Image Fusion of PMMW and Optical Images for Concealed Object Detection

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Abstract. This paper addresses a method of concealed objects detection by passive millimeter wave (PMMW) images, and on this basis, the fusion techniques of passive millimeter-wave images and optical images is discussed. According to PMMW real-time imager acquired image characteristics and storage methods, firstly, using correlation coefficient method to screen sequence images and the selected images are optimized using wavelet fusion algorithm. Secondly, the concealed objects are detected by Gaussian filter, threshold segmentation and edge detection. Finally, based on YIQ transform, discrete wavelet transform and a fusion rule, the optical image and the extracted concealed object contour are merged. The experimental results show that the proposed method can be effectively applied to human body concealed object detection in millimeter wave video and fuse two different types of images in a fully automated way.

1. Introduction

Millimeter wave is widely used in the field of human security due to its distinguished radiometric properties[1-5]. It has high reflectivity for artificial objects and metals[6], and has very low energy attenuation when passing through items such as clothing, bags. Thus, it can identify concealed objects under clothing.

Passive millimeter wave (PMMW) imaging system captures thermal noise radiated from the objects[7-9]. The currently used PMMW security inspection system requires the subject to cooperate to collect a static single frame image for hidden object detection[10-12], but the information provided by a single frame image is limited and cannot meet the real-time requirements. Therefore, researchers have developed an array PMMW real-time imaging system[1], which has greatly improved the imaging speed and image quality. At present, researchers[13-16] mainly propose detection algorithms for the problems of low signal-to-noise ratio, low spatial resolution, and low contrast in single-frame PMMW images, and there are few studies on human hidden object detection algorithms for sequence images.

A single PMMW image contains limited information. In the detection of human concealed objects, researchers often use image fusion to increase the amount of information contained in the image and improve the consistency of the detection result with the actual, such as multiple related millimeter wave image fusion, feature fusion, Optical or infrared image fusion with millimeter wave image[16-20] and other methods. Among them, millimeter-wave image fusion can increase an amount of...
information of hidden objects, but the specific location of concealed objects cannot be determined due to the low resolution of the image; feature fusion has a small amount of calculation but the accuracy of the detection results is insufficient; infrared images and millimeter-wave image fusion Although the higher image resolution can be obtained, the optical effect is not good. In this paper, the detection method of human hidden objects in serial PMMW images is studied, and on this basis, the fusion method of PMMW images and optical images is discussed.

The paper is organized as follows. In Section 2, the PMMW imaging system, correlation coefficient method and image fusion are briefly illustrated. Section 3 describes the human concealed object detection and image fusion process. The experimental and results analysis are presented in section 4. The conclusions follow in section 5.

2. Methodology

2.1. The PMMW Imaging Principle
The PMMW imaging system does not need to emit electromagnetic waves to the target, and it can image the difference between the brightness temperature of the scene, hidden objects and human radiation. It is mainly composed of antenna, radiometer receiver, servo control device, signal processor and display control device. When the imaging system is working, the antenna receives the millimeter-wave radiation energy of the radiating target, converts and processes the millimeter-wave radiation brightness temperature of the target through the radiometer receiver and signal processor, and then sends it to the display and control device to store and display the corresponding millimeter wave image.

2.2. Correlation Coefficient Method
The correlation degree of the image can be quantitatively expressed by the correlation coefficient of the image-related parameters. The correlation coefficient is greater, the more similar the two images represents, i.e. radiation in the scene and the background becomes relatively stable. The specific correlation coefficient calculation formula is as follows:

\[
0 \leq r(I_i, I_j) = \frac{\text{Cov}(I_i(x, y), I_j(x, y)) (\text{Var}[I_i(x, y)] \text{Var}[I_j(x, y)])^{\frac{1}{2}} \leq 1 \quad (i, j \in N^*)
\]

where \( r(I_i, I_j) \) is the correlation coefficient between image \( I_i \) and \( I_j \), \( \text{Cov}(I_i(x, y), I_j(x, y)) \) is the covariance between image \( I_i \) and \( I_j \), and \( \text{Var}[I_i(x, y)] \text{Var}[I_j(x, y)] \) is the variance of the images \( I_i \) and \( I_j \).

2.3. Image Fusion
Image fusion is the process of using different remote sensors to image targets in the same area, and combining the obtained image information to obtain a new image[21-22] to achieve better visualization and facilitate further analysis.

2.3.1. Wavelet fusion. Wavelet transform is a frequency-based image transform method, of which discrete wavelet transform (DWT)[23] is most widely used. The specific mathematical model of DWT is as follows:

\[
(DW_{\phi,f})(j, k) = \langle f(t), \psi_{j,k}(t) \rangle
\]

Where \( \psi_{j,k}(t) = 2^j \psi(2^j t - k), j, k \in Z \). The fusion process is shown in Figure 1.
2.3.2. YIQ transform. In the YIQ color space [24], saturation Q and hue I contain image color information, while brightness Y contains image gray information.

The YIQ color space can separately extract and store the luminance component Y in the image, and meet the linear transformation between YIQ and RGB color space. Good clustering characteristics and small amount of data for easy calculation. Therefore, YIQ transform can be used to process color images to obtain better results, and it can collect target information under complex motion background.

The mathematical conversion relationship from RGB to YIQ is as follows:

\[
\begin{bmatrix}
Y \\
I \\
Q
\end{bmatrix} =
\begin{bmatrix}
0.2990 & 0.5870 & 0.1140 \\
0.5960 & -0.2740 & -0.3220 \\
0.2110 & -0.5230 & 0.3120
\end{bmatrix}
\begin{bmatrix}
R \\
G \\
B
\end{bmatrix}
\]  

(3)

3. Concealed Object Detection and Image Fusion

3.1. Human Concealed Object Detection Method Based on Sequence PMMW Image

The complex imaging environment and the limitation of hardware equipment make the quality of a single frame of passive millimeter-wave images low. Detection based on a single image frame sometimes loses or incorrectly detects hidden objects. Aiming at this shortcoming, this paper uses multiple frames of the same scene to increase the amount of information, and proposes a multi-frame PMMW image based on human body hidden object detection algorithm based on wavelet fusion.

The steps of passive millimeter wave human hidden object detection are as follows:

- Use the 8mm PMMW real-time imaging human security detector to conduct experiments and collect simulated security inspection image.
- Use the correlation coefficient method to select two optimal correlation images.
- Fusion of the selected passive millimeter wave images using wavelet fusion method.
- Filter the image to remove noise. In this paper, we try to use 3 × 3 mean filter operator and Gaussian filter operator to de-noise the fused image. After comparative analysis, we choose a better method for de-noising the passive millimeter wave image.
- Segment the de-noised image and perform edge detection to obtain the outline of the human body and hidden objects. This paper uses Canny operator to implement edge detection of hidden objects.

3.2. Image Fusion of Optical and Concealed Objects PMMW Image Based on Wavelet Fusion

The low resolution of PMMW wave images will cause the human body contour to be lost, making it impossible to determine the exact position of the hidden object in the human body. Therefore, in this paper, millimeter wave images of hidden objects and optical images are fused together, so that security personnel can obtain better optical effects, and improve the security speed and accuracy. The steps to fuse the optical image with the concealed objects millimeter wave image are as follows:

- YIQ transforms the optical image, extracts its gray components and stores color information.
- Adjust the hidden millimeter wave image and optical image to the same resolution.
- Optical image gray component fusion with hidden millimeter wave image.
- Combine the fused hidden object image and the previously stored color information into a false color hidden object fusion image.

3.3. Flow Chart of Concealed Object Detection and Image Fusion
The human body hidden object detection process based on optical and millimeter wave fusion in this paper is shown in Figure 2. First, input the optical and millimeter wave raw image data, and then preprocess the millimeter wave image accordingly (i.e. fusion and de-noising). And then perform segmentation processing on the fused data and edge detection to obtain the hidden result. The YIQ decomposition of the optical image is fused with the acquired millimeter wave concealment data to finally obtain the display and positioning of the concealment in the human optical image.

4. Experimental Results and Analysis

4.1. Data Description
The experimental data is the simulated security inspection image and corresponding optical image acquired by the 8mm band passive millimeter wave real-time imaging human security detector. Part of the data is shown in Figure 3. Figure 3(a), Figure 3(b) and Figure 3(c) are PMMW image containing hidden objects, 3(d) is the corresponding optical image. The pistol model used in the experiment is a metal pistol, as shown in Figure 3(e).

![Figure 3](image_url)

Figure 3. Examples of PMMW image and sample of contraband

4.2. Experimental Analysis
The most relevant two millimeter-wave images are selected from the serial millimeter-wave images by using the correlation coefficient as a screening index. Correlation coefficients between some images
are shown in TABLE I. Therefore, passive millimeter wave images Figure 3(a) and Figure 3(b) with \(r(a,b) = 0.9753\) are selected.

| Number | Correlation coefficient |
|--------|-------------------------|
| \(r(a,b)\) | 0.9753 |
| \(r(a,c)\) | 0.9198 |
| \(r(b,c)\) | 0.9439 |

Wavelet fusion is performed on the filtered image. The fusion result is shown in Figure 4(a). By comparing with the pre-fusion image, it can be seen that the hidden details of the PMMW image after fusion are well preserved and the information content of the hidden objects is enhanced. The results of the mean filtering and Gaussian filtering are shown in Figure 4(b) and Figure 4(c), respectively. A comparative analysis shows that both filtering methods can suppress noise information to a certain extent, but the Gaussian filtering effect is better, which not only removes the noise of the passive millimeter wave image, but also reduces the suppression of hidden information. Threshold segmentation and binarization are performed on the de-noised passive millimeter wave image. Threshold segmentation and binarization of the de-noised passive millimeter wave image, adaptive threshold is 0.6314, and the result is shown in Figure 4(d). The result of edge detection is shown in Figure 4(e). The method can automatically detect hidden objects and human contours in PMMW images, but the actual shape of hidden objects needs to be improved.

In order to improve the visual effect, the detection result is fused with the corresponding optical image. Since the optical image and the millimeter-wave image have different numbers of information channels, the optical image has three channels of RGB and the millimeter-wave image is a single channel. Therefore, in this paper, the YIQ method is used to decompose the optical image to obtain the gray component and also store the color information.

The gray component is obtained by performing YIQ transformation on the original optical image. The original optical image and its gray component are shown in Figure 5(a) and Figure 5(b), respectively. Using wavelet fusion, the gray component is fused with the detected PMMW hidden object image to obtain the results shown in Figure 5(c). Figure 5(d) is the fused false color image obtained after the inverse YIQ transformation. Compared with the original PMMW image, it can be seen that the fused false color image retains the rich human body information of the optical image, and corresponding hidden information. This helps security personnel to more accurately determine the position of the human body where the hidden object is located, improves security efficiency, and emphasizes the identity characteristics of the person and the object intended to be hidden.
Figure 5. Process and fusion result of detected hidden object image and corresponding optical image

5. Conclusion
This paper mainly focuses on the concealed object detection method and image fusion of optical and millimeter wave image. Passive millimeter wave images have lower resolution, poor visual effects and less information. Therefore, we proposed a method that combines the correlation coefficient and wavelet fusion to detect human hidden objects in PMMW sequence images. The YIQ transform and fusion rules were used to decompose and fuse the optical image and the detected PMMW image. Experimental results show that this method can effectively detect passive millimeter-wave concealed objects, and solves the problem that the concealed object cannot be accurately positioned on the human body.

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