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Multi-resolution image fusion technique and its application to forensic science

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Abstract

Image fusion is a process of combining two or more images into an image. It can extract features from source images, and provide more information than one image can. Multi-resolution analysis plays an important role in image processing, it provides a technique to decompose an image and extract information from coarse to fine scales. In some practical forensic examinations (such as the cartridge image check), we cannot obtain all information from just one image; on the contrary, we need information from images with difference light sources (or light ways). In this paper, we apply an image fusion method based on multi-resolution analysis to forensic science. Synthetic and real images (such as images from closed-up photography and flash photography) are used to show the capability of the multi-resolution image fusion technique.

Keywords: Image fusion; Multi-resolution analysis; Forensic image processing

1. Introduction

Image fusion is a process of combining two or more images into an image. It can extract features from source images, and provide more information than one image can [1–3]. In other words, image fusion is a technique to integrate information from multiple images. These images may come from one sensor or multiple sensors [3]. Image fusion provides a useful tool to integrate multiple images into a composite image that is more suitable for the purposes of human visual perception and can help us to extract more features [1,2]. For example, in flight navigation, the fusion of visual and infrared images can aid pilots navigate in poor weather conditions and keep the safety of aerial sailing [2]; in military fields, it can assist armed forces to ascertain where the enemies are in the night fighting; in medical applications, the fusion of computer tomography and magnetic resonance images may display the whole structure in bioscience (Fig. 1) [2,4,5].

The aim of image fusion is to integrate complementary and redundant information from multiple images to create a composite image that contains a better description of the scene. By integrating information, image fusion can reduce dimensionality. This results in a more efficient storage and faster interpretation of the images. By using redundant information, image fusion may improve accuracy as well as reliability; and by using complementary information, image fusion may improve interpretation capabilities with respect to subsequent tasks. According to above characteristics, image fusion leads more accurate data, increased utility and robust performance [2,3,6,7].

When using the image fusion technique, some general requirements must be considered [2,8–10]:

- The fusion algorithm should not discard any information contained in the source images.
- The fusion algorithm should not introduce any artifacts or inconsistencies that can distract or mislead a human observer or any subsequent image processing steps.
- The fusion algorithm must be reliable, robust and have, as much as possible, the capability to tolerate imperfections such as noise or misregistrations.

The simplest method of fusing images is accomplished by computing their average generally [2]. Through averaging, features from each source image are presented in the fused image; however, the contrast of the original features may be

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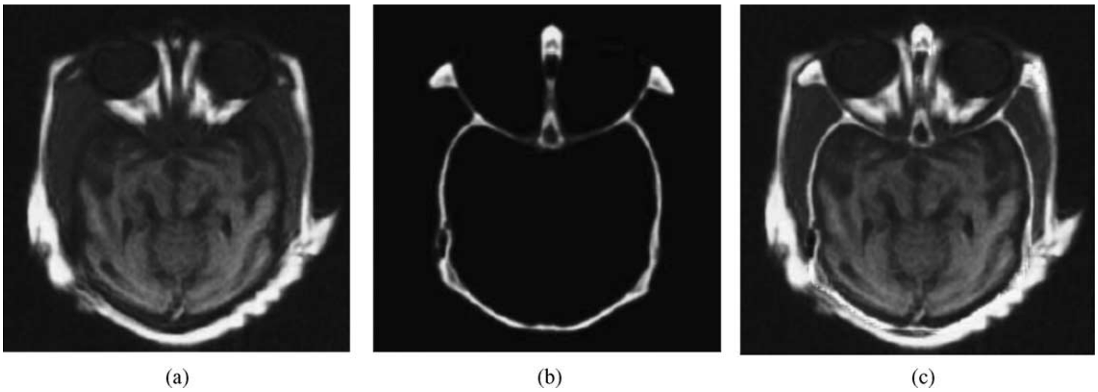


Fig. 1. An example of image fusion in medical imaging: (a) MRI image; (b) CT image; (c) the fused image from (a) and (b) [2].

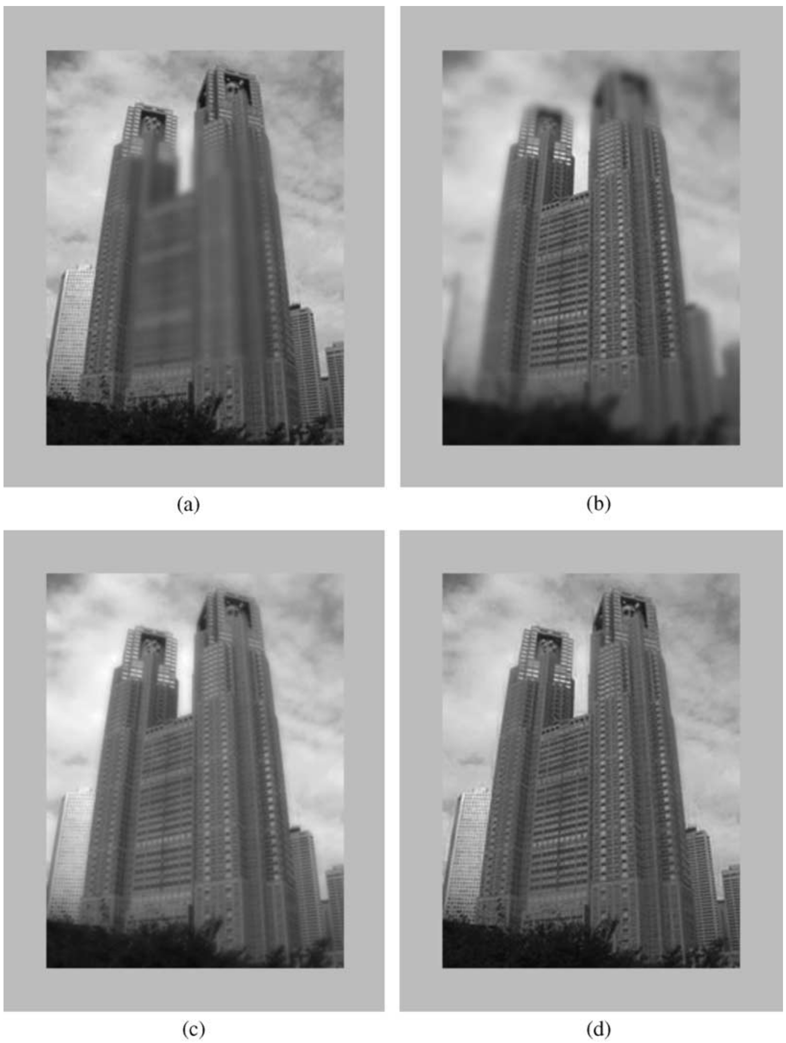


Fig. 2. An example for comparing averaging fusion and multi-resolution fusion: (a) the first building image with the blurred middle portion; (b) the second building image with the blurred outside portion; (c) the fusion result with averaging both images; (d) the fusion result with the multi-resolution fusion (wavelet image fusion).

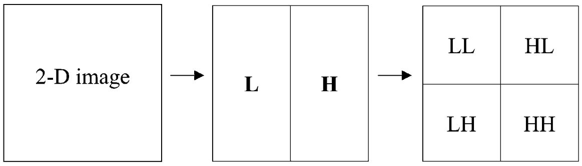


Fig. 3. The Haar wavelet transform framework for two-dimensional image decomposition.

significantly reduced, especially for the details. In this paper, we apply an image fusion method based on multi-resolution analysis to forensic science. Synthetic and real images (such as images from closed-up photography and flash photography) are used to show the capability of the multi-resolution image fusion technique.

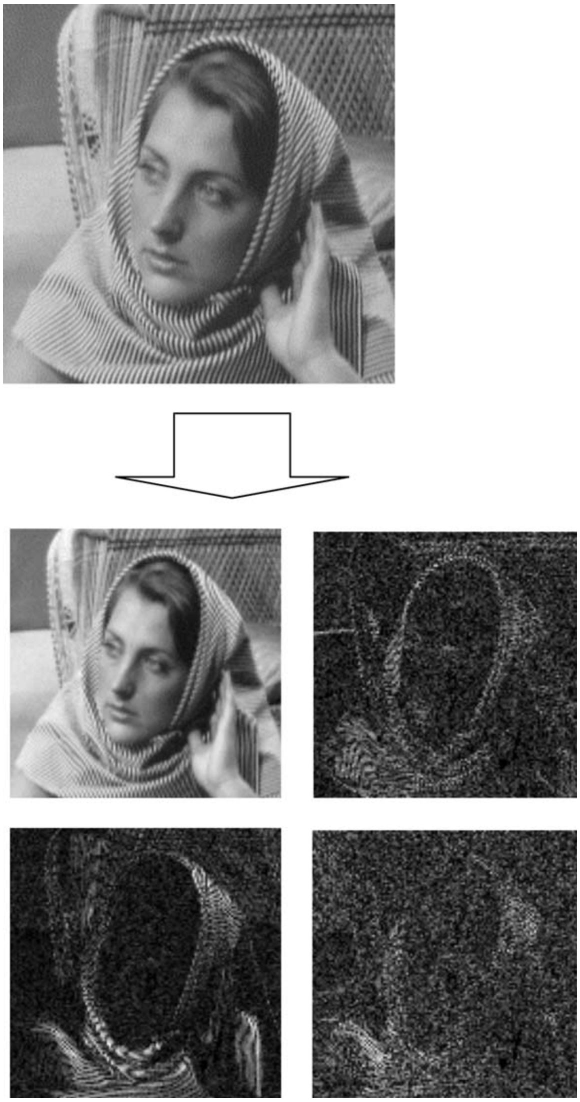


Fig. 4. An example for the Haar wavelet transform framework in two-dimensional image decomposition (one level wavelet decomposition).

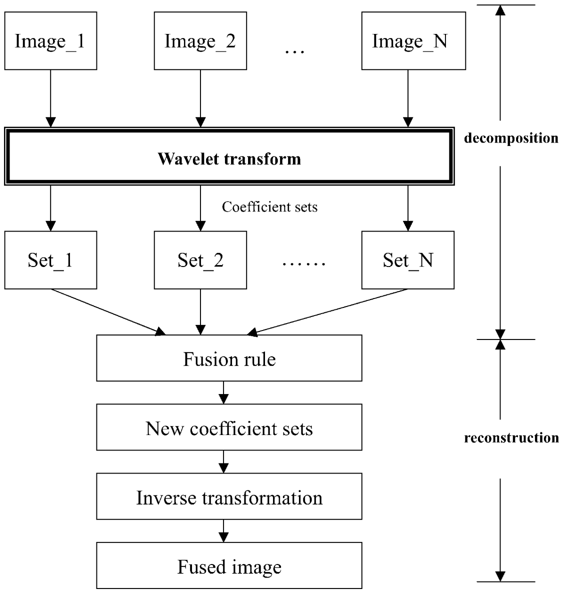


Fig. 5. The flowchart of wavelet image fusion (WIF) [1].

2. Methods

2.1. The reason of using multi-resolution image fusion

The simplest method of fusing images is to average all source images. Through averaging, features from each

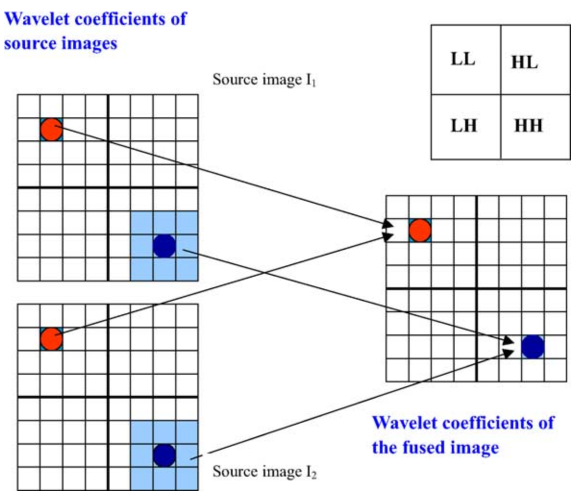


Fig. 6. The fusion rule used in this paper: in LL, we average the coefficients from two sources; in HL, LH and HH, we make a 3×3 mask to measure the variation of pixels in the window for each image. We use the center pixel value of the window with larger variation as the fusion value in the corresponding position.

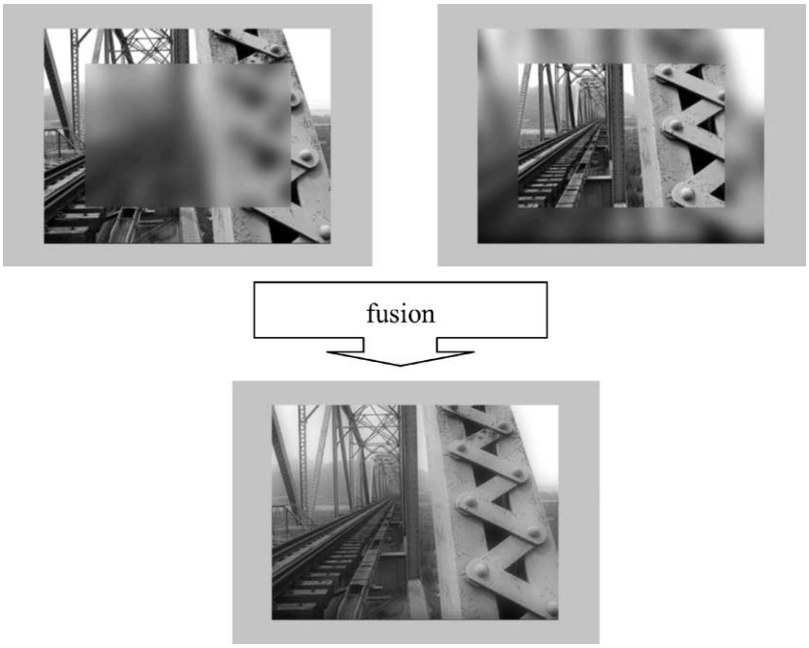


Fig. 7. An example of WIF.

Fig. 8. An example for the shift effect of WIF: (a and b) source images; (c) the fused image, we can see the sculpture portion is blurred.

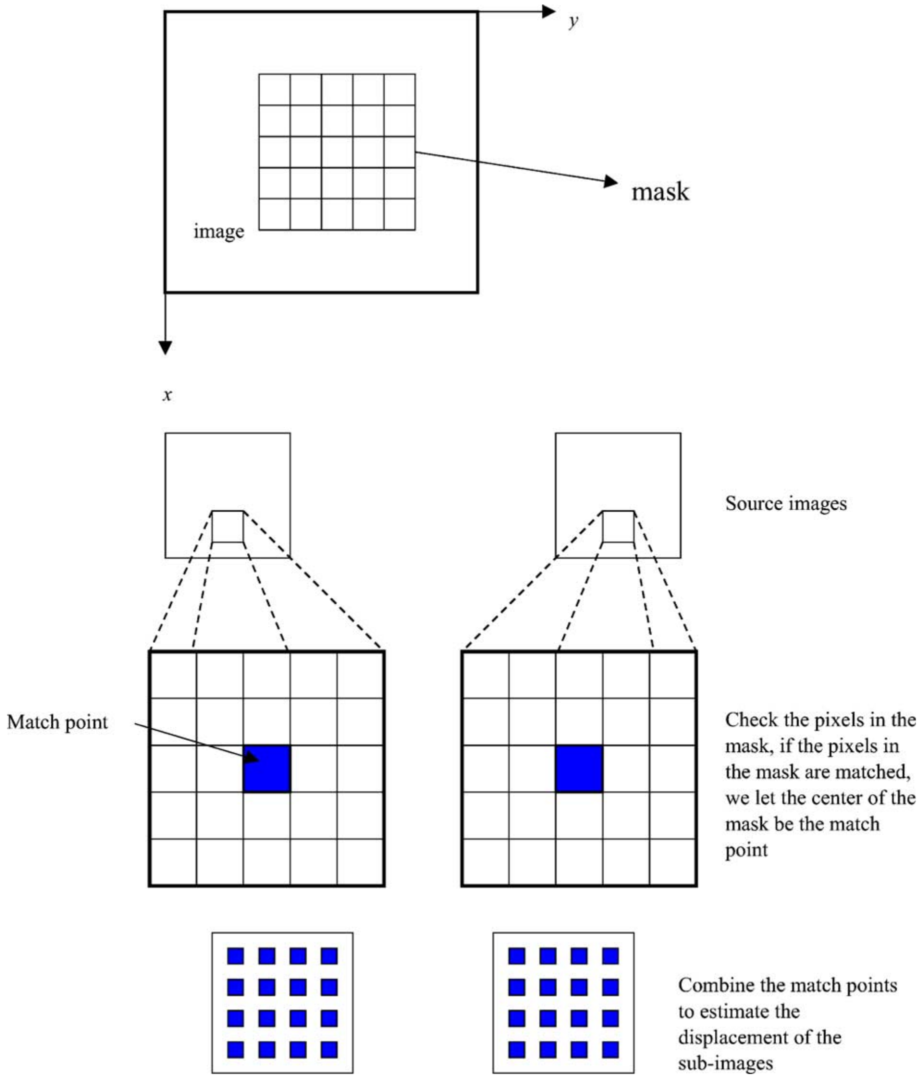


Fig. 9. Finding the match points in the shift-compensation process.

source image are presented in the fused image; however, the contrast of the original features may be significantly reduced, especially for the details.

Multi-resolution analysis plays an important role in image and signal processing fields, and it provides a technique to decompose an image into small components from coarse to fine scales. From the decomposed components, we can extract information with different scales [1–3,6–8].

We take the building image (Fig. 2) as an example to compare the performance of averaging fusion and multi-resolution fusion. In Fig. 2(a), the middle portion of the image is blurred; on the contrary, in Fig. 2(b), the outside portion of the image is blurred. Fig. 2(c) shows the fusion result with averaging both images. Fig. 2(d) shows the fusion result with the multi-resolution fusion (wavelet image fusion, we will discuss it later). From Fig. 2(c) and (d), we can see the windows of the building in Fig. 2(c) are still blurred after averaging; on the contrary, those of the building in Fig. 2(d) look better.

2.2. *Wavelet transform (WT)*

In this paper, we use the wavelet decomposition method (wavelet transform) to implement the multi-resolution analysis, since it can decompose the image information in the localization of both spatial and frequency domains. Another advantage of the wavelet transform is that we can implement it with the use of extension of one-dimensional operator to compute the two-dimensional image decomposition. It will save the computational time [7,8,11,12].

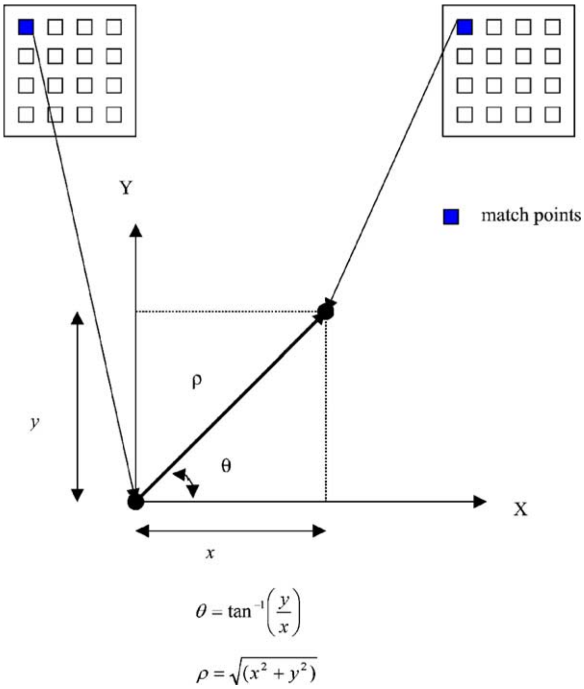


Fig. 10. We use a moving vector to show the displacement of the match points in the shift-compensation process.

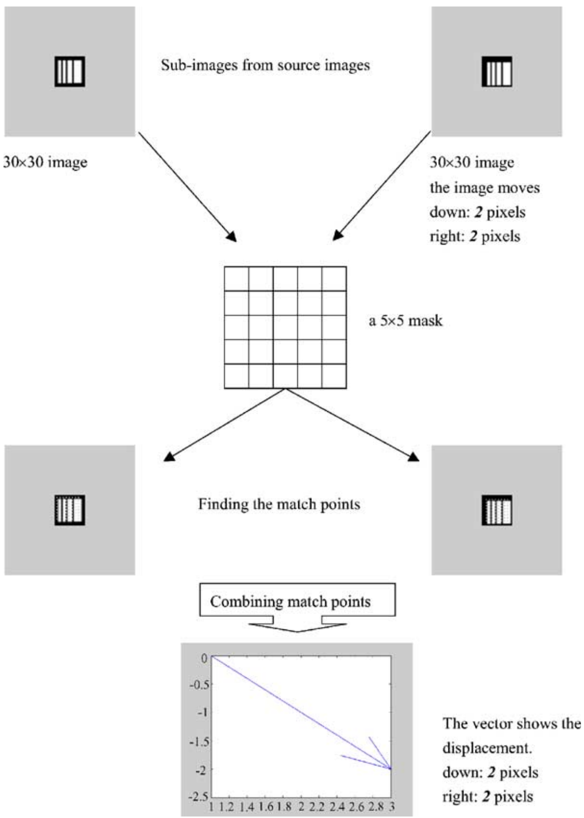


Fig. 11. A synthetic image example for moving vector estimation.

With the one-dimensional scaling function φ and corresponding wavelet ϕ, we can give separable two-dimensional scaling and wavelet functions [11,12]:

$$\varphi(x, y) = \varphi(x)\varphi(y),$$

$$\phi^H(x, y) = \phi(x)\varphi(y),$$

$$\phi^V(x, y) = \varphi(x)\phi(y),$$

$$\phi^D(x, y) = \phi(x)\phi(y),$$

where the symbols H, V and D stand for the directional wavelet coefficients. The transformation basis functions are defined as

$$\varphi_{j,m,n}(x, y) = 2^{j/2}\varphi(2^j x - m, 2^j y - n)$$

$$\psi^i_{j,m,n}(x, y) = 2^{j/2}\psi^i(2^j x - m, 2^j y - n), \quad i = \{H, V, D\}.$$

Thus, the resulting two-dimensional wavelet transform can be used in an image $f(x, y)$ of size $M \times N$ [13]:

$$W_\varphi(j_0, m, n) = \frac{1}{\sqrt{MN}} \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x, y)\varphi_{j_0,m,n}(x, y)$$

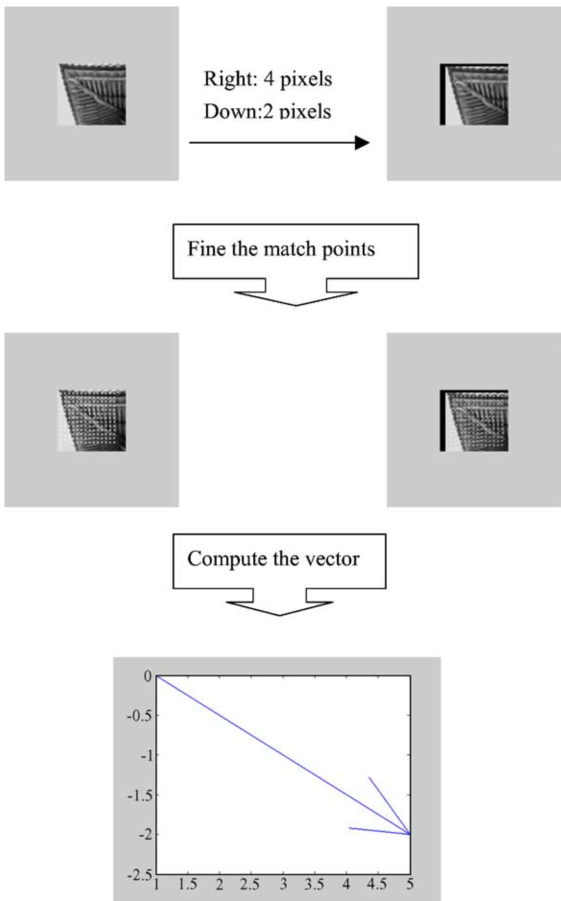


Fig. 12. A real image example for moving vector estimation.

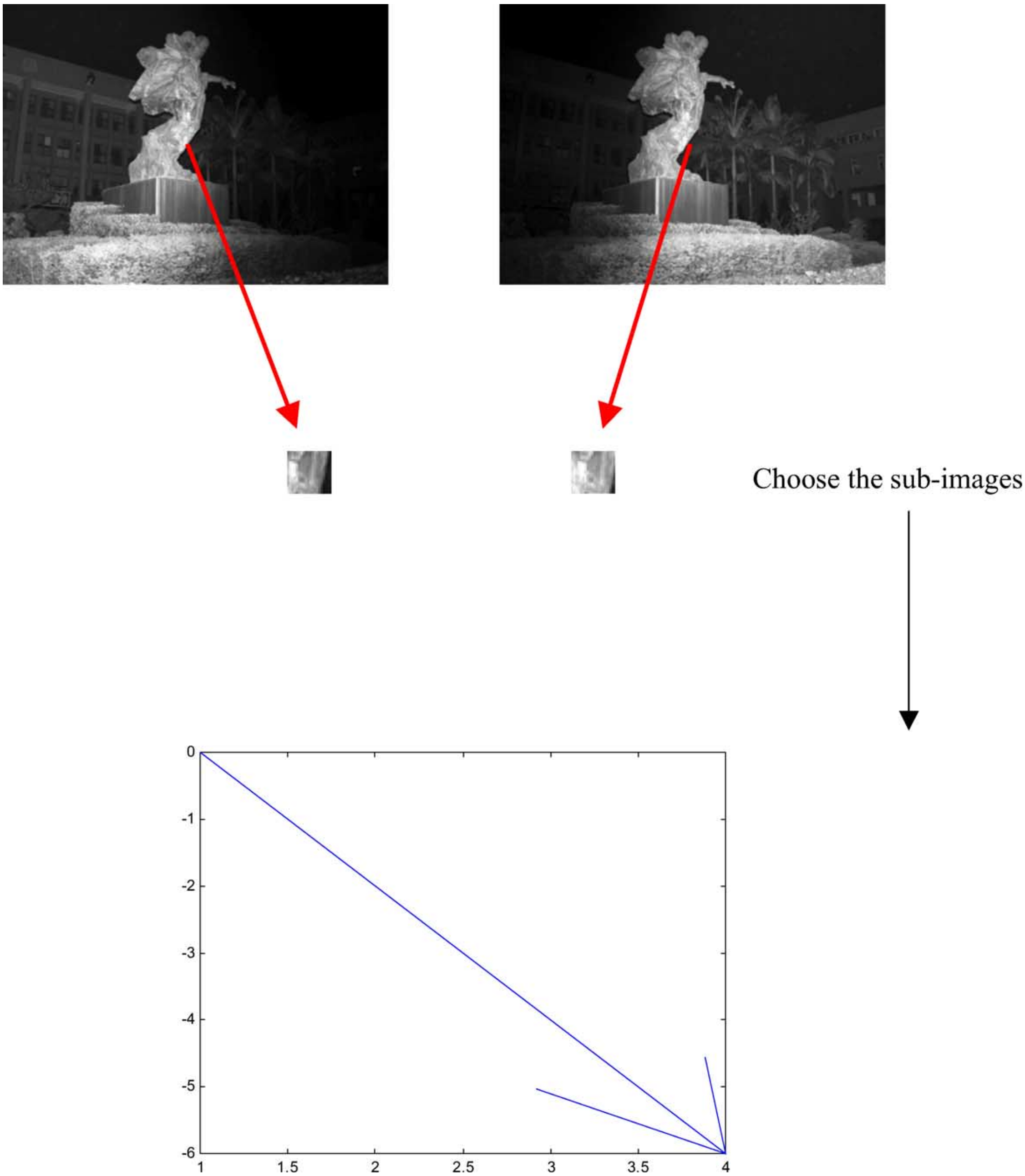


Fig. 13. The moving vector estimation for Fig. 8.

$$W_{\psi}^{i}(j,m,n) = \frac{1}{\sqrt{MN}}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1} f(x,y)\psi_{j,m,n}^{i}(x,y),$$
$$i = \{H,V,D\}.$$

The Haar wavelet transform framework for two-dimensional image decomposition is shown in Fig. 3. In Fig. 4, we show an example for one level wavelet decomposition.

2.3. The framework of wavelet image fusion (WIF)

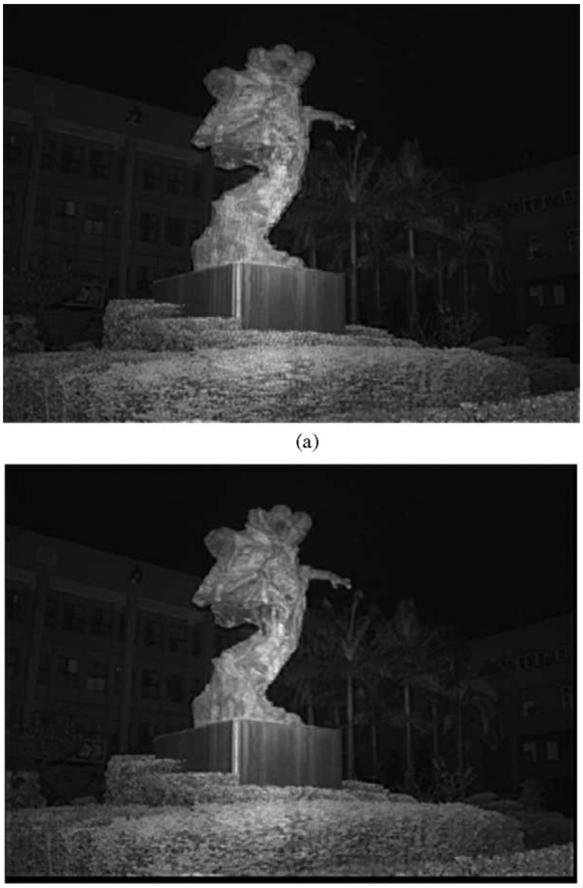
The flowchart of wavelet image fusion (WIF) is shown in Fig. 5. In Fig. 5, the technique of WIF can be divided into two parts [1,2,7,8]: decomposition and reconstruction. In decomposition, the source images are decomposed into sub-images by the wavelet transform. We can extract features and obtain information sets. In reconstruction, the information sets are combined by the so-called fusion rule. Then a new set of coefficients can be obtained at the fusion stage. Finally, by applying the inverse wavelet transformation, the fused image can be constructed.

The fusion rule is described as follows (see Fig. 6): in LL, we average the coefficients from two sources; in HL, LH and HH, we make a 3×3 mask to measure the variation (σ^2) of pixels in the window for each image. We use the center pixel value of the window with larger variation as the fusion value in the corresponding position. A WIF example is shown in Fig. 7.

2.4. Shift-compensated wavelet image fusion

In the framework of WIF, the fusion rule plays an important role. The key point of the fusion rule is to find the matching sub-images from each source images, that is, we must to find the most "similar" parts from each source images. If each source images are shift-free (images with the same scale, the same imaging angle, and the same imaging position) to each other, we can just process WIF directly; otherwise, we must apply shift compensation before processing WIF. Fig. 8 shows an example for the shift effect of WIF. We can see the sculpture portion is blurred.

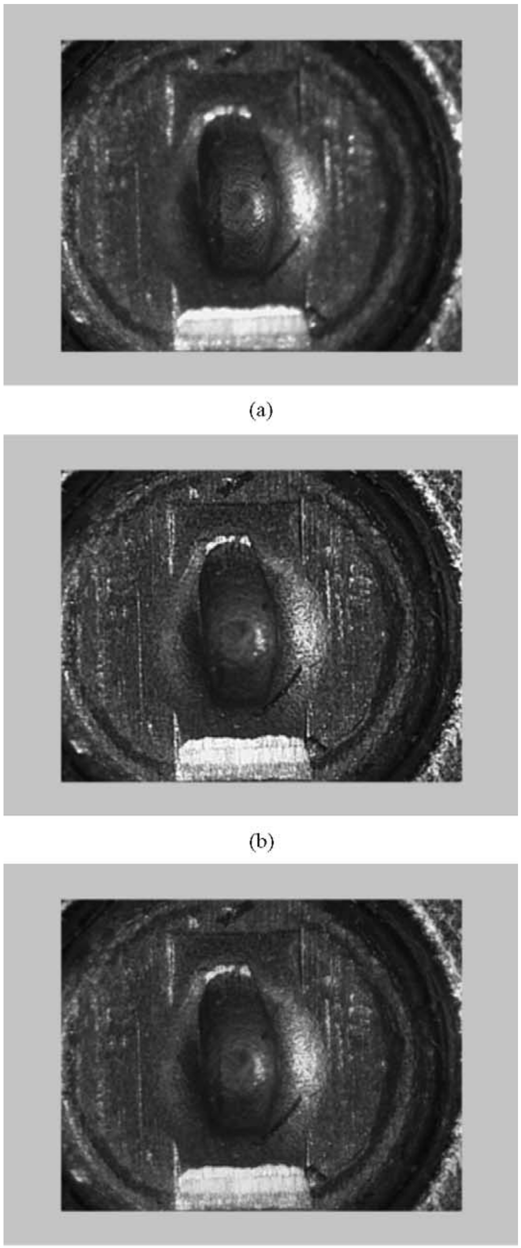
The method to find the match points in the shift-compensation process is shown as Fig. 9. We use a mask to



(a)

(b)

Fig. 14. The fusion results: (a) without shift-compensation; (b) with shift-compensation.

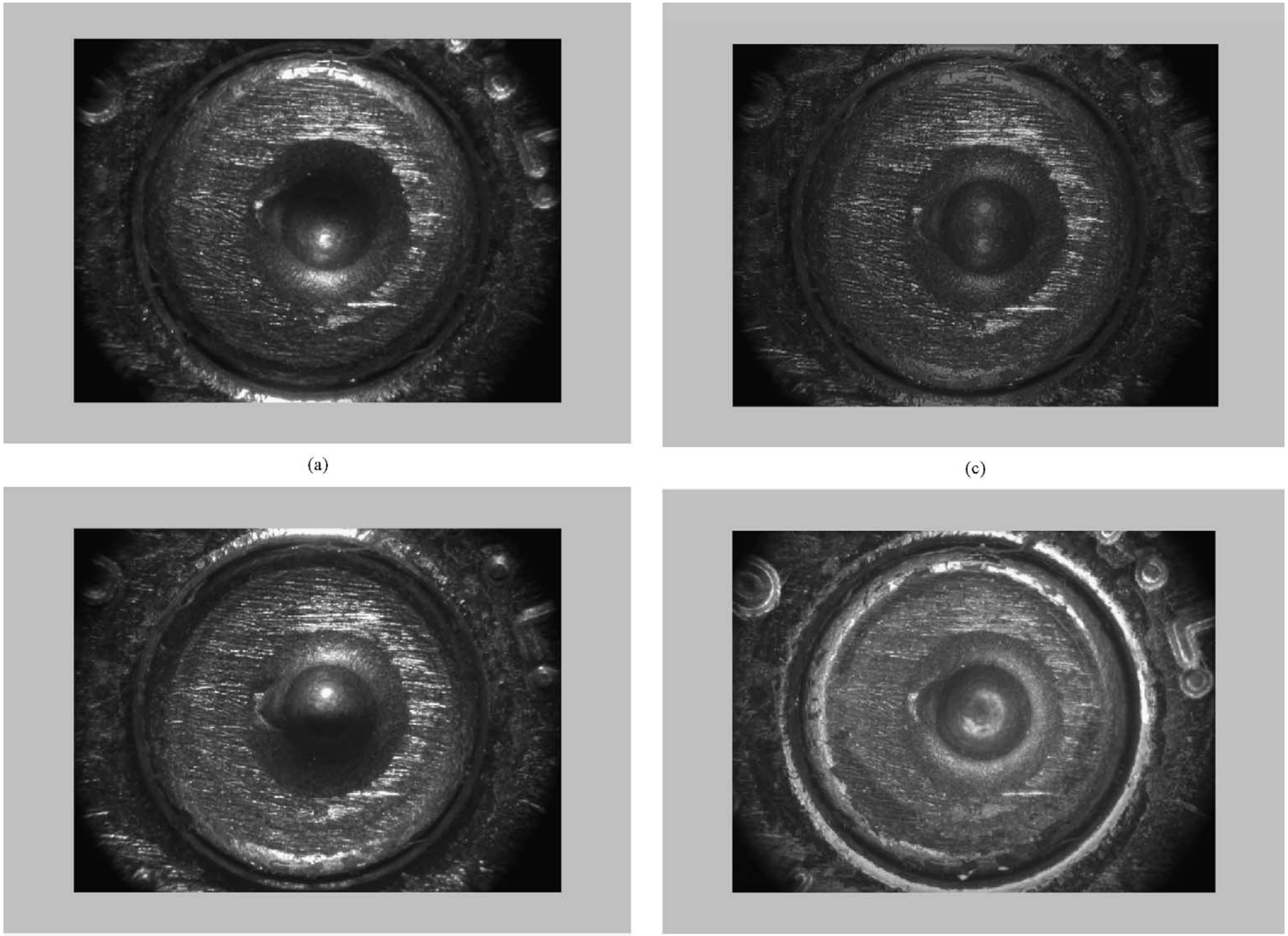


(a)

(b)

(c)

Fig. 15. Applying WIF to bullet examination (with different focuses): (a) image 1, the breech face impression is blurred; (b) image 2, the firing pin impression is blurred. Applying WIF to bullet examination (with different focuses): (c) the fusion result image.



(a) (c)

(b) (d)

Fig. 16. Applying WIF to bullet examination (with different light ways): (a) image 1, with the top way light; (b) image 2, with the down way light. Applying WIF to bullet examination (with different light ways): (c) the fusion result image; (d) the image taken by the ring light.

(a)

(b)

Fig. 17. The fusion experiment for the flash photography: (a) image 1, taken with the right way flashlight; (b) image 2, taken with the left way flashlight; (c) the fusion result by WIF.

(c)

Fig. 17. (*Continued*).

(a)

Fig. 18. The fusion experiment for the flash photography: (a) image 1, taken with the right way flashlight; (b) image 2, taken with the left way flashlight; (c) the fusion result by WIF.

(b)

(c)

Fig. 18. (*Continued*).

measure the similarity between source images. Starting from the relative positions of each source images, we use the mask to choose sub-images from each source images and calculate their mean square error. After moving the mask around the relative position, we can find the sub-images with the minimum mean square error, and we let the center of the mask be the match point of sub-images. With match points, we can estimate the displacement of the sub-images. In Fig. 10, we use a moving vector to show the displacement of one-pair match points. Fig. 11 shows a synthetic image example for moving vector estimation. Fig. 12 shows a real image example for moving vector estimation. We redo the fusion for Fig. 8 and obtain the results in Figs. 13 and 14.

3. Results

In this paper, we will use several images to show the performance of WIF.

3.1. Closed-up photography

Closed-up photography plays an important role in forensic science, for example, fingerprints and tool impressions may be recorded by closed-up photography. In closed-up photography, focus adjusting is accomplished by varying the distance between the specimens and the objective lens. However, there are two major problems make it difficult to have the whole clear closed-up photography: (1) the surface of the specimen is not always smooth; (2) the limited depth of the field makes focus adjusting difficult. To avoid above problems, we usually concentrate on one part of the specimen, that is, we take photos with the closed-up photography. That will make us obtain part information instead of the whole information. In this case, it is very helpful for us to apply the image fusion to integrate the information from several photos [14,15].

Here, we use bullet images as an example. Because the focus adjusting range of the comparison microscopy is limited, when the surface of the firing pin is not smooth (it is with different depth), it is difficult to take the whole clear photography of the cartridge images with single focus. This limit causes that we cannot obtain clear breech face and firing pin impressions at the same time. Fig. 15(a) and (b) are the photos of the bottom of a cartridge, they are from the comparison microscopy. In Fig. 15(a), the breech face impression is blurred; on the contrary, in Fig. 15(b), the firing pin impression is blurred. With WIF, we can integrate information from them. The fusion result is shown in Fig. 15(c).

The image fusion technique can be also applied to images taken with different light ways. In Fig. 16(a), the image is taken with the top way light. In Fig. 16(b), the image is taken with the down way light. Fig. 16(c) shows the fusion result. The ring light is used in many firearm laboratories. The ring light provides all direction light source to improve the different light way problem. However, it cannot provide the whole clear image, either. When comparing Fig. 16(c) and (d), we can see the latter one lose some fine textures in the breech face impression.

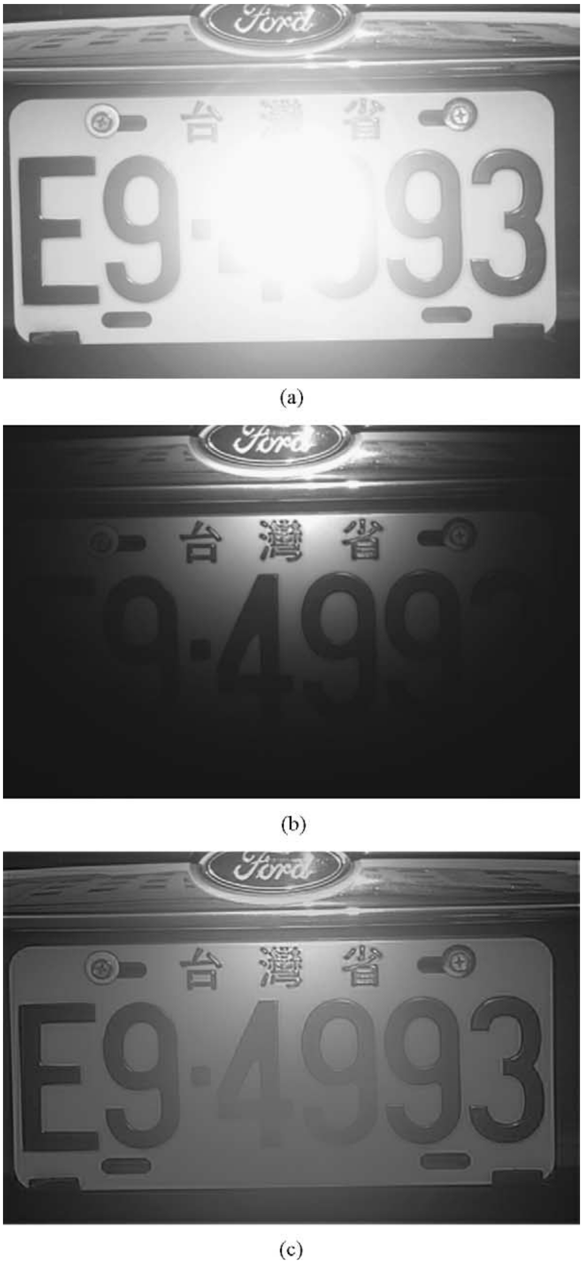
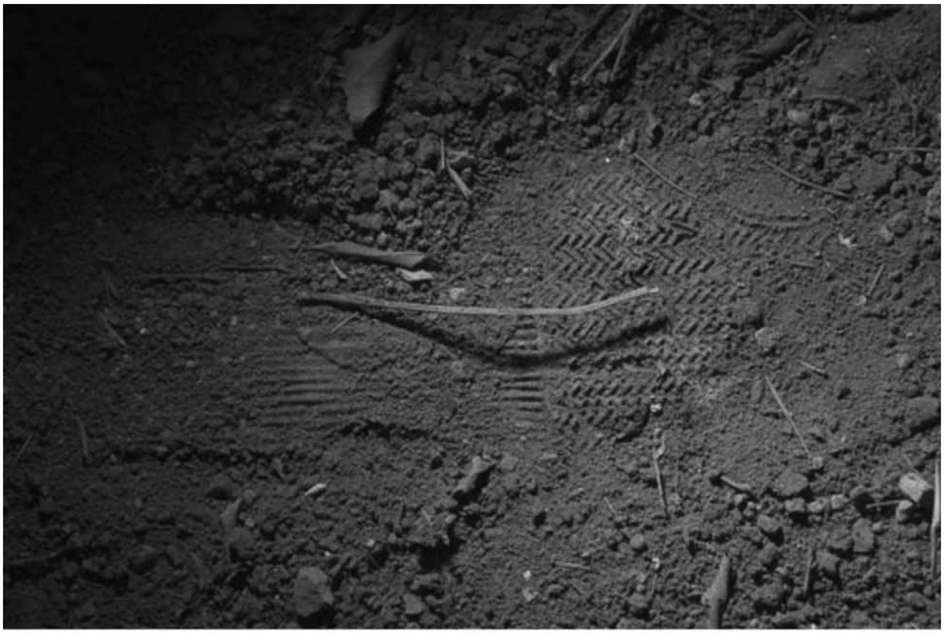


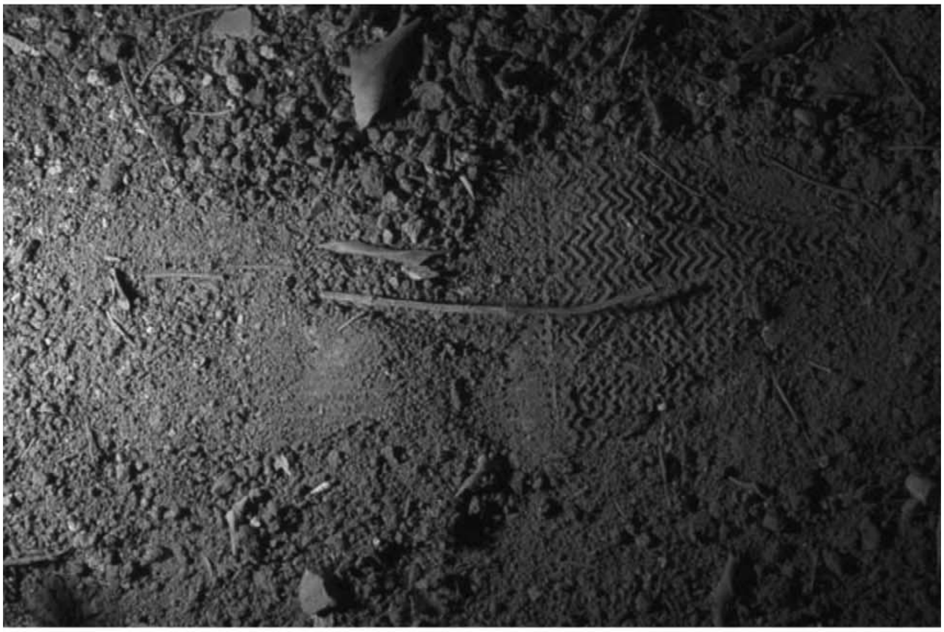
Fig. 19. The fusion experiment for the flash photography: (a) image 1, taken with the middle way flashlight; (b) image 2, taken with the top way flashlight; (c) the fusion result by WIF.

3.2. Flash photography

When taking pictures under poor light condition (e.g. taking a picture of a wide area, such as the outdoor crime scene), it is necessary to use the supplemental light source, such as the flashlight. However, it is not easy for us to control the flashlight to be the proper light source. From Fig. 17(a) and (b), we can see the effects of the unbalanced light source (underexposure and overexposure) when using the flashlight. Fig. 17(c) shows the fusion result with WIF. Figs. 18 and 19 provide other examples.



(a)



(b)

Fig. 20. The fusion experiment for the footprints: (a) image 1, taken with the right up way light; (b) image 2, taken with the left way light; (c) the fusion result by WIF.

3.3. Forensic applications

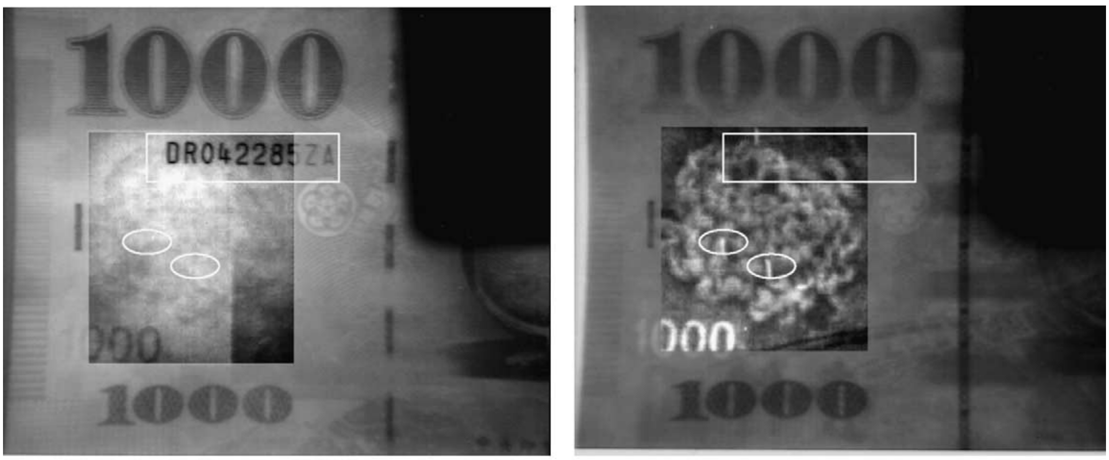
We use two samples (Fig. 20: footprint and Fig. 21: money texture) to explain our method on forensic applications.

Fig. 20(a) and (b) are the images taken with the right up and left way light, respectively. Fig. 20(c) is the fusion result by WIF. We can obtain the overview of the footprint with the proposed method.

(c)

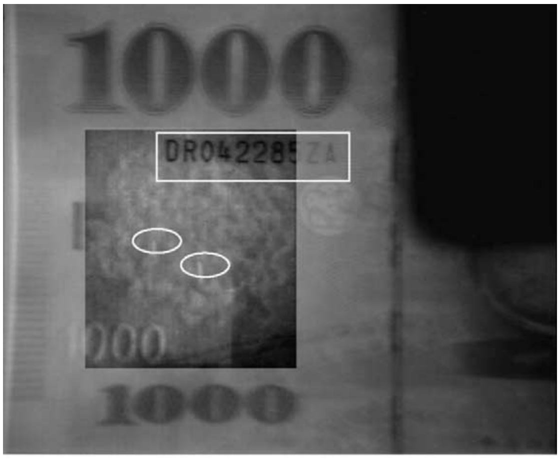
Fig. 20. (*Continued*).

Fig. 21 shows the experiment with images taken by the video spectral comparator (VSC-1). Fig. 21(a) and (b) are the images taken with the visible light and the transmitted visible/UV light, respectively. Fig. 21(c) is the fusion result by WIF. In order to improve the legibility, we enhance the watermark portion. The money number appears in Fig. 21(a), but not in Fig. 21(b). The strips of the fluorescent paper appear in Fig. 21(b), but not in Fig. 21(a). With the proposed method, we can see both of them in the fusion image (Fig. 21(c)). Besides, the watermark is clearer in Fig. 21(c) than in Fig. 21(a).



(a) (b)

Fig. 21. The fusion experiment for the money texture (all samples are taken by VSC-1): (a) image 1, taken with the visible light; (b) image 2, taken with the transmitted visible/UV light; (c) the fusion result by WIF. In order to improve the legibility, we enhance the watermark portion.



(c)

Fig. 21. (*Continued*).

4. Conclusion

In some practical forensic examinations, we cannot obtain all information from just one image; on the contrary, we need information from images with difference light sources (or light ways). Image fusion is a process of combining two or more images into an image. It can extract features from source images, and provide more information than one image can. In this paper, we summarize the multi-resolution fusion technique based on the wavelet transform, and use synthetic and real images (images from closed-up photography and flash photography) to show the capability of WIF. From the experimental results, we can see the fusion technique may provide many potential applications in forensic science.

Acknowledgements

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