Research Journal of Applied Sciences, Engineering and Technology 4(20): 4118-4121, 2012
ISSN: 2040-7467

Submitted: March 16, 2012 Accepted: April 14, 2012 Published: October 15, 2012

Concealed Weapon Detection Using Multiresolution Additive Wavelet Decomposition

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Abstract: Image fusion is studied for detecting concealed weapons or any object which is concealed by a person. In this study a new algorithm is developed for fusing visual Image and Infrared (IR) image which is based on additive wavelet decomposition. The obtained fused image maintains the high resolution of the visual image by incorporating the concealed weapon. The efficiency of the proposed method is evaluated using quantitative measures such as Correlation Coefficient (CC), RMSE, ERGAS, Spectral Angle Mapper (SAM), Universal Image Quality Index (UIQI), Relative bias, variance and standard deviation.

Keywords: Image fusion, multiresolution analysis, wavelet decomposition

INTRODUCTION

Concealed Weapon Detection (CWD) appears to be the most important law enforcement problem for the upcoming decade. It appears to be a vital technology for dealing with military and police area. It is enviable to detect the obscured weapon from a standoff distance automatically but it is a technical challenge that requires innovative solution in sensor technologies and image processing. The Concealed Weapon Detection (CWD) program was started in 1995 to address this problem under the sponsorship of National Institute of Justice through the administration of the Air Force Research Laboratory in the United States. The goal is the eventual development of automatic weapon detection and recognition.

Existing image sensor technologies for CWD applications include thermal/Infrared (IR), Millimeter Wave (MMW) and visual. A number of sensors based on different phenomenology as well as image processing support are being developed to observe the weapon or object underneath people's clothing. Since no single sensor technology can provide acceptable performance in CWD application, the image fusion using IR and visual sensors has been identified as a key technology to achieve improved CWD procedure. In our study, the visual and IR images have been aligned by image registration. In IR image, the body is brighter than the background, shows little detail because of the high thermal emissivity of body. The weapon seems darker than the body due to a temperature difference between it and the body. The resolution in the visual image is higher than that of the IR image but it doesn't provide any information about the hidden weapon.

Several image fusion technologies have been applied in fusing visual image and IR image for CWD applications includes Color Image Fusion (Zhiyun and Rick, 2003), Dual Tree- Complex Wavelet Transform (DT-CWT) (Wang and Lu, 2009), Wavelet Transform (WT) (Yocky, 1995; Shu-long, 2002), Expectation Maximization-Covariance Intersection (EM-CI) (Siyue and Henry, 2009), Multiscale-Decomposition Based (MDB) fusion method (Zhang and Rick, 1999) etc., Wavelet Decomposition is also applied in image fusion in recent years and better result are obtained (Jorge *et al*., 1999; Yonghyun *et al*., 2011). A Multiresolution Wavelet Decomposition (MWD) method is applied for CWD application in this study.

Multiresolution wavelet decomposition: Multiresolution analysis allows to decompose images into a set of new images with coarser and coarser spatial resolution. The wavelet transform describes the difference in the information of two consecutive approximation images (wavelet coefficient images). The discrete approach of the wavelet transform can be performed using several different algorithms:

- **Decimated algorithm-mallat:** It is a fast wavelet transform algorithm based on a Multiresolution dyadic scheme that allows to decompose an image A_2^{i} at a resolution 2^i, into an approximation image A_2^{i-1} at a resolution 2^{i-1} and three wavelet coefficient images DH_2^{i-1}, DV_2^{i-1} and DD_2^{i-1}, which denotes the horizontal, vertical and diagonal detail that is los between the images A_2^{i} and A_2^{i-1}. If the original image A has B columns and C rows, the approximation and the wavelet coefficient images obtained applying this multiresolution decomposition have B/2 columns and C/2 rows. The computation of the approximation and the detail coefficient is

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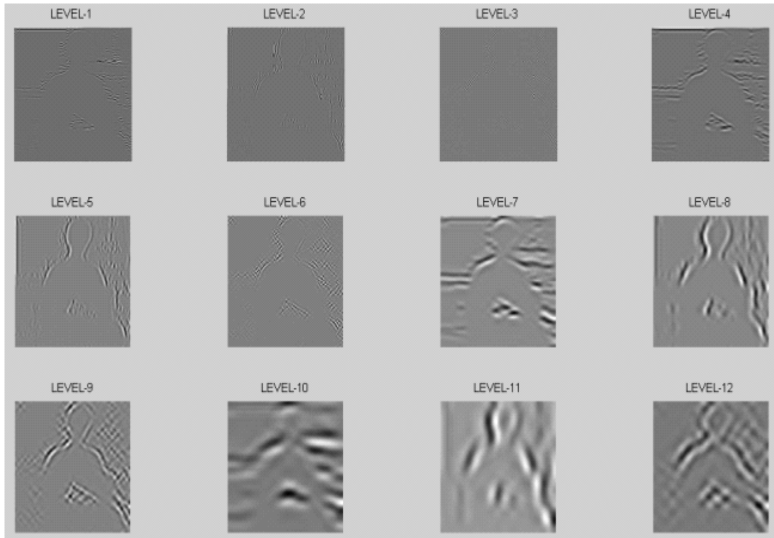

Fig. 1: Wavelet decomposition levels of an IR image

accomplished with a pyramidal scheme based on convolutions along rows and columns with one-dimensional filters followed by a subsampling or decimation operation.

When the MWD process is inverted, the original image A_2^i can be reconstructed exactly from an approximation image A_2^{i-1} and the wavelet coefficients DH_2^{i-1}, DV_2^{i-1} and DD_2^{i-1} applying an upsampling or oversampling process followed by filtering. Both decomposition and reconstruction filters have to be quadrature mirror filter in order to satisfy constraints inherent to a perfect reconstruction of the original image A_2^i.

- **Undecimated algorithm-*à trous*:** It is a redundant wavelet transform algorithm based on a multiresolution dyadic scheme accomplished not with the pyramidal scheme but with the parallelepiped scheme. This algorithm is based on the idea of no decimation. The original image A_2^i at a resolution 2^i is decomposed into an approximation image A_2^{i-1} at a resolution 2^{i-1} and three wavelet coefficient images DH_2^{i-1}, DV_2^{i-1} and DD_2^{i-1}, which denotes the horizontal, vertical and diagonal detail that is los between the images A_2^i and A_2^{i-1}. In contrast to the decimated algorithm, the undecimated algorithm allows shift-invariant discrete wavelet decomposition. All the approximation and wavelet coefficient images obtained by applying this algorithm have the same number of columns and rows as the original image thus such decomposition is highly redundant. A detailed discussion on undecimated algorithms can be found in Lang *et al*. (1995).

The practical implementation of this algorithm is similar to the Mallat's decimated algorithm but in this case, the subsampling or decimated operation is suppressed and the decomposition and reconstruction filters are upsampled inserting zeros between its coefficients with a step 2^{i-1}. The number of coefficients of these filters and the value of each coefficient depends on the Mother Wavelet function used in this analysis. In this study, we have used Daubechies four-coefficient wavelet basis to perform both the decimated and the undecimated algorithms.

Generally, the algorithm-based image fusion can be performed in two ways: Substitute-Wavelet (SW) method and Additive-Wavelet (AW) method. The SW method can lose some information about the visual image during substitution process. These problems can generate aircrafts in fused image. If these aircrafts are not taken into account, the fused image will suffer from both radiometric and geometric distortions. To overcome this problem, the AW method is applied, which maintains all the information of the visual image, which is not done by the SW method. In addition, this method can reduce the redundant high-frequency injection problem. Figure 1 outlines the wavelet decomposition levels of an IR image (L = 12).

These are the steps followed in our proposed algorithm:

- Coregister both images and resample the Visual Image (VI) to make its pixel equal to that of the Infra-Red (IR) image, in order to get perfectly superposable images
- Obtain intensity I of visual image using SAIHS

$$I = R + 0.75G + 0.25B + NIR/3$$

- Generate a new IR image whose histogram matches that of I
- Obtain Low resolution IR (LIR) image by passing High resolution IR (HIR) image through the Gaussian low-pass filter
- Generate a new LIR image whose histogram matches that of I
- Apply the undecimated wavelet decomposition to the histogram-matched HIR and LIR, using the Daubechies four-coefficient wavelet. For each image decomposition, four half-resolution image are obtained (J = 1)

The first one, the approximation image, is a low-frequency version of the IR image and the other three images (HD^{xx}, VD^{xx}, DD^{xx}), the wavelet coefficient zero-mean images.

Add the difference of *n* wavelet planes of the HIR and LIR image to the visual image to produce fused image:

$$\text{Fused Image (FI)} = VI_i + \sum_{j=1}^{n} w_{(HIR-LIR)}$$

EVALUATION METHODOLOGY

Correlation coefficient: Correlation indicates the similarity between the original and the fused image and the CC for MxN image is calculated as follows where *x* and y indicates original and fused images $\bar{y}$ and $\bar{x}$ stands for the mean value of the images:

$$CC(x/y) = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N}\left(x_{i,j}-\bar{x}\right)\left(y_{i,j}-\bar{y}\right)}{\sqrt{\sum_{i=1}^{M}\sum_{j=1}^{N}\left(x_{i,j}-\bar{x}\right)^2\sum_{i=1}^{M}\sum_{j=1}^{N}\left(y_{i,j}-\bar{y}\right)^2}}$$

The value ranges from -1 to 1 and the best correspondence between fused and original image data shows the highest correlation values.

RMSE: The RMS error is the difference of standard deviation and the mean of the fused and the original image:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{M}\sum_{j=1}^{N}\left(x_{i,j}-y_{i,j}\right)^2}{M \times N}}$$

ERGAS: ERGAS is the abbreviation of Erreur Relative Globale Adimensionnelle de Synthèse (Relative global-dimensional error). For comparison of different fusion methods the spatial and spectral quality is taken into account. Spatial quality is estimated by the sharpness of the edges whereas the spectral quality estimation is done with many matrices. ERGAS is one among that, which calculates the amount of spectral distortion and the formula is given by:

$$ERGAS = 100\frac{h}{l}\sqrt{\frac{1}{N}\sum_{i=1}^{N}\frac{RESM^2(B_i)}{M_i^2}}$$

where, *h* is the resolution of the high resolution image, *l* is the resolution of the low spatial resolution image and M_i is the mean radiance of each spectral band involved in the fusion, where, *h/l* is the ratio between the pixel size of PAN and MS image.

UIQI: The Universal Image Quality Index (UIQI) (Zhou and Alan, 2002) measures how much of the salient information contained in reference image. UIQI is devised by considering loss of correlation, luminance distortion and contrast distortion. The range of this metrics varies from -1 to +1:

$$UIQI = \frac{\sigma_{AB}}{\sigma_A\sigma_B}\cdot\frac{2\mu_A\mu_B}{\mu^2{}_A+\mu^2{}_B}\cdot\frac{2\sigma_A\sigma_B}{\sigma^2{}_A+\sigma^2{}_B}$$

where, σ represents the standard deviation and μ represents the mean value. The first term in RHS is the correlation coefficient, the second term represents the mean luminance and the third measures the contrast distortion UIQI is also used to find the similarity between the two images.

SAM or SA: The Spectral Angle Mapper Classification (SAM) is widely used method comparing spectral similarities of images. The SAM or SA for two given spectral vectors *v* and *w* is defined as:

$$SAM(v,w) = COS-1\left(\frac{\sum_{i=1}^{L} v_i w_i}{\sqrt{\sum_{i=1}^{L} v^2{}_i}\sqrt{\sum_{i=1}^{L} w^2{}_i}}\right)$$

where, v_i *and* w_i are the mean values of *v* and *w*.

BIAS, VAR and SD: The bias is the difference between the mean of the original image and that of the fused one. In the relative value, the bias is divided by the mean of the original image. The relative VAR is the difference in VAR between the original and fused images, divided by the VAR of the original image. The ideal value for each of these measures is zero. The SD of the difference image in relation to the mean of the original image indicates the level of the error at any pixel. The lower the value of SD, the better is the spectral quality of the fused image.

EXPERIMENTAL RESULTS AND ANALYSIS

Visual analysis: The experimental results of visual and IR image fusion based on the Multire solution Wavelet Decomposition are illustrated in Fig. 2. Figure 2a is the

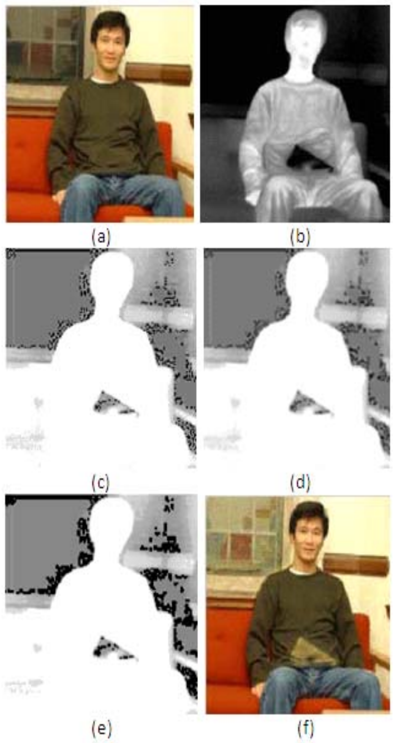

Fig. 2: (a) Visual image, (b) IR/HIR image, (c) LIR image, (d) HIR matched, (e) LIR matched, (f) Fused image

Table 1: Quantitative measurements of proposed method

Quality indicators	Wavelet decomposition method
SAM	2.2052
RMSE	37.5546
ERGAS	10.0251
UIQI	0.014505
Relative bias	0.014541
Relative variance	0.0011482
Standard deviation	0.03464
Correlation coefficient	0.871957

original color visual image, its resolution is high but the obscured weapon is invisible. Figure 2b is the IR image, which shows the hidden weapon and the body is brighter than the background, shows little detail because of the high thermal emissivity of body. The weapon seems darker than the body due to a temperature difference between it and the body. Figure 2c shows the low resolution IR image which is obtained by using Gaussian low-pass filter. Figure 2d is the histogram matched HIR image. Figure 2e is the histogram matched LIR image. Figure 2f is the eventual fused image. Its resolution seems close to original color image and it provides concealed weapon information.

Quantitative analysis: Existing statistical evaluation indicators, both unimodal (Universal Image Quality Indicator (UIQI), Root Mean Square Error (RMSE), Relative bias and Variance, Standard Deviation (SD) and Correlation Coefficient (CC)) and multimodal (Spectral Angle Mapper (SAM), Erreur Relative Globale Adimensionnelle de Synthèse (ERGAS)), have been calculated and the results are reported in Table 1 and are relative to the test image shown in Fig. 2.

CONCLUSION

In this study, we proposed a new image fusion method for a concealed weapon detection application by fusing visual and IR image to provide fused image that provides a detailed description of the people in the scene and any hidden weapons detected by the IR image. The utility of the proposed method is demonstrated in the experiment tests.

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