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Image Fusion Methods and Quality Assessment Parameters

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***Abstract* – Image processing techniques primarily focus upon enhancing the quality of an image or a set of images and to derive the maximum information from them. Image Fusion is such a technique of producing a superior quality image from a set of available images. It is the process of combining relevant information from two or more images into a single image wherein the resulting image will be more informative and complete than any of the input images. A lot of research is being done in this field encompassing areas of Computer Vision, Automatic object detection, Image processing, parallel and distributed processing, Robotics and remote sensing. In this paper, we have described the various 11 fusion methods (IHS, PCA, Pyramid method, Wavelet transform etc.) and the different quality assessment parameter (PSNR, MSE, average difference, NAE etc.) used to assess the quality of the fused image. The various application areas of image fusion are also included in this paper.**

***Keywords:* Image fusion, IHS, PCA, PSNR, Average difference, NAE**

I. Introduction

Image fusion can be broadly defined as the process of combining multiple input images into a smaller collection of images, usually a single one, which contains the "relevant" information from the inputs, in order to enable a good understanding of the scene, not only in terms of position and geometry, but more importantly, in terms of semantic interpretation. The images to be combined will be referred to as *input* or *source* images, and the fusion result image (or images) as composite image or fused image. With rapid advancements in technology, it is now possible to obtain information from multi source images to produce a high quality fused image with spatial and spectral information [1] [10]. Researchers are applying the fusion technique since from three decades and propose various useful methods and techniques. A detailed review in the literature is given by [11]. Generally, IF methods can be classified into three categories based on the merging state: pixel or sensor level, feature level, and decision level [10]. According to the generic framework proposed by Wang *et al.* [2], an image fusion scheme is usually composed of (a) multi scale decomposition, which maps source intensity images to more efficient representation;(b) activity measurement that determines the quality of each input; (c) coefficient grouping method to determine whether or not cross scale correlation is considered; (d)coefficient combining method where a weighted sum of source representations are calculated and finally (e) consistency verification to ensure neighboring coefficients are calculated in similar manner.

The evolution of the research work into the field of image fusion [1] [10] [11] [12] can be broadly put into the following three stages

- Simple Image Fusion
- Pyramid Decomposition based fusion
- Discrete Wavelet transform based fusion

The eleven algorithms discussed here are such that all the three of the above categories are covered for assessment. The various image fusion methods are as follows [1] [11][5] [12]:

- Averaging method
- Select Maximum method
- Select Minimum method
- Principal Component Analysis Method
- Filter Subtract Decimate Pyramid Method
- Laplacian Pyramid Method
- Gradient Pyramid Method
- Ratio Pyramid Method
- Morphological Pyramid Method
- Haar Wavelet Method
- DBSS(2,2) wavelet Method

The various Image Quality Metrics to assess the quality of the fused images with respect to a sample perfect image for a given pair of input images are[10][8][11][12]: Mean Square Error (MSE),Peak Signal to Noise Ratio (PSNR), Average Difference(AD), Normalized cross Correlation (NCC), Maximum Difference (MD),Normalized Absolute Error (NAE), Structural Content (SC),Structural Similarity Index Metric (SSIM), Universal image quality index.

II. Image Fusion Techniques

Averaging Method - The very concept of information fusion arose from the idea of averaging the available information. In this method the basic concept to fuse a set of input image was to average the pixel intensities of the corresponding pixels. The fused image produced by this method projects both the good and the bad information from the input images. Due to the averaging operation, both the good and the bad information are minimized arriving at an averaged image. Thus the algorithm does not actually fuse the images perfectly. The value of the pixel P (i, j) of each image is taken and added. This sum is then divided by 2 to obtain the average. The average value is assigned to the corresponding pixel of the output image which is given in equation (1). This is repeated for all pixel

$K (i, j) = \{X (i, j) + Y (i, j)\}/2$

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

Select Maximum - In this method, the pixel with maximum intensity is selected and is put in as the resultant pixel of the fused image. Thus, effectively, every pixel of the fused image will be the pixel with maximum intensity of the corresponding position pixels in the input image. One advantage of this method over averaging method is that there is no compromise made over the good information available in the input images. But of course, it is combined with the disadvantage that higher pixel intensity does not always mean better information. It depends on the type of image under consideration. Thus, you either take the whole of the information or totally avoid the same. Thus, here the value of the pixel P (i, j) of each image is taken and compared to each other. The greatest pixel value is assigned to the corresponding pixel of resultant fused image [1][11].

Select Minimum - The minimum selecting method, being yet another trivial image fusion method, is very similar to the Maximum Selection method; except for, here, the selection criteria differs as the pixel with minimum density is picked up. Thus, for every pixel position, the pixel of the fused image will be the pixel of the corresponding position from the input set of images having the least pixel intensity value. The quality of the fusion is specific to the type of image we are dealing with. In certain cases, say, images with dark shades would generate a good fusion image with this method.

Principle Component Analysis - The PCA is used extensively in image compression and image classification. The PCA involves a mathematical procedure that transforms a number of correlated variables into a number of uncorrelated variables called principal components. It computes a compact and optimal description of the data set. The PCA algorithm looks into scaling the pixel values of the images with a weight. The algorithm can be summarized as the following [12]:

1. Generate the column vectors, respectively, from the input image matrices.
2. Calculate the covariance matrix of the two column vectors formed in 1
3. The diagonal elements of the 2x2 covariance vector would contain the variance of each column vector with itself, respectively.
4. Calculate the Eigen values and the Eigen vectors of the covariance matrix
5. Normalize the column vector corresponding to the larger Eigen value by dividing each element with mean of the Eigen vector.
6. The values of the normalized Eigen vector act as the weight values which are respectively multiplied with each pixel of the input images.
7. Sum of the two scaled matrices calculated in 6 will be the fused image matrix.

Filter Subtract Decimate Pyramid Method - Every pyramid transform consists of three major phases: Decomposition, Formation of the initial image for recomposition, Recomposition.

Decomposition is the process where a pyramid is generated successively at each level of the fusion. The depth of fusion or number of levels of fusion is pre decided.

The number of levels of fusion is decided based on the size of the input image. The recomposition process, in turn, forms the finally fused image, level wise, by merging the pyramids formed at each level to the decimated input images. In this method the decomposition phase consists of three steps [11]:

- Low pass filtering using $W = [\frac{1}{16}, \frac{4}{16}, \frac{6}{16}, \frac{4}{16}, \frac{1}{16}]$.
- Subtract the low pass filtered input images and form the pyramid
- Decimate the input image matrices by halving the number of rows and columns (we did by neglecting every alternate row and column).

The recomposition phase would include steps:

- Undecimating the image matrix by duplicating every row and column
- Low pass filtering with 2*W

Matrix addition of the same with the pyramid formed in the corresponding level.

***Laplacian Pyramid Method* -** The Laplacian pyramidal method is identical to FSD pyramid except for an additional low pass filtering performed with 2*W. All the other steps are followed as in FSD pyramid [12].

Ratio Pyramid Method - The Ration pyramidal method is also identical to FSD pyramid except for, in the decomposition phase, after low pass filtering the input image matrices, the pixel wise ratio is calculated instead of subtraction as in FSD.

Gradient Pyramid Method - The decomposition process here would include the following steps: Two low pass filters are considered here $W = [\frac{1}{16}, \frac{4}{16}, \frac{6}{16}, \frac{4}{16}, \frac{1}{16}]$ and $V = [\frac{1}{4}, \frac{2}{4}, \frac{1}{4}]$. Additional to this, four directional filters are applied on to the input image matrices.

Horizontal filter, $\begin{matrix} 0 & 0 & 0 \\ 1 & -2 & 1 \\ 0 & 0 & 0 \end{matrix}$ Vertical filter $\begin{matrix} 0 & 1 & 0 \\ 0 & -2 & 0 \\ 0 & 1 & 0 \end{matrix}$

Diagonal filter, $\begin{matrix} 0 & 0 & 0.5 \\ 0 & -1 & 0 \\ 0.5 & 0 & 0 \end{matrix}$ Diagonal Filter $\begin{matrix} 0.5 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 0.5 \end{matrix}$

The rest of the steps are similar to that of FSD pyramid method.

Morphological Pyramid Method - The decomposition phase in this method consists of the following steps:

- Two levels of filtering are performed on the input image matrices. Image opening and image closing. followed by image dilation. Image closing is theother way round. A combination of image opening and image closing gets rid of noise in the image.
- The rest of the steps are as in FSD pyramid method.

The recomposition phase would be similar to the FSD method except for the step where the low pass filter is applied on the image matrix. Instead, image dilation is performed over the matrix.

Haar Wavelet Method- The Haar wavelet is the first known*wavelet. The Haar wavelet ψ (t) can be described as*

$$\psi(t) = \begin{cases} 1 & 0 \le t < 1/2, \\ -1 & 1/2 \le t < 1, \\ 0 & otherwise. \end{cases} \tag{2}$$

and its scaling function φ (t) can be described as

$$\phi(t) = \begin{cases} 1 & 0 \le t < 1, \\ 0 & otherwise \end{cases} \tag{3}$$

The 2x2 Haar matrix is associated with $H=\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$ The filters thus, considered here would be

F1 = [* 0.5 * 0.5 *]
F2 = [0.5 * −0.5 *]*

The couple of filters, when applied on the input images matrices, would produce 4 resultant matrices. The fourth matrix, which would consist of all the high frequencies, would act as the input matrix for the next level of decomposition. The other three matrices, consisting of the low frequencies, are used to produce 3 pyramids at each level. The pyramids are produced as in pyramidal method. The re-composition process is performed with the help of the three pyramids formed at each level of decomposition. The disadvantage of the Haar wavelet is that it is not continuous and therefore not differentiable.

***DBSS (2,2) Wavelet Method* -** the Daubechies wavelets are a family of orthogonal wavelets defining a discrete wavelet transform and characterized by a maximal number of vanishing moments for some given support . In general the

Daubechies wavelets are chosen to have the highest number A of vanishing moments, (this does not imply the best smoothness) for given support width $N=2A$, and among the 2^{A-1} possible solutions the one is chosen whose scaling filter has extremal phase[12].

The filter considered here are:

H1 = [−1 2 6 2 −1]
H1 = [−1 −2 6 −2 −1]
G1 = [2 4 2]
G1 = [2 4 2]

The input image matrices of the level M1 and M2 are filtered into four bands each, say, A1, A2, A3, A4 and B1, B2, B3, B4 respectively.

- Calculate Z1 and Z2 by filtering M1 and M2 respectively with G1 filter at row level.
- A1 is calculated by filtering Z1 with transpose of G1 filter at column level.
- Calculate Z1 and Z2 by filtering M1 and M2 again with H1 filter at row level.
- A3 is calculated by filtering Z1 with transpose of G1 filter at row level.
- A4 is calculated by filtering Z1 with transpose of H1 filter at row level.
- Similarly, B1, B2, B3 and B4 are calculated for M2 as in the case of M1.
- Three set of coefficient matrices (pyramids) are formed in this wavelet method, say, E1, E2 and E3.

The recomposition process was performed with superimposing of the pyramids formed at each level to the undecimated image matrix at that level.

III. Image Quality Assessment Parameter

Assumptions made in the following equations are

A - The perfectimage

B - The fused image to be assessed i - Pixel row index

j - Pixel column index

m - The height of the Image implying the number or pixel rows

n - The width of the image, implying the number of pixel columns.

Mean Square Error (MSE)- Mean square error is one of the most commonly used error projection method where, the error value is the value difference between the actual data and the resultant data. The mean of the square of this error provides the error or the actual difference between the expected/ideal result to the obtained or calculated result. The mathematical equation of MSE is giver by the equation

$$MSE = \frac{1}{mn}\sum_{i=1}^{m}\sum_{j=1}^{n}\left(A_{ij} - B_{ij}\right)^2 \tag{4}$$

MSE value will be 0 if both the images are identical.

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][7]. The PSNR measure is given by:-

$$PSNR = 10log_{10}\left\{\frac{peak^2}{MSE}\right\} \tag{5}$$

This basically projects the ratio of the highest possible value of the data to the error obtained in the data. If both the fused and the perfect images are identical, then the MSE value would be 0. In that case, the PSNR value will remain undefined.

Average Difference (AD) - Average Difference, as explained by the term itself, is the average value of the difference between the actual/ideal data and the obtained/resultant data. It is measured as[12]

$$AD = \frac{1}{mn}\sum_{i=1}^{m}\sum_{j=1}^{n}\left(\left|A_{ij} - B_{ij}\right|\right) \tag{6}$$

The difference of the corresponding pixel density values is averaged to obtain the metric. This metric helps in providing the overall average difference between the corresponding pixels of the two images proving us a value that specifies, how much different is the fused image from the perfect image.

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

$$\mathrm{NCC} = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n}(A_{ij} * B_{ij})}{\sum_{i=1}^{m}\sum_{j=1}^{n}(A_{ij}{}^2)} \tag{7}$$

The Normalized Cross Correlation value would ideally be 1 if the fused and the perfect images are identical.

Normalized Absolute Error (NAE)- This is a metric where the error value is normalized with respect to the expected or the perfect data. That is, The net sum of the error value which is the difference between the expected values and the actual obtained values is divided by the net sum of the expected values. [11]

$$NAE = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n}\left(\left|A_{ij} - B_{ij}\right|\right)}{\sum_{i=1}^{m}\sum_{j=1}^{n}\left(A_{ij}\right)} \quad (8)$$

The Normalized Absolute value will be zero (0) if both the fused and the perfect images are identical.

Structural Content (SC)- It is the ratio between the net sum of the square of the expected data and the net sum of square of the obtained data.

$$\mathbf{SC}= \frac{\sum_{i=1}^{m}\sum_{j=1}^{n}(A_{ij}{}^2)}{\sum_{i=1}^{m}\sum_{j=1}^{n}(\mathrm{B}_{ij}{}^2)} \quad (9)$$

For the fused and perfect image being identical, the Structural Content metric value would be 1. But SC being 1 does not mean that the fused and perfect images are identical.

Structural Similarity Index Metric (SSIM) - The Structural Similarity Index measures the similarity between two images. It is an improved version of traditional methods like PSNR and MSE. SSIM is considered to be one of the most effective and consistent metric. SSIM is calculated based on two parameters - (i) K vector being a constant in the SSIM index formula with default value: K = [0.01 0.03], (ii) L being the dynamic range of the images. The values C1 and C2 are calculated based on the following formula [5]:

$$\mathrm{C}_1 = (K_1 * L)^2 \qquad \mathrm{C}_2 = (K_2 * L)^2$$

G being a Gaussian filter window with default value given in matlab and the input images A and B are low pass filtered with G giving and respectively. The filter operation or convolution operation performed is denoted by “.”.

$$\mu_1 = A \cdot G\ ,\ \ \mu_2 = B \cdot G$$

Then the values, $\sigma_1{}^2$, $\sigma_2{}^2$and $\sigma_{12}{}^2$ are calculated based on the following formula.

$$\sigma_1{}^2 = \left(A_{ij}{}^2 \cdot G\right) - \mu_1{}^2$$
$$\sigma_2{}^2 = \left(B_{ij}{}^2 \cdot G\right) - \mu_2{}^2$$
$$\sigma_{12}{}^2 = \left(A_{ij}B_{ij} \cdot G\right) - \mu_1 \cdot\!* \mu_2$$

Once the above values are calculated, finally the SSIM value is calculated based on the following formula:

$$\mathrm{SSIM} = \mathrm{mean}\{(2\mathrm{X}\mu_1\mu_2 + C_1) \cdot\!* (2\mathrm{X}\sigma_{12} + C_2) \cdot\!/((\mu_1{}^2 + \mu_2{}^2 + C_1) \cdot\!* (\sigma_1{}^2 + \sigma_2{}^2 + C_1))\} \quad (10)$$

The SSIM index is a decimal value between 0 and 1. A value of 0 would mean zero correlation with the original image, and 1 means the exact same image.

Universal Image Quality Index (UIQI) - This measures how much of the salient information contained in reference image has been transformed into the fused image. The range of this metric is -1 to 1 and the best value 1 would be achieved if and only if reference and fused images are alike [10]. The lowest value of -1 would occur when $I_f = 2\mu_{I_r} - I_r$

$$QI = \frac{4\sigma_{I_f I_r}(\mu_{I_r} + \mu_{I_f})}{(\sigma_{I_r}{}^2 + \sigma_{I_f}{}^2)\,(\mu_{I_r}{}^2 + \mu_{I_f}{}^2)} - (20) \quad (11)$$

Where $\sigma_{I_r}{}^2$ Variance of reference image, $\sigma_{I_f}{}^2$ Variance of fused image, $\sigma_{\mathrm{I_f I_r}}$ Covariance of reference and fused image, $\mu_{\mathrm{I_r}}$ Mean of reference image, $\mu_{\mathrm{I_r}}$ Mean of fused image.

$$\mu_{I_r} = \frac{1}{mn}\sum_{i=1}^{m}\sum_{j=1}^{n} I_r(i,j)$$
$$\mu_{I_f} = \frac{1}{mn}\sum_{i=1}^{m}\sum_{j=1}^{n} I_f(i,j)$$

$$\sigma_{I_r}{}^2 = \frac{1}{mn-1}\sum_{i=1}^{m}\sum_{j=1}^{n}(I_r(i,j) - \mu_{I_r})^2$$
$$\sigma_{I_f}{}^2 = \frac{1}{mn-1}\sum_{i=1}^{m}\sum_{j=1}^{n}(I_f(i,j) - \mu_{I_f})^2$$

$$\sigma_{I_f I_r} = \frac{1}{mn-1}\sum_{i=1}^{m}\sum_{j=1}^{n}\left(I_f(i,j) - \mu_{I_f}\right)(I_r(i,j) - \mu_{I_r})$$

IV. Applications

Image fusion is widely recognized as a valuable tool for improving overall system performance in image-based application areas such as defense surveillance, remote sensing, medical imaging and computer vision. We list some application fields.

Military- Historically, military appears to be the first application area for image fusion. It covers sub-areas such as detection, identification and tracking of targets, mine detection, tactical situation assessment, and person authentication.

Geosciences- This field concerns the earth study with satellite and aerial images (remote sensing). A major problem is interpretation and classification of images. The fusion of images from multiple sensors allows the detection of roads, airports, mountainous areas, etc.

Robotics and industrial engineering- Here, fusion is commonly used to identify the environment in which the robot or intelligent system evolves. It is also employed for navigation in order to avoid collisions and keep track of the trajectory. Image fusion is also employed in industry, for example, for the monitoring of factories or production lines, or for quality and defect inspection of products.

Medical imaging- Fusion of multimodal images can be very useful for clinical applications such as diagnosis, modeling of the human body or treatment planning. The application of image fusion of various medical images is listed as follows [14]:

1. Neurology - Neurosurgical monitoring and planning through preoperative, intra-operative and post- operative assessment of therapeutic interventions through fusion of CT, PET, MRS and/or MRA/MRV with MRI. Image guided neurosurgery system based on preoperative MRI and intraoperative US to detect brain tissue deformation during craniotomy and monitor extent of lesion removal.

2. Cardiology - Quantitative measurements of coronary vessels in 3D and 4D based on X-ray angiography and IVUS. Facilitate volumetric and velocity measurements to monitor atherosclerosis. Tagged MRI and F18-FDG PET fusion system for the assessment of myocardial viability in patients with coronary heart disease.

3. Oncology - MRI, CT, and PET fusion for tumor segmentation and localization for radiation therapy.

V. Conclusion and Disscussion

Although selection of fusion algorithm is problem dependent but a good fused image must have qualities which must match with the reference image, so the combination such fusion techniques which give better result can give the best quality fused image. For example- the combination of DWT & spatial domain fusion method (like PCA) fusion algorithm improves the performance as compared to use of individual DWT and PCA algorithm. Imaging systems may introduce some amounts of distortion or artifacts in the signal, so the quality assessment is an important problem. For this purpose some statistical measures are performed. However, the results given by the tests were quite uneven, and no clearly conclusion could be obtained. Finally this review concludes that the visual performance-based assessment methodology is equally important and may be the future trend of research regarding image fusion.

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