International Journal of Scientific Engineering and Technology (ISSN : 2277-1581)
Volume No.3 Issue No.4, pp : 375-379 1April 2014

Comparative Study of Different Image fusion Techniques

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Abstract
Image Fusion is one of the major research fields in image processing. It is a process of combining the relevant information from a set of images, into a single image, without the introduction of distortion wherein the resultant fused image will be more informative and complete than any of the input images. Image fusion techniques can improve the quality and increase the application of these data. This paper discusses some of the existing image fusion techniques for image fusion like the Averaging Method, Select Maximum/Select Minimum, Discrete Wavelet transform based fusion and Principal component analysis (PCA) based fusion and gives their comparative study together. This report also gives evaluation techniques used to evaluate fused images along with the applications of image fusion.

Keywords: Image Fusion, Discrete Wavelet Transform, Applications, Image Quality Metrics, Comparison

I. Introduction

With the recent rapid developments in the field of sensing technologies, multisensory systems have become a reality in a growing number of fields such as remote sensing, medical imaging, machine vision and the military applications for which they were first developed. The result of the use of these techniques is a great increase in the amount of data available. Image fusion provides an effective way of reducing this increasing volume of information while at the same time extracting all the useful information from the source images. The aim of image fusion, apart from reducing the amount of data, is to create single enhanced image more suitable for the purpose of human visual perception and for further image processing tasks such as segmentation, object detection or target recognition in applications such as remote sensing and medical imaging.

II. Categories Of Image Fusion

We categorize the IF methods according to the data entering the fusion and according to the fusion purpose. Input images could be from any of the following categories [xvii]:

1) Multimodal Images: Multimodal fusion of images is applied to images coming from different modalities like visible and infrared, CT and NMR, or panchromatic and multispectral satellite images. The goal of the multimodal image fusion system is to decrease the amount of data and to emphasize band-specific information.
2) Multifocal Images: In applications of digital cameras, when a lens focuses on a subject at a certain distance, all subjects at that distance are not sharply focused. A possible way to solve this problem is by image fusion, in which one can acquire a series of pictures with different focus settings and fuse them to produce a single image with extended depth of field. The goal of this type of fusion is to obtain a single all-in focus image.
3) Multi-view Images: In multi-view image fusion, a set of images of the same scene is taken by the same sensor but from different viewpoints or several 3D acquisitions of the same specimen taken from different viewpoints are fused to obtain an image with higher resolution. The goal of this type of fusion is to provide complementary information from different viewpoints.
4) Multi-Temporal Images: In Multi-temporal image fusion, images taken at different times (seconds to years) in order to detect changes between them are fused together to obtain one single image.

III. Classification Of Image Fusion Techniques

The actual fusion process can take place at different levels of information representation. Image fusion algorithms can be categorized into different levels [i]:-

1) Low or pixel level: The pixel-level method works either in the spatial domain or in the transform domain. Image fusion at pixel level amounts to integration of low-level information, in most cases physical measurements such as intensity
2) Middle or feature level: The feature-level algorithms typically segment the image into contiguous regions and fuse the regions together using their properties. The features used may be calculated separately from each image or they may be obtained by the simultaneous processing of all the images.
3) High or decision level: Decision level fusion uses the outputs of initial object detection and classification as inputs to the fusion algorithm to perform the data integration.

Image fusion method can be broadly classified into two groups:-

a) Spatial domain fusion method: In spatial domain techniques, we directly deal with the image pixels. The pixel values are manipulated to achieve desired result.
b) Transform domain fusion method: In transform domain method image is first transferred in to frequency domain.

There are various methods that have been developed to perform image fusion. Some well-known image fusion methods are listed below [v]:

1. Intensity-hue-saturation (IHS) transform based fusion.
2. Principal component analysis (PCA) based fusion.
3. Arithmetic combinations
    a. Brovey transform.
    b. Synthetic variable ratio technique.
    c. Ratio enhancement technique
4. Multi scale transform based fusion
    a. High-pass filtering method.

b. Pyramid method
- Gaussian pyramid.
- Laplacian Pyramid
- Gradient pyramid.
- Morphological pyramid
- Ratio of low pass pyramid.
- Contrast pyramid.
- Filter-subtract-decimate pyramid.

c. Wavelet transforms
- Discrete wavelet transforms (DWT).
- Stationary wavelet transforms
- Multi-wavelet transforms
- Dual tree discrete wavelet transforms.
- Lifting wavelet transform.

d. Curvelet transforms

5. Total probability density fusion.
6. Biologically inspired information fusion.

IV. Image Fusion Techniques

A. Simple Average Method

In this method the resultant fused image is obtained by taking the average intensity of corresponding pixels from both the input image. The equation used to find the average value is given in equation (i) [v].

$$P(i,j) = \frac{\{X(i,j) + Y(i,j)\}}{2} \quad \text{.... (1)}$$

Where X (i, j) and Y (i, j) are two input images.

B. Select Maximum/ Minimum Method

A selection process is performed here wherein, for every corresponding pixel in the input images, the pixel with maximum/minimum intensity is selected, respectively, and is put in as the resultant pixel of the fused image [v]. Equation (2) and (3) give the maximum and minimum method equation respectively.

$$P(i,j) = \sum_{i=0}^{m} \sum_{j=0}^{n} \max X(i,j) Y(i,j) \quad \text{.... (2)}$$

$$P(i,j) = \sum_{i=0}^{m} \sum_{j=0}^{n} \min X(i,j) Y(i,j) \quad \text{.... (3)}$$

Where X (i, j) and Y (i, j) are two input images.

C. Brovey Transform (BT)

Brovey transform (BT), also known as colour normalized fusion, is based on the chromaticity transform and the concept of intensity modulation. It is a simple method to merge data from different sensors, which can preserve the relative spectral contributions of each pixel but replace its overall brightness with the high spatial resolution image [v]. The basic procedure of the Brovey Transform first multiplies each MS band by the high-resolution PAN band, and then divides each product by the sum of the MS bands. The Brovey Transform is good for producing RGB images with a higher degree of contrast in the low and high ends of the image histogram and for producing visually appealing images. Consequently, it should not be used if preserving the original scene radiometry is important. However, Since the Brovey Transform is intended to produce RGB images, only three bands at a time should be merged from the input multispectral scene.

D. Intensity Hue Saturation (IHS) Technique

It is most popular fusion methods used in remote sensing. The fusion is based on the RGB-HIS conversion model, whose various mathematical representations have been developed. The intensity I defines the total color brightness and exhibits as the dominant component [v]. The main steps for the standard IHS fusion scheme are:-

i. Perform image registration (IR) to PAN and MS, and resample MS.
ii. Convert MS from RGB space into IHS space.
iii. Match the histogram of PAN to the histogram of the I component.
iv. Replace the I component with PAN.
v. Convert the fused MS back to RGB space.

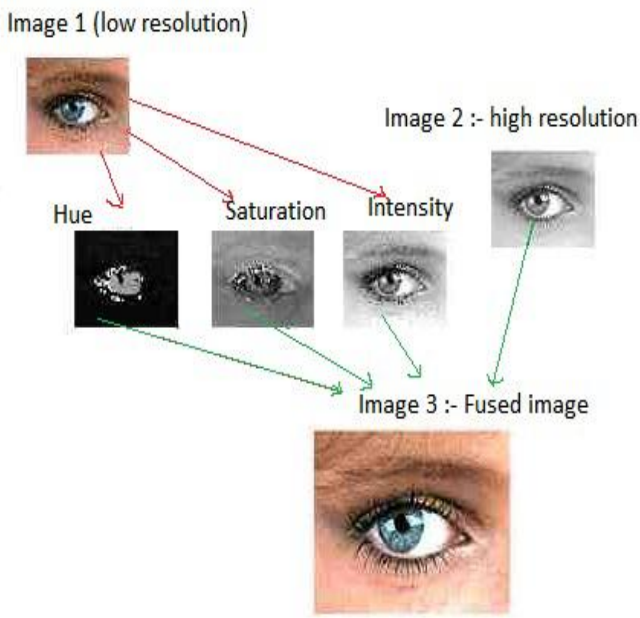

Figure 1: IHS Transformation [xvii]

E. Principal Component Analysis (PCA) Technique

Principal Component Analysis is a sub space method, which reduces the multidimensional data sets into lower dimensions for analysis. The PCA involves a mathematical procedure that transforms a number of correlated variables into a number of uncorrelated variables called principal components. The first principal component accounts for as much of the variance in the data as possible and each succeeding component accounts for as much of the remaining variance as possible. The second principal component is constrained to lie in the subspace perpendicular of the first. The third principal component is taken in the maximum variance direction in the subspace perpendicular to the first two and so on. The PCA is also called as Karhunen-Love transform or the Hotelling transform [x].

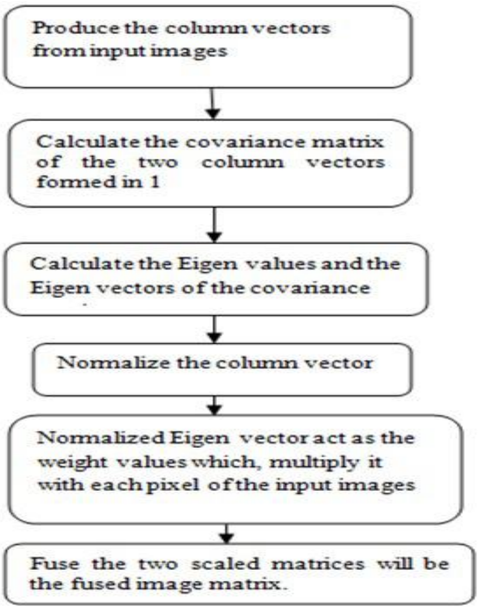

Figure 2: PCA Algorithm[x]

F. Discrete Wavelet Transform (DWT)

Wavelet transforms are multi-resolution image decomposition tool that provide a variety of channels representing the image feature by different frequency sub-bands. It is a famous technique in analyzing signals. 2-D Discrete Wavelet Transformation (DWT) converts the image from the spatial domain to frequency domain. The image is divided by vertical and horizontal lines and represents the first-order of DWT, and the image can be separated with four parts those are LL1, LH1, HL1 and HH1 [i]. When decomposition is performed, the L-L band contains the average image information whereas the other bands contain directional information due to spatial orientation. Higher absolute values of wavelet coefficients in the high bands correspond to salient features such as edges or lines. In wavelet transformation due to sampling, the image size is halved in both spatial directions at each level of decomposition process thus leading to a multi resolution signal representation. The most important step for fusion is the formation of fusion pyramid. It is difficult to decide a uniform standard for fusion principle.

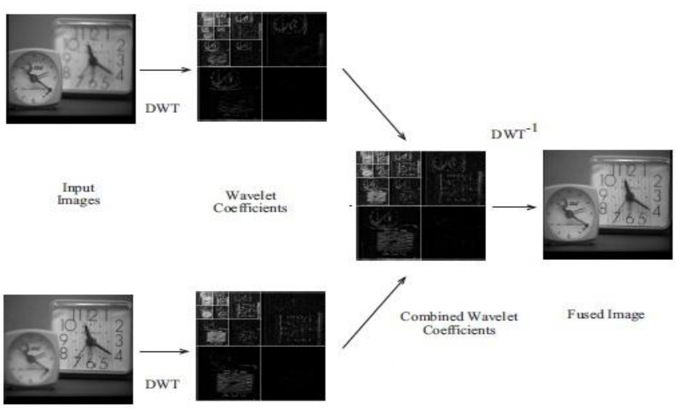

Figure 3: DWT Transformation

V. Fused Image Evaluation

Image quality metrics are used to benchmark different image processing algorithm by comparing the objective metrics. There are two types of metrics that is subjective and objective used to evaluate image quality. In subjective metric users rate the images based on the effect of degradation and it vary from user to user whereas objective quality metrics quantify the difference in the image due to processing. Furthermore, fusion assessment can be classified as either qualitative or quantitative in nature. Assessment of image fusion performance can be first divided into two categories [ix]:

1) Assessment Without Reference Images:
   In assessment without reference images, the fused images are evaluated against the original source images for similarity.
   a) Entropy as a Quality Metric: Entropy is defined as amount of information contained in a signal. The entropy of the image can be evaluated as:-

$$H = -\sum_{i=1}^{G} P(i)\,log_2\left(P(d_i)\right)$$

.... (4)

   Where G is the number of possible gray levels, P (di) is probability of occurrence of a particular gray level di. The maximum value of entropy can be produced when each gray level of the whole range has the same frequency. If entropy of fused image is higher than parent image then it indicates that the fused image contains more information.
   b) Standard Deviation as a Quality Metric: This metric is more efficient in the absence of noise. It measures the contrast in the fused image. An image with high contrast would have a high standard deviation. It is given by the following equation:-

$$\sigma = \sqrt{\sum_{i=0}^{L}(i-\bar{i})^2 h_{I_f}(i)}, \cdots \bar{i} = \sum_{i=0}^{L} i\, h_{I_f}(i)$$

.... (5)

   Where h_{If} (i) is the normalized histogram of the fused image, if (x, y) and L is number of frequency bins in histogram.
   c) Other parameters are: Cross entropy, Fusion mutual information, Fusion quality index, Fusion similarity metric, Spatial Frequency etc.

2) Assessment With Reference Image:
   In reference-based assessment, a fused image is evaluated against the reference image which serves as a ground truth.
   a) Root Mean Square Error (RMSE): A commonly used reference-based assessment metric is the root mean square error (RMSE) which is defined as follows:-

$$RMSE = \sqrt{\frac{1}{mn}\sum_{m=1}^{m}\sum_{n=1}^{n}(Aij - Bij)^2}$$

.... (6)

Where, A is the perfect image, B is the fused image to be assessed, i is pixel row index, j is pixel column index and m, n are the no. of rows and columns.

b) Mean Squared Error (MSE): The mathematical equation of MSE is given by the following equation:-

$$MSE = \frac{1}{mn}\sum_{m=1}^{m}\sum_{n=1}^{n}(Aij - Bij)^2$$

.... (7)

c) Normalized Cross Correlation (NCC): Normalized cross correlation are used to find out similarities between fused image and registered image is given by the following equation[1]:-

$$NCC = \frac{\sum_{m=1}^{m}\sum_{n=1}^{n}(Aij * Bij)}{\sum_{m=1}^{m}\sum_{n=1}^{n}(Aij)^2}$$

.... (8)

d) Peak Signal to Noise Ratio (PSNR): PSNR is the ratio between the maximum possible power of a signal and the power of corrupting noise that affects the fidelity of its representation [1]. The PSNR measure is given by:-

$$PNSR = 20log\frac{255\sqrt{3mn}}{\sum_{m=1}^{m}\sum_{n=1}^{n}(B'ij - Bij)^2}$$

.... (9)

e) Structural Content (SC): The structural content measure is used to compare two images in a number of small image patches the images have in common. The large value of structural content SC means that image has poor quality. This value should be small. The SC measure is given by:-

$$SC = \frac{\sum_{m=1}^{m}\sum_{n=1}^{n}(Aij)^2}{\sum_{m=1}^{m}\sum_{n=1}^{n}(Bij)^2}$$

.... (10)

f) Other parameters are: Percentage fit error, Signal to noise ratio, Mutual information, Universal quality index, Measure of structural similarity etc.

VI. Comparison Of Different Image Fusion Techniques

Table (1): Advantages and Disadvantages of the Different Image Fusion Techniques [iv].

Sr. No.	Fusion Method	Advantages	Disadvantages
1	Simple Average	Simplest, works well for single sensor images containing additive noise, good for high contrast input images	Reduced contrast
2	Simple Max/ Min	Simple, highly focused output image obtained as compared to average method.	Blurring, it has higher pixel intensity but it does not mean more content.
3	Brovey Method	Simple and fast method, good for multisensory images, provides superior visual and high resolution MS image.	This method ignores the requirement of high quality synthesis of spectral information and causes spectral distortion
4	IHS	It is a simple method to merge the images attributes and provides high spatial quality	It suffers from artifacts and noise which tends to higher contrast. It causes colour distortion. The major limitation that only three bands are involved
5	PCA	Simple, fused images have high spatial quality. It prevents certain features from dominating the image because of their large digital numbers.	This method is highly criticized because of the distortion of the spectral characteristic between the fused images and the original low resolution images [v]. Resulting image does not preserve faithfully the colors found in the original images
6	DWT	The DWT fusion method has least spectral distortion. It also provides better SNR than pixel based approach.	In this method final fused image have a less spatial resolution.

VII. Applications

Some of the applications of Image Fusion Techniques in given below:-

1. Intelligent robots
    a. Require motion control, based on feedback from the environment from visual, tactile, force/torque, and other types of sensors.
    b. Stereo camera fusion.
    c. Intelligent viewing control.
    d. Automatic target recognition and tracking.
2. Medical image
    a. Fusing X-ray computed tomography (CT) and magnetic resonance (MR) images.
    b. Computer assisted surgery.
    c. Spatial registration of 3-D surface.

3. Manufacturing
    a. Electronic circuit and component inspection.
    b. Product surface measurement and inspection.
    c. Non-destructive material inspection.
    d. Manufacture process monitoring.
    e. Complex machine/device diagnostics.
    f. Intelligent robots on assembly lines.
4. Military and law enforcement
    a. Detection, tracking, identification of ocean (air, ground) target/event.
    b. Concealed weapon detection.
    c. Battle-field monitoring.
    d. Night pilot guidance.
5. Remote sensing etc.

VIII. Conclusion

This report performs the Comparative study of Image fusion techniques. Here, various Image Fusion techniques that are useful to create a single enhanced image more suitable for the purpose of human visual perception, object detection and target recognition have been discussed with applications. On the basis of the study and examples mentioned we have found out various issues in different techniques. This review concludes which approach is better among all the existing Image Fusion techniques. Although selection of fusion algorithm is problem dependent but this review concludes that spatial domain techniques provide high spatial resolution but these techniques have image blurring problem. The Wavelet transform is a very good technique for image fusion providing a high quality spectral content.

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