TELKOMNIKA Telecommunication, Computing, Electronics and Control
Vol. 18, No. 3, June 2020, pp. 1216~1223
ISSN: 1693-6930, accredited First Grade by Kemenristekdikti, Decree No: 21/E/KPT/2018
DOI: 10.12928/TELKOMNIKA.v18i3.13541

Image processing analysis of sigmoidal Hadamard wavelet with PCA to detect hidden object

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Article Info

Article history:

Received Jul 9, 2019
Revised Jan 29, 2020
Accepted Feb 26, 2020

Keywords:

Concealed weapon detection
IR image
Principle component analysis
Sigmoidal Hadamard
Support vocter machine

ABSTRACT

Innovative tactics are employed by terrorists to conceal weapons and explosives to perpetrate violent attacks, accounting for the deaths of millions of lives every year and contributing to huge economic losses to the global society. Achieving a high threat detection rate during an inspection of crowds to recognize and detect threat elements from a secure distance is the motivation for the development of intelligent image data analysis from a machine learning perspective. A method proposed to reduce the image dimensions with support vector, linearity and orthogonal. The functionality of CWD is contingent upon the plenary characterization of fusion data from multiple image sensors. The proposed method combines multiple sensors by hybrid fusion of sigmoidal Hadamard wavelet transform and PCA basis functions. Weapon recognition and the detection system, using Image segmentation and K means support vector machine A classifier is an autonomous process for the recognition of threat weapons regardless of make, variety, shape, or position on the suspect's body despite concealment.

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1. INTRODUCTION

Remote detection of person borne concealed weapons from a secure distance is the need of the hour but currently, available detection systems require physical examination within a prescribed distance. Detecting the presence of weapons such as guns, knives, explosives, etc., via channel checkpoints is time-consuming leading to delays, and is also susceptible to a high incidence of false alarms. Many advanced surveillance systems are developed by researches with robust, inbuilt sensors that can operate from a secure distance to detect concealed weapons without any physical contact. Many variants of sensor technology such as thermal or infrared, microwave, millimeter waves, or terahertz are available, but only non-invasive and non-hazardous sensors are used in public security surveillance systems. To improve the spatial resolution, multispectral. Data of the same scene, taken from multiple sensors are combined through a process called Image Fusion. Different image fusion techniques have been developed to take full advantage of the integration of complementary information and have found extensive applications in the fields of computer vision, remote sensing, medicine, biometrics, robotics, etc. The block diagram of general image fusion is shown in Figure 1.

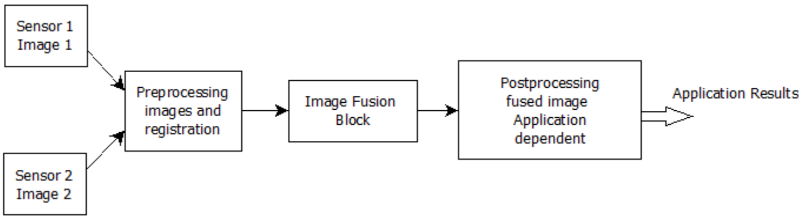

Figure 1. General image fusion schema

The data acquired from multiple sensors is passed through a pre-processing registration stage, which is a pixel to pixel correspondence to avoid any inconsistencies and halo effect. The registered images are then passed through the image fusion block wherein images are fused as per the chosen fusion rule algorithm. Post fusion, computations are performed depending on the desired application, including image enhancement, filtering, feature extraction, classification, object detection, and recognition. Traditional walk through detectors or handheld devices installed at the airports, public transport stations, and other public venues have been known to produce false positives, and in other cases have failed to detect attackers with weapons resulting in catastrophic damage. An adaptive fusion process to track weapons using visual image information along with deep IR images is implemented in the proposed method to perceptually enhance images. The aim is utilizing infrared sensors is to exploit the capability of looking through fabric or cloth material and provide sufficient geometric resolution to identify threat elements such as knives, guns or chemicals. In this study, the used images are generated from visible light cameras and long-wavelength IR cameras Figure 2.

Shows the functional block diagram of IR camera, resolution in a VL camera image is higher than an IR image, but the composite fused image has expanded information content and high resolution. A Hybrid image fusion is achieved by combining the best features of various transforms to obtain excellent energy compactness, reduced dimensions and enhanced features with minimum artifacts. A sigmoidal Hadamard wavelet transform is applied to multiple sensor images to produce a high-resolution fused image. A further goal of the proposed method beyond detecting the concealed weapon is the classification of the weapon using the K-means support vector machine classifier. The proposed implementation of an automatic concealed weapon detection system requires innovative sensor technological solutions and efficient machine learning algorithms in conjunction with image processing applications.

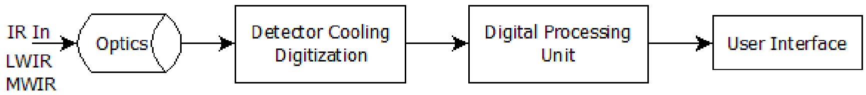

Figure 2. Thermal image sensing camera

2. RELATED WORK

The problems of image analysis using to detecting hidden objects underneath clothes it has exposed in many fields of detecting domain [1-3]. The methods of detecting object behind clothes using x-ray, terahertz and MMW were elucidated [4, 5]. The situational perception awareness provided by image fusion supports the researchers a power in the medical field, military major, computer science vision field, defense and lot of another field [6-8]. However, in our real-time system, the commercial, computational and the type of enhancement it becomes important in commercial surveillance systems. Consequently, multiple-sensor image fusion of visual and infrared images has been tested extensively [9, 10]. Earlier research studies also explored psuedocoloring of X-ray images, clutter removal with latency time responses, neural networks, MIMO-SAR based UWB imaging, fast LTR Analysis [11-13]. The focus was diverted from the extensively used discrete wavelet transform, principal component analysis to the older Walsh Hadamard image transform along with sigmoid Function which provides excellent energy compaction. This ability of Hadamard transform has earned itself the distinction of the transform in ITU-T.86 JPEG_XR image compression standard [14].

3. METHODOLOGY

The need for concealed weapon detection systems has increased tremendously due to a rise in crime and terrorism. Images captured from typical visual and infrared camera systems provide low-contrast images, lacking uniform illumination; reducing visual accuracy [15, 16]. Recent developments in image fusion techniques resolve these issues. Image fusion is a technique which involves fusing captured visual and infrared images allowing contextual enhancement, good image contrast, and provides accurate visual information, a novel image fusion technique is proposed to enhance the visual information of the fused image, minimizing redundancy and providing good energy compactness. Fused images obtained from this novel approach enable detection of concealed weapons easily with the help of clustering and classification techniques. The functional block diagram of the proposed system is shown in Figure 3.

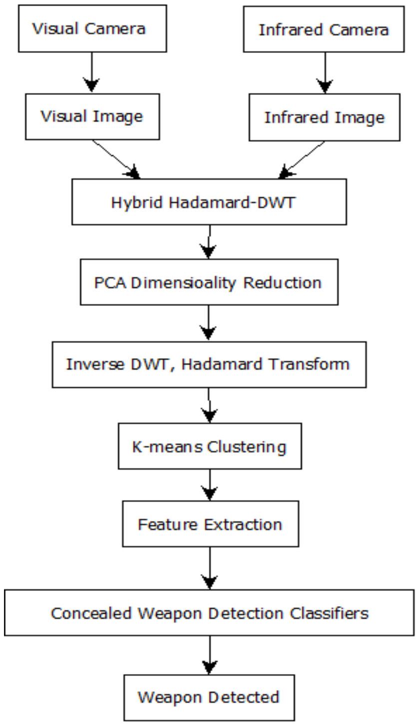

Figure 3. Functional block diagram of hybrid proposed system

3.1. Proposed method

Transformation techniques including Hadamard, Wavelets and PCA methods. To fuse visual and infrared images captured from their respective camera systems, the images are subjected through three different transformations and a fusion process is doing to get the demanding image. The image obtained after the fusion process is then processed in a concealed weapon detection system which detects the hidden weapon using K-means clustering and SVM classification algorithms. The proposed method is described in the following steps: First, resize the registered visual and infrared images. Then compute the Hadamard transform matrix which is used to transform the images into Hadamard transformed images. These images are then scaled using the sigmoidal basis function. Next, we should modify these images into DWT2 Daubechies decomposition, vectorise the decomposed approximate and detail coefficients, then Compute mean, covariance. After this compute eigenvalues and eigen process vectors for Hadamard-DWT, then find PCA of the coefficients processing of decomposing, apply fusion rule by multiplying the principal components with the Hadamard-DWT decomposed Coefficients and fuse them together, Apply Inverse DWT and inverse Hadamard transform to get the fused image, Subject the Fused Image to a concealed weapon detection system, perform clustering using K-means algorithm on the fused image, extract features of the fused image and Use SVM classifier to detect whether a weapon is concealed or not.

3.2. Image fusion process sigmoidal Hadamard wavelet transform and PCA

A novel approach which combines the Sigmoidal Hadamard transform along with DWT and PCA is used as an image fusion technique as shown in Figure 4 to improve the overall performance. The energy compactness of the fused image from the proposed algorithm is excellent and redundancy is minimal. The modified DWT coefficients for both visual and infrared images obtained from Sigmoidal Hadamard Wavelet transform are fed to the PCA. The PCA generates principal components to be used for image fusion. The fusion analysis process is doing to each of the decimated hybrid Hadamard DWT coefficients by multiplying them with principal components. After that using the result of the fused process together using the fusion process to form a fused image. The fused image obtained from the sigmoidal Hadamard wavelet transform with PCA is then given to a concealed weapon detection system to detect the hidden weapon.

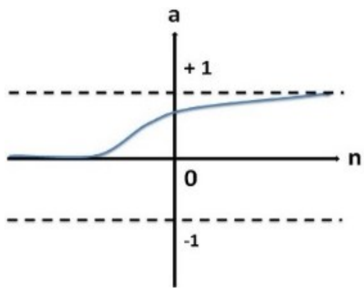

Figure 4. Log sigmoid function

3.3. Hadamard Transform

These are special cases of Fourier Transforms which perform symmetric, linear, orthogonal and complex operations. The transform being orthogonal and non-sinusoidal in nature effectively allows the decomposition of a signal into sets of rectangular and orthogonal signals called Walsh functions. These Walsh functions are made up of only two values, +1 and -1 [17]. The transformation is not weighted and provides only real values. WHT is unitary, real with no multipliers and is suitable for applications like speech processing, medical image analysis, filtering, non-medical image processing and compression [18]. The Hadamard matrix for 2x2 m is computed by (1).

$$\mathrm{H_m} = \frac{1}{\sqrt{2\mathrm{m}}}\begin{bmatrix} \mathrm{H_m} & \mathrm{H_m} \\ \mathrm{H_m} & -\mathrm{H_m} \end{bmatrix} \quad (1)$$

$\mathrm{H_m}$ – Hadamard Matrix, $\frac{1}{\sqrt{2}}$ – normallization factor
$m - order$, When m = 1, the Hadamard matrix is as defined by

$$H_1 = \frac{1}{\sqrt{2}}\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \quad (2)$$

The Hadamard matrix, H_m when multiplied by its transpose $H_m{}'$ gives an identity matrix as defined in the (3),

$$H_m H_m' = I \quad (3)$$

$H_m - Hadamard\ Matrix$, $\mathrm{H'_m}$ – Transposed Hadamard Matrix , $I - Identity\ Matrix$

The visual and infrared images are individually given to Hadamard transformation. The transformation of images is performed based on the (4) and (5).

$$VI' = \frac{H_m VI\, H_m{}'}{m} \quad (4)$$

$$,IR' = \frac{H_m IR\, H_m{}'}{m} \quad (5)$$

The inverse transformation of the transformed visual and infrared images are calculated by the (6) and (7),

$$VI = \frac{H_m VI'\, H_m}{m} \quad (6)$$

$$IR = \frac{H_m IR'\, H_m}{m} \quad (7)$$

$VI - Visual\ ImageIR - Infrared\ Image$
$VI' - Transformed\ Visual\ Image$
$IR' - Transformed\ Infrared\ Image$
$H_m - Hadamard\ Matrix$
$H_m' - Transposed\ Hadamard\ Matrix$

The transformed coefficients produced by discrete wavelets (DWT) and discrete cosine transform (DCT) add more noise to the input images [19]. Noise is added in the middle and lower frequency sub-bands during decomposition [20]. The coefficients generated by Hadamard Transforms are similar to those of DWT and DCT coefficients, but with the addition of less noise [21]. The Hadamard transform has only real values, is symmetric and orthogonal in nature which helps in the fast decomposition of images. It uses only two operations - additions and subtractions, and it provides excellent energy compactness. Scaling Hadamard matrix by sigmoidal basis functions sigmoidal basis functions are transfer functions [22] used to calculate the output of the layer from the input. The transfer function of the logarithmic sigmoidal function is in (8).

$$logsig(n) = \frac{1}{(1+\exp(-n))} \tag{8}$$

The logarithmic sigmoidal transfer function's graph is shown in Figure 4. This transfer function's elements have values between 0 and 1 only. This transfer function produces a non-trivial, real-valued, unique, continuous and differentiable solution. The scaling of Hadamard transformed image generates an enhanced visual perception of the image.

3.4. Discrete wavelet transform (DWT)

Alfred Haar, the Hungarian mathematician was the first to invent the discrete wavelet transform (DWT) as a data transformation tool. The discrete wavelet transform method converts time domain data to frequency domain data and divides the signal into two bands, a lower frequency and a higher frequency band [23]. The decomposed signal now contains four bands, low-low (LL), low-high (LH), high-low (HL) and high-high (HH) frequency bands. The decomposition is based on the human visual system, so the DWT decomposes the image data into approximate and detailed coefficients. Low-frequency bands contain coarse data of image constituting the approximate coefficients. The higher frequency bands (LH, HL, and HH) contain detailed information of the image and constitute detailed coefficients. Based on the wavelets used, variants of the DWT include Daubechies, Symlets, Haar, Coiflets, bi-orthogonal, and dual-tree complex wavelet transform (DCWT). Wavelets are similar to waves with oscillations having amplitude around the origin (zero). The most frequently used DWT variant is Daubechies wavelets. This was formulated in 1988 by the famous Belgian mathematician, Ingrid Daubechies. Mother wavelets show properties like symmetry, orthogonality, etc. DWT is extensively used in image compression [24, 25]. As it provides excellent energy compactness, is robust, and achieves greater compression. The DWT can perform N level decomposition depending on the application requirements. 2D-DWT is defined by (9).

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$$F(a_1, b_1, a_2, b_2) = \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} \left(f(i,j) \frac{1}{\sqrt{b_1 b_2}} \varphi\left(\frac{i-a_1}{b_1}, \frac{j-a_2}{b_2}\right) \right) \tag{9}$$

where $\frac{1}{\sqrt{b_1 b_2}} \varphi\left(\frac{i-a_1}{b_1}, \frac{j-a_2}{b_2}\right)$. Represents a wavelet type. The inverse 2D-DWT is defined by (10)

$$,f(i, \mathrm{j} = \sum_{a_1=0}^{A_1-1} \sum_{b_1=0}^{B_1-1} \sum_{a_1=0}^{A_2-1} \sum_{a_1=0}^{B_2-1} P \tag{10}$$

where P is, $P = \left(F(a_1, b_1, a_2, b_2) \frac{1}{\sqrt{b_1 b_2}} \varphi^{-1}\left(\frac{i-a_1}{b_1}, \frac{j-a_2}{b_2}\right) \right)$. Mimicking the human visual system, DWT is used in many applications in different fields including engineering, science, computers, wireless communications, mathematics, biomedical signal processing and image processing.

3.5. Principal component analysis (PCA)

Principal component analysis (PCA) is a dimensionality reduction algorithm invented in 1901 by the English mathematician, Karl Pearson. In the 1930s, the American mathematician Harold Hotelling developed the same PCA to suit more applications. PCA is also known as the 'Hotelling transform' or 'Kosambi-Karhunen-Loeve transform. In layman's terms, PCA finds patterns in the data and expresses the data items of its differences and similarities. This feature allows the data to be compressed, which results in a reduction of the dimension of data without any loss of information. As the demand for digital data has increased exponentially over recent years, the need for compression techniques has so increased. PCA caters to ever increasing demand for compression algorithms. This being a statistical multivariate analysis method, it can be performed using either singular value decomposition of data or by eigenvalue decomposition of covariance of data. This technique is lossy in nature. The first principal components are known to contain

90% of the image information. All other principal components contain variance information. The empirical mean vectors for the input features dataset are Xi calculated by the (11).

$$\text{Mean} \quad \bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \tag{11}$$

The eigenvectors and eigenvalues are computed using (12).

$$[A][x] = \lambda X \tag{12}$$

The resulting eigenvectors are sorted in the descending order W. Then the principal components are projected onto the input. Features dataset by using the (13).

$$Y = W^T x \tag{13}$$

Known to generate some loss as it identifies patterns and based on them expresses the data as differences or similar patterns, the performance of object-identification systems with PCA decreases.

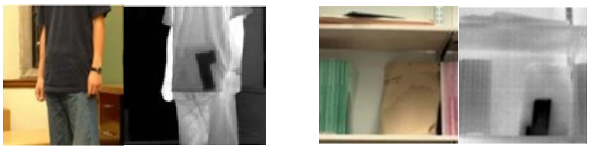
3.6. Concealed weapon detection

The fused image obtained from the proposed Sigmoidal Hadamard Wavelet with PCA technique is given to the concealed weapon detection (CWD) system. The CWD system is composed of a Clustering block and a classifier block. The fused image is first enhanced to remove any noise and clustering is performed on the enhanced fused image. K-means clustering is performed on the fused image, with the best cluster chosen from several clusters and the region of interest is extracted from it. This is then fed to a support vector machine (SVM) classifier to classify whether the selected clustered image contains a weapon or not.

4. RESULT AND DISCUSION

Experiments were conducted on a set of visual and infrared image datasets to test the efficiency of the proposed hybrid algorithm over traditional image fusion techniques to detect the concealed weapon from a secure distance. The selected image datasets [26] are registered with two cameras viz visible light camera and infrared camera with the test object hidden under plain clothing as shown in the sample image dataset in Figure 5. The different fusion approaches compared were Pixel average fusion, Pixel Maximum fusion, DWT average fusion, DWT with PCA fusion and the proposed hybrid fusion. The illustrative comparison of different fusion approaches are shown in Figure 6 and Figure 7.

It is vividly clear the fused image is sharper with enhanced contrast, showing a hidden weapon. Though there is some additive noise due to the transformation, this artifact does not result in Image loss. The following metrics PSNR, MSE, entropy, standard deviation, and mutual information are measured to appreciate the image quality of the proposed image fusion method versus other fusion algorithms. The performance metrics for image sets 1 and 2 are tabulated in Table 1 and Table 2 shows that the proposed image fusion method outperforms the traditional fusion techniques. The fused image is then processed by the concealed weapon detection system which consists of a clustering block and a classifier block. The fused image is enhanced and K-means clustering is performed with the best cluster provided to the supervising classifier. The evaluation of the classifier performance is done by metrics such as detection rate (true positive rate) and false incidence rate. The classifier performance metrics were analyzed for the different fusion techniques and it is noted that the combined detection rates and false incidence rates outperform all traditional fusion methods. The classifier metrics tabulated in Table 3 very clearly showcase that the false positive rate of the proposed system is zero and the detection rate is superior to traditional methods.



(a) (b)

Figure 5. (a) Image datasets1 (man standing visual and IR), (b) Image datasets2 (book shelf visual and IR)

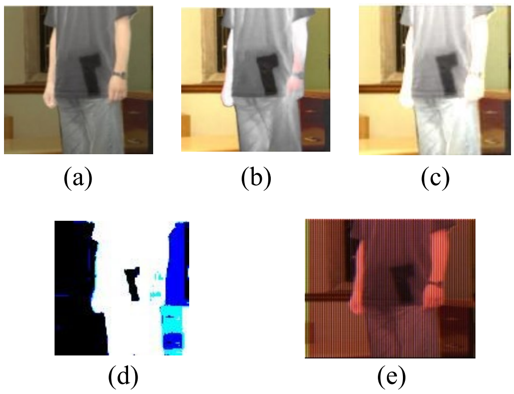


Figure 6. Illustrative comparison of image fusion techniques (L-R), (a) PixAvg, (b) PixMax, (c) DWT, (d) DWT+PCA, (e) proposed method – image dataset2

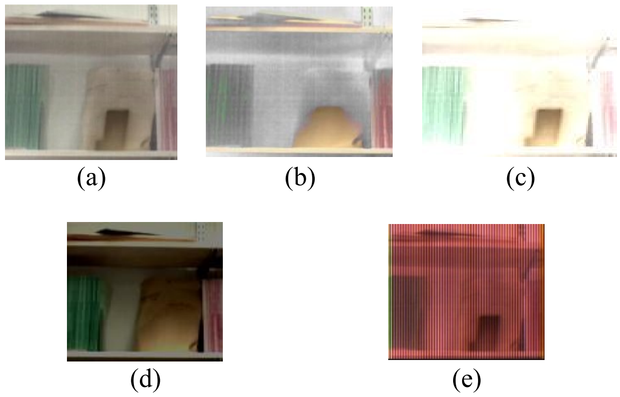


Figure 7. Illustrative comparison of image fusion techniques (L-R), (a) PixAvg, (b) PixMax, (c) DWT, (d) DWT+PCA, (e) proposed method – image dataset2

Table 1. Image fusion performance metrics of different image fusion methods for imageset1

Methodology	Std Dev	Entropy	Mutual Info	MSE	PSNR
Pixel Avg	2.5973e-16	0	0.1441	6.7454e-32	35.8407
Pixel Max	2.5973e-16	0	0.1441	6.7454e-32	36.7641
DWT	0	0.1390	0.1441	0.01	68.1308
DWT+PCA	0.3687	1.1867	-1.0426	0.1702	55.8220
Hadamard+DWT+PCA	0.0664	0.0429	0.1592	0.0050	71.1406

Table 2. Image fusion performance metrics of different image fusion methods for imageset2

Methodology	Std Dev	Entropy	Mutual Info	MSE	PSNR
Pixel Avg	2.1635e-16	0	0.0311	6.7454e-32	37.1407
Pixel Max	2.1635e -16	0	0.0311	6.7454e-32	38.7194
DWT	0	0.0764	0.0311	0.02	65.1205
DWT+PCA	0.2443	0.0871	-0.056	0.1020	58.0448
Hadamard+DWT+PCA	0.0664	0.0410	0.0980	0.0041	72.003

Table 3. Object detection classifier metrics for imageset1

Methodology	Std Dev	Entropy	Mutual Info	MSE	PSNR
Pixel Avg	2.1635e-16	0	0.0311	6.7454e-32	37.1407
Pixel Max	2.1635e -16	0	0.0311	6.7454e-32	38.7194
DWT	0	0.0764	0.0311	0.02	65.1205
DWT+PCA	0.2443	0.0871	-0.056	0.1020	58.0448
Hadamard+DWT+PCA	0.0664	0.0410	0.0980	0.0041	72.003

5. CONCLUSION

This paper concludes that the proposed hybrid image fusion algorithm based on a combination of sigmoidal Hadamard wavelet transforms and PCA with morphological processing will heavily improve the image fusion quality and can be the future lodestar of research and development in data fusion fields. Present commercially available early weapon detection systems require manual screening, but the proposed concealed weapon detection system can be operated accurately at a secure distance. Subjective visual analysis of output images from traditional fusion approaches and the image quality metrics conclude that the proposed fusion algorithm outperforms existing algorithms. The methodology is not computationally complex or expensive; hence the hybrid image fusion the approach can be used in applications where image data compression, high quality, and precision are not of paramount importance. The proposed system can be combined with human emotional expression, behavior and gait analysis as the suspect can have a dynamic range of capricious biological indicators.

ACKNOWLEDGEMENTS

This work was supported in part by the Department of Information technology, Al-Furat Al-Awsat Technical University, Technical Collage of Management, Iraq.

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