Terahertz /Visible Dual-band Image Fusion Based on Hybrid Principal Component Analysis

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Abstract. This study puts forward a kind of passive terahertz image and visible image fusion method. Our method takes two steps of image fusion. First step involves a pre-processing of the passive terahertz image and image fusion using principal component analysis. Registered terahertz image is segmented and pseudo-color encoded. Taking the characteristics of terahertz image and visible image into account, principal component analysis is used to fuse the dual-band images. HIS method is used for the second step of image fusion. The experiment results show that this algorithm can effectively fuse passive terahertz and visible image and is helpful to detect and locate dangerous objects concealed under the clothes of the target subjects to strengthen the practicability of terahertz imaging system for security screening.

1. Introduction
Terahertz has unique advantages as a security screening technology for its high penetrating capability through plastic, cloths, leather and other materials. In addition, terahertz is found to have relatively very low radiation to human body, and therefore, is suggested to be a no-harm security check technique [1-3]. Recent years have observed a significant amount of research devoted into analyzing security check by using terahertz technique [4,5]. However, terahertz images only give incomplete information about subjects under checked. One major drawback with using terahertz for security check is lacking detailed information about security check scene and the subjects need to be checked. Visible images give these kinds of detailed information but cannot present the hidden objects carried by the subjects under checked. The technique of image fusion makes it possible to take advantage from different sensors, not a single sensor [6-8]. It is needed to fuse these two bands images to advance the terahertz security screening technique. In this paper, we propose a novel dual-band terahertz and visible image fusion method based on hybrid principal component analysis.

2. Terahertz image acquisition
We developed terahertz scanning system using single terahertz detector and this system adopts total reflection working mode to reduce terahertz radiation loss after penetrating through terahertz lenses. Figure 1(a) presents the imaging system. The system is composed of five parts, including the subjects to be checked, the frame scan plane mirror, trihedral focusing scanning mirror, reflecting mirror, and the terahertz imaging front-end. Best imaging distance of the system is 1.7m. The system has imaging
speed as fast as 2s, and its best resolving ability is 4cm@0.1THz. Figure 1(b) shows the image it captures.

3. Passive Terahertz/Visible image registration and pre-processing

Image registration is the condition for image fusion. Because passive terahertz imaging system and the visible imaging system gather images at different frame rate, using different equipments, at different angles, therefore, one of the two bands of images must be transformed in order to register dual-band images. It is challenging to extract characteristic points of passive terahertz image. This study adopts mutual information as the similarity measure. Genetic algorithm combined with Powell algorithm yield to the hybrid algorithm which is adopted in this study for dual-band image registration.

In particularly, adopting mutual information means that the algorithm uses the statistical correlation between two band image grey scale values. This approach does not require extracting characteristic points and has its advantage of high precision degree, but the disadvantage is it will be very likely to arrive at local extremum. GA’s advantage is in its searching capability, but low precision. Powell algorithm can reach high precision but is very strict at selecting the initial points. Therefore, we combine these three approaches to have good precision, and global searching capability.

In the GA algorithm, initial population is 100, selection operator is Roulette selection method, variation function is Gaussian function. Stagnation band number is 100. Before the image registration, to easy the calculation of the mutual information between the two-band images, we pre-processed the visible image by using morphological processing. Figure 2(a) shows the original visible image, figure 2(b) shows the image after morphological processing. Figure 2(c) shows the original passive terahertz image, figure 2(d) shows the image after GA registration, and Figure 2(e) gives the image after processed with the hybrid method. The mutual information of Figure 2(c), Figure 2(d), and Figure 2(e) is 0.2076, 0.5793, 0.9908. Apparently, images processed using hybrid approach have the best quality.
With the objective of making the targets more identifiable, we pre-processed the terahertz image after image registration. We took three steps. The first step was to perform image segmentation using region-growing method. Secondly, we assign values to the target region using the normalized mutual correlation algorithm. Lastly, we enhanced the color of the image by using pseudo-color method. Figure 3 shows the experimental results.

4. Passive Terahertz/Visible dual-band image fusion

PCA image fusion method has spatial information preserved from image with high spatial resolution and spectral information from image with high spectral resolution. We analysed the image captured through our system. Visible image has high spatial resolution and big volume of spectral information. Passive terahertz image’s resolution is low, and the image is grayscale. Fusing these dual-band images can achieve both of the target identification and the high spectral information and high resolution. The following describes the steps of the PCA image fusion method: 1) compute the principle component transformation matrix and the respective feature vectors of the visible image; 2) compute principle component using equation (1):

\[ p_{\text{fc}} = \sum_{j=1}^{n} x_{j}\phi_{j,k} \]  

(1)
3) perform the histogram matching between the terahertz image and visible image’s first principle component and replace first principle component with terahertz image. Then we perform the inverse principle component transformation with the replaced image to get the fused image. Figure 4 shows the fused resulting image by using PCA method.

By only using PCA methods to perform image fusion, we can obtain image with high resolution but lost spectral information. Therefore, we combine HIS transformation with the PCA method by following these steps. 1) compute the visible image’s principle component transformation matrix and its according feature vector, and then we perform the histogram matching between the terahertz image and first principle component of visible image. The first principle component was replaced by the terahertz image and after performing the inverse principle component transformation on the replaced image, we get the PCA fused image. 2) we convert the R, G, B three channels of visible image to the HIS space and get I, H, S channels. Then we use histogram matching to guide the image fusion. We fused the PCA fused image and the I channel of visible image to replace the luminance component. We put together H, S channels and finally get the fused image by HIS inverse transformation back to RGB space. Figure 5 shows the image fusion results using our hybrid principal component analysis method. Results shows that fused image has both of the visible image’s high resolution and spectral information and the passive terahertz image’s identifiable targets.

![Figure 4. fused image based on PCA method](image)

![Figure 5. fused image based on hybrid method](image)

| Table 1. objective evaluation of terahertz/visible image fusion |
|---------------------------------------------------------------|
| spatial frequency | standard deviation | entropy | average gradient | correlation | distortion degree |
| Visible image     | 31.0693             | 94.0404 | 3.1557         | 7.5264      |                  |
| Terahertz image   | 55.7501             | 111.9837| 0.8282        | 8.9718      |                  |
| PCA fused image   | 32.1748             | 93.6275 | 3.1349        | 7.9654      | 0.9876           | 5.5203           |
| HIS fused image   | 32.9408             | 93.0246 | 3.1015        | 7.6221      | 0.9863           | 5.8334           |
| hybrid method fused image | 32.9889 | 93.0239 | 3.2404        | 8.0923      | 0.9991           | 1.1565           |

5. Method Objective Evaluation
We rely on spectral and spatial information to evaluate the quality of our proposed image fusion method. Specifically, we used various statistics parameters to evaluate the image. Details of spatial information, such as spatial frequency, standard deviation, entropy, and average gradient, were used.
Meanwhile, details of spectral information, such as correlation and distortion degree. Table 1 shows the results. Results showed our method outperformed the other methods.

6. Conclusion
In this study, we proposed a novel method for visible and passive terahertz images fusion using PCA method combined with HIS method. The improved method can quickly locate the targets carried by human objects from the background scene. This method has the advantage of preserving the visible images’ high resolution and spectral information. In order to speed up the security check speed and reduce the errors of the target identification, future study can continuously improve the correctness and efficiency of the image fusion method.

Acknowledgments
Supported by the National Natural Science Foundation of China (61875140) and Beijing Natural Science Foundation (4181001).

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