan 335, Taiwan, R.O.C.

ABSTRACT

This paper presents a novel personal identification method by extracting unique object features from optical speckle patterns using the SIFT (Scale Invariant Feature Transform) algorithm. Accurate identification is achieved by developing an invariant speckle capturing device and recognition criteria. Experimental results show that optical speckle pattern of a given material is invariant after slight movement and the patterns captured from different areas of the same material are distinct. Therefore, this merit can be adopted for security applications by using the surface of specific object as the personal identification card and extracting speckle patterns from this surface to recognize the identity of certain subject.

Index Terms— Laser Speckle Patterns, Identification System, SIFT, Recognition.

1. INTRODUCTION

Detailed light speckles can be generated by laser light sources via the optical interference reaction [1]. The speckle patterns are normally considered as noises that are believed to deteriorate the image quality [2]. However, after optical speckle was discovered to be related to the movement, it was used as sensing techniques for surface displacement, distortion, strain, vibration, rotation and deformation [3-4]. Compared with the Light Emitting Diodes (LEDs), laser is a light source with high coherence that can directly reflect the surface details suitable for recognition without the need of shadow [5] and the speckle images generated by the laser light can provide superb resolution quality.

Speckle patterns resulting from the field interference contain 3-D information of the illuminated surface and tend to produce irregular distribution of tiny spots. Since the laser speckle is sensitive to its reflected surface profile, the shape of speckle pattern is easy to be changed by the relative difference of optical phase after relative surface motion such as displacement. To keep the speckle pattern invariant and reduce the variation of relative difference of optical phase is essential for image recognition. The key factors for correctly recognizing LSPs (Laser Speckle Patterns) include an adequate speckle size [6], visible speckle patterns, and the most important one, the speckle shape invariance in a speckle pattern image. To solve the problems described above, in this paper, a speckle capturing device is developed [7-8].

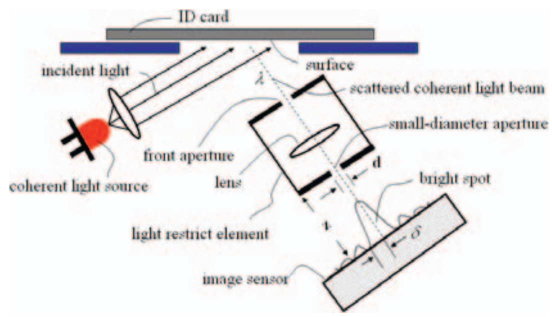

Figure 1 The optical configuration of the proposed device

This paper presents a novel personal identification method by applying image recognition techniques at laser speckle patterns. The proposed optical configuration is shown in Fig. 1. Inside the device, the optical speckle capturing device [7] developed by Laser Physics Section of Chung-Shan Institute of Science & Technology is adopted. Using the prototype of the optical speckle capturing device, laser speckle patterns captured from the test material are invariant. Also, due to that the invariant speckle include rich feature information, it is feasible to do personal identification using the features of the speckle patterns reflected from the test materials called ID cards. Furthermore, since the 3D texture on the object surface is hard to be deliberately duplicated, personal identity can be uniquely recognized by matching the speckle pattern captured from the ID card against the stored patterns inside the database.

2. INVARIANCE OF LASER SPECKLES

As shown in Fig. 1, a highly coherent light is emitted from a laser light source and then the scattered lights from the surface pass through a light restrictive element. The light restrictive element is implemented with an aperture and lens resulting in a diffractive effect for the incoming scattered lights and the diffractive effect produces several concentric rings called Airy disks on the image sensor. The relationship for the half-width δ of the central bright spot, the light wavelength λ, the aperture diameter d, and the distance z between the aperture and the image sensor is represented by

$$\delta = 1.22\frac{\lambda}{d}z \tag{1}$$

Given the wavelength λ of the laser light source, the size of bright spot can be adjusted via the ratio of z/d. For the image to be correctly recognized, the spot size should be larger than the minimum cell size of image sensor. In general, the half-width δ value is designed to be close to the cell size of image sensor such that miniature bright spots can be detected by the image sensor and the resolution is increased.

According to Fig. 1, each scattered light from adjacent scattering points on the illuminated surface passes through the light restrictive element. Therefore, different bright spots interfere with each other and produce a distribution of bright and dark spots that forms a speckle pattern. If the lights from a scattering point and its adjacent scattering points generate constructive interferences on the image sensor, then a bright and large size speckle is created. As shown in Fig. 1, a convergent lens and a front aperture are introduced along the optical path to confine the incident angle of the scattered light from the surface, i.e. to restrict the image capturing area on the surface. Once the image capturing area is limited, the maximum variation of optical path difference λ/5 can be satisfied and a shape-invariant speckle image is obtained from the image sensor while a relative motion occurs between the optical speckle capturing device and the surface [8].

By properly adjusting the diameter and the position of the aperture, the speckle size can be enlarged and the capturing area from the surface can be limited. Then the resulted speckle can be shifted accordingly and, at the same time, the speckle pattern is invariant with respect to the relative motion [8].

3. SPECKLE CAPTURING AND RECOGNITION

3.1 Setup of Experimental Environment

As shown in Fig. 2, an experimental system for speckle capturing is built for analyzing the speckle patterns. This system consists of the speckle capturing device, the personal computer with an image frame grabber, and the manual moving stage. Furthermore, the speckle capturing device includes a laser diode, the optical lens and the image sensor constituting off-the-shelf high resolution digital cameras.

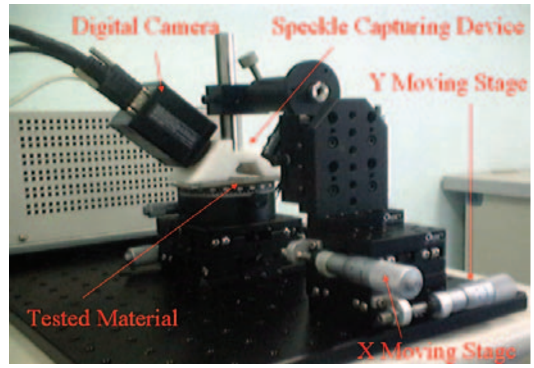

Figure 2 Experimental speckle capturing system.

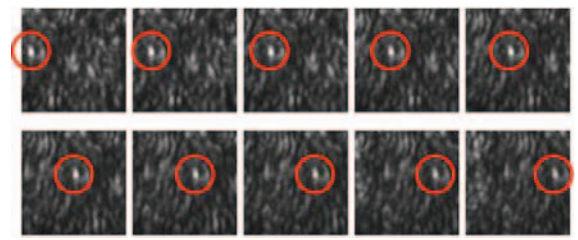

Figure 3 Exemplar speckle patterns from the tested material

The wavelength of laser light is 650 nm and the pixel size of image sensor is 3.45 um × 3.45 um. The resolution of image sensor is designed to be 2448 × 2050 pixels and only 64 × 64 pixels are adopted as the ROI (Region of Interest) transmitted to the frame grabber card of IBM PC. Due to the magnification ratio of the optical capturing device is designed to be 0.5, the actual coverage area of the 64 × 64 pixels image is about 442um × 442um (442um = 64 × 3.45um × 2).

A relative movement between the speckle capturing device and tested materials is given by the manual moving stage. An Aluminum pad is chosen as the test material and the manual moving stage is moved in one direction with a step size 50um. The captured image sequences are shown in Fig. 3. As shown in Fig. 3, the speckle patterns captured from tested materials are shape invariant and this feature can be adopted for the recognition applications using speckle patterns.

3.2 Speckle Recognition Using SIFT Features

SIFT [9] (Scale-invariant feature transform) is an algorithm in computer vision for extracting distinctive and invariant features from images and those features can be used to perform reliable matching between the capturing image and those images in the database. The initial speckle pattern is used as the model and its corresponding features are stored in the database for image matching in the future. Note that, after SIFT analysis, the image with 64 × 64 pixels contains around 50 to 130 keypoints.

As shown in Fig. 2, when the manual moving stage is moved along the X-direction with a step size of 50um, corresponding features are extracted from each individual image captured in every step. The extracted features of each image are then matched with those keypoints of the model in the database. As shown in Fig. 4, the matched features between the captured image and the model image are linked with red lines. Feature matching is accomplished by identifying the nearest neighbors of model keypoints to the extracted keypoints of the captured image. The nearest neighbors are defined as the extracted keypoints with minimum Euclidean distance to the given model keypoints. The probability of a correct match can be determined by taking the ratio of the distance to the closest neighbor to that to the second closest [10]. In this paper, the ratio is defined as the Distance Ratio Threshold (DRT). To improve the match robustness, those keypoints with the DRT value greater than 0.6 are rejected.

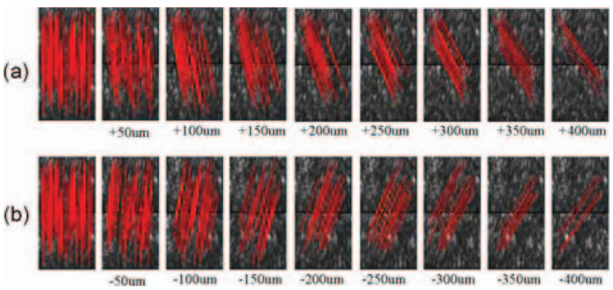

Figure 4 The matched features between the original images (top row) and the moved images (bottom row) (a) along the +X direction (b) along the -X direction (DRT =0.6)

As shown in Fig. 4, the speckle images can be still identified correctly even while the test material is moved with a limited displacement. As the displacement is changed, the number of matched feature keypoints varies. According to the experimental results, when the displacement is over 442um, there will be no matches by choosing an appropriate DRT value. The evaluation of robust identification process will be discussed in the next section.

4. PERFORMANCE ANALYSIS

To further analyze the performance of feature matching between the captured image and the model image while the captured image is moving, we have used the match count to measure the similarity of those two images. Match count is obtained by accumulating the number of matched keypoints between two images. As shown in Fig. 5, the match count between the captured image and the model image is different under different displacement cases. The larger the DRT becomes, the larger the match count is. Also, when the displacement in both directions becomes larger, the match count value will turn into smaller. Note that a few incorrect matches included in the match count can be eliminated by using the RANSAC [11] (RANdom SAmple Consensus) process. RANSAC is an iterative method to estimate the parameters of a mathematical model from a set of observed data which contains outliers.

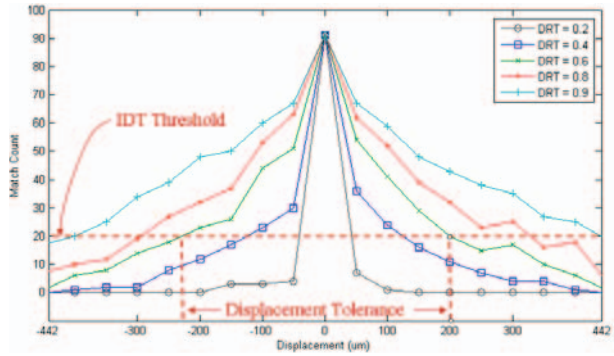

Figure 5 The match count between the captured image and the model image using different DRT values

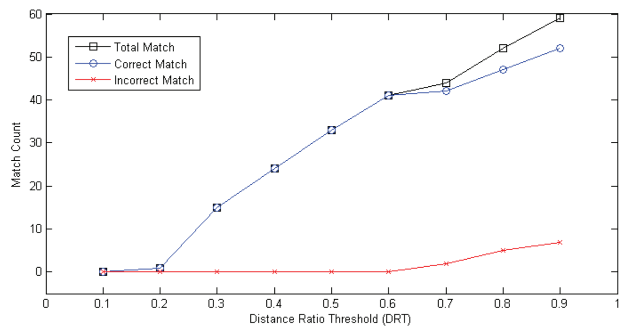

Figure 6 The correct match and incorrect match between the capturing image and the model image (with 100um displacement)

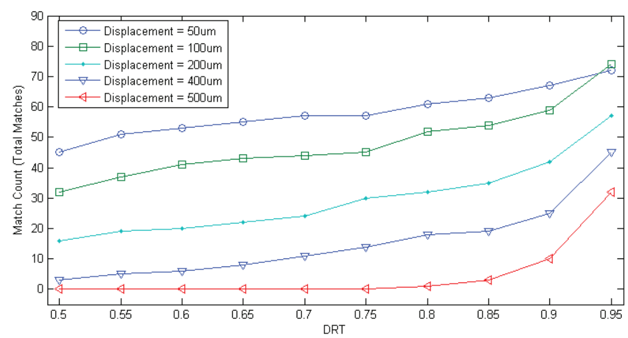

Figure 7 Matching count vs. DRT in different displacement values

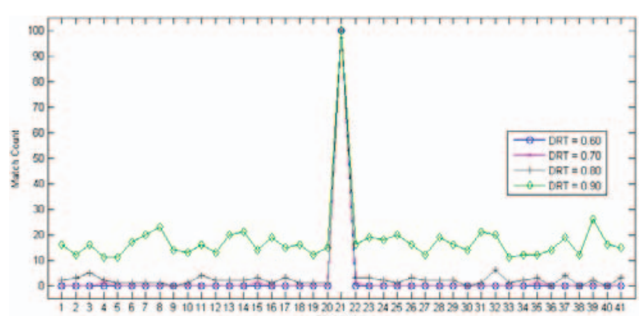

Figure 8 The match count of ID card #21 with 41 models in different DRT

By fixing the displacement to 100um, Fig. 6 shows the relationship between parameters of match count and DRT. Note that the curves of correct match and incorrect match are greatly separated after the DRT value is larger than 0.2. The incorrect match is increased when the DRT value is greater than 0.6. Fig. 7 also shows the relationship between parameters of match count and DRT, however, five different displacement values are considered. The larger the DRT becomes, the larger the match count is.

To apply the feature matching scheme mentioned above for ID card recognition, we have collected 41 Aluminum pads as the ID cards. They are numbered from 1 to 41 and preprocessed as 41 models. The 21st ID card is chosen as the candidate to be recognized. Matching results of the candidate ID card to all 41 models are shown in Fig. 8. As we can see in Fig. 8, the number of incorrect match keypoints is increased when the DRT value becomes larger. The incorrect matches can be eliminated by using the RANSAC procedure or by choosing an appropriate DRT value that robust identification results can be achieved. According to the experimental results, the DRT value can be set as 0.6.

Although Fig. 8 only shows the match count results of the 21st ID card to all 41 models, the other 40 ID cards can be individually tested in turn and similar results are obtained. As shown in Fig. 5, a threshold value called IDT (IDentification Threshold) is defined. In the identification procedure, the largest match count between the captured image and all model images are compared with the IDT value to verify whether the identification system can successfully recognize the ID card. The possibility of identification error will be reduced while setting a larger IDT value.

On the other hand, the tolerant displacement of the ID card should be taken into consideration when the ID card is inserted into the identification system and the tolerance depends on the values of IDT and DRT. As shown in Fig. 5, when the threshold values of IDT and DRT are set to 20 and 0.6, respectively, the tolerant displacement of the ID card is about ±200um. To increase the IDT value will reduce the possibility of identification errors; however, the tolerant displacement of the ID card is also decreased. Therefore, by choosing appropriate threshold values of DRT and IDT, better displacement tolerance and more robust identification results can be achieved.

5. CONCLUSIONS

This paper presents a novel personal identification method by applying image recognition techniques at laser speckle patterns. Unique object features can be extracted from optical speckle patterns using the SIFT algorithm. Accurate recognition is achieved by developing an invariant speckle capturing device and recognition criteria. We have demonstrated that the integration of invariant speckle patterns and feature recognition algorithm can produce robust personal identification results.

Experimental results show that the optical speckle pattern of a given material is invariant during small displacement and the optical speckle patterns on different areas of the same material are different. This merit provides the potential of speckle patterns for security applications by using the object surface as the personal identification card to recognize the identity of certain subject. By using the SIFT algorithm and the RANSAC procedure for feature extraction, personal identification using the speckle patterns reflected from the ID card becomes feasible with great potential.

ACKNOWLEDGMENT

This research is supported in part by the National Science Council, Taiwan under the grant NSC 100-2221-E-130 -021.

REFERENCES

[1] J. W. Goodman, *Laser Speckle and Related Phenomena*, Springer-Verlag, Berlin, Chapter 2, 1975.

[2] T. Iwai, T. Asakura, "Speckle reduction in coherent information processing," *Proceedings of the IEEE*, 84(5), pp. 765-781, May 1996.

[3] B. Rose, H. Iman, S. G. Hanson, H. T. Yura, and R. S. Hansen, "Laser-speckle angular-displacement sensor-theoretical and experimental study," *Applied Optics*, 37(11), pp. 2119-2129, 1998.

[4] P. Popov, S. Pulov, and V. Pulov, "A laser speckle pattern technique for designing an optical computer mouse," *Optics and Lasers in Engineering*, 42(1), pp. 21-26, July 2004.

[5] M. Sjo¨dahl and L. R. Benckert, "Systematic and random errors in electronic speckle photography," *Applied Optics*, 33(31), pp. 7461-7471, November 1994.

[6] Yi-Yuh Hwang, Ming Chen, Mau-Ran Wang, Wen-Chen Huang, and Shin-I Ma, *Device and method for capturing speckles*, US Patent, US 2007/0139659 A1, 2007.

[7] Yi-Yuh Hwang, Ming Chen, Shin-I Ma, Chin-Der Hwang, Mau-Ran Wang, and Wen-Chen Huang, *Image invariant optical speckle capturing device and method*, US Patent, US2008/0088853 A1, 2008.

[8] Chih-Ming Liao, Ping S. Huang, Yi-Yuh Hwang, Ming Chen, and Chung-Cheng Chiu, "Robust technique of analyzing and locating laser speckle patterns for optical computer mice," *Optics and Lasers in Engineering*, 47(7-8), pp. 875-883, 2009.

[9] D. G. Lowe, "Distinctive image features from scale - invariant keypoints," International Journal of Computer Vision, 60(2), pp. 91-110, November 2004.

[10] M. A. Fischler and R. C. Bolles, "Random Sample Consensus: A Paradigm for Model Fitting with Applications to Image Analysis and Automated Cartography," *ACM Communications*, 24(6), pp. 381-395, June 1981.

[11] P. D. Kovesi. *Matlab and octave functions for computer vision and image processing*. School of Computer Science & Software Engineering, University of Western Australia. Available from: <http://www.csse.uwa.edu.au/~pk/research/matlabfns/>