Comprehensive and Comparative Study of Image Fusion Techniques

S. S. Bedi, Rati Khandelwal

Abstract— Image Fusion is one of the major research fields in image processing. Image Fusion is a process of combining the relevant information from a set of images, into a single image, wherein the resultant fused image will be more informative and complete than any of the input images. Image fusion process can be defined as the integration of information from a number of registered images without the introduction of distortion. It is often not possible to get an image that contains all relevant objects in focus. One way to overcome this problem is image fusion, in which one can acquire a series of pictures with different focus settings and fuse them to produce an image with extended depth of field. Image fusion techniques can improve the quality and increase the application of these data. This paper discusses the three categories of image fusion algorithms – the basic fusion algorithms, the pyramid based algorithms and the basic DWT algorithms. It gives a literature review on some of the existing image fusion techniques for image fusion like, primitive fusion (Averaging Method, Select Maximum, and Select Minimum), Discrete Wavelet transform based fusion, Principal component analysis (PCA) based fusion etc. The purpose of the paper is to elaborate wide range of algorithms their comparative study together. There are many techniques proposed by different authors in order to fuse the images and produce the clear visual of the image. Hierarchical multiscale and multiresolution image processing techniques, pyramid decomposition are the basis for the majority of image fusion algorithms. All these available techniques are designed for particular kind of images. Until now, of highest relevance for remote sensing data processing and analysis have been techniques for pixel level image fusion for which many different methods have been developed and a rich theory exists. Researchers have shown that fusion techniques that operate on such features in the transform domain yield subjectively better fused images than pixel based techniques. For this purpose, feature based fusion techniques that are usually based on empirical or heuristic rules are employed. Because a general theory is lacking fusion, algorithms are usually developed for certain applications and datasets. To implement the pixel level fusion, arithmetic operations are widely used in time domain and frequency transformations are used in frequency domain. In many applications area of navigation guidance, object detection and recognition, medical diagnosis, satellite imaging for remote sensing, rob vision, military and civilian surveillance, etc., the image fusion plays an important role. It also provides survey about some of the various existing techniques applied for image fusion and comparative study of all the techniques concludes the better approach for its future research.

Keywords— Discrete Wavelet Transform, Image Fusion, Pyramid Methods, Principal Component Analysis

I. INTRODUCTION

Image Fusion is a process of combining the relevant information from a set of images of the same scene, into a single image, wherein the resultant fused image will be more informative and complete than any of the input images. Input images could be multi sensor, multimodal, multifocal or multi temporal. One of the goals of image fusion is to create a single enhanced image more suitable for the purpose of human visual perception, object detection and target recognition. One of the important pre-processing steps for the fusion process is image registration, i.e., the coordinate transformation of one image with respect to other. Fusion algorithms are input dependent .Image fusion find application in the area of navigation guidance, object detection and recognition, medical diagnosis, satellite imaging for remote sensing, rob vision, military and civilian surveillance, etc.Image fusion systems are widely used in surveillance and navigation applications, for both military and domestic purposes. This is achieved by the use of multiple sensors to obtain the visual information and by utilizing the synergism of different imaging sensors for better situation assessment. Image fusion algorithms can be categorized into different levels: low, middle, and high; or pixel, feature, and decision levels. The pixel-level method works either in the spatial domain or in the transform domain. Pixel level fusion works directly on the pixels obtained at imaging sensor outputs while feature level fusion algorithms operate on features extracted from the source images. The prerequisite for such an operation is that the images have been acquired by homogeneous sensors, such that the images reproduce similar or comparable physical properties of the scene. 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. Decision level fusion uses the outputs of initial object detection and classification as inputs to the fusion algorithm to perform the data integration. Both feature level and decision level image fusion may result in inaccurate and incomplete transfer of information. Several fusion algorithms starting from simple pixel based to sophisticated wavelets and PCA based are available. Image fusion system has several advantages over single image source and resultant fused image should have higher signal to noise ratio, increased robustness and reliability in the event of sensor failure, extended parameter coverage and rendering a more complete picture of the system. The actual fusion process can take place at different levels of information representation. A common categorization is to distinguish between pixel, feature and decision level, although there may be crossings between them. Image fusion at pixel level amounts to integration of low-level information, in most cases physical measurements such as intensity. Generally, the pixel based image fusion methods average pixel intensity values of the source images pixel by pixel which leads to undesired side effects in the resultant image. Recently researchers have recognized that it is more meaningful to combine objects or regions rather than pixels. The region based algorithm has many advantages over pixel based

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algorithm like it is less sensitive to noise, better contrast, less affected by mis-registration but at the cost of complexity. In order to study the differences between various existing techniques comprehensive and comparative study is required. Section 2 describes brief concepts of Image fusion given by different authors whereas in Section 3 we elaborate image Fusion techniques, in Section 4 presents the comprehensive and comparative study among various existing image fusion techniques. During the study we have observe various issues which are summarized in Section 5 and conclusion is presented in Section 6.

II. BACKGROUND

In applications of digital cameras, when a lens focuses on a subject at a certain distance, all subjects at that distance are sharply focused. Subjects not at the same distance are out of focus and theoretically are not sharp. It is often not possible to get an image that contains all relevant objects in focus. One way to overcome this problem is image fusion, in which one can acquire a series of pictures with different focus settings and fuse them to produce an image with extended depth of field. During the fusion process, all the important visual information found in the input images must be transferred into the fused image without introduction of artifacts. In addition, the fusion algorithm should be reliable and robust to imperfections such as noise or mis-registration. Image fusion is a branch of data fusion where data appear in the form of arrays of numbers representing brightness, color, temperature, distance, and other scene properties. Such data can be two-dimensional (still images), three-dimensional (volumetric images or video sequences in the form of spatio-temporal volumes), or of higher dimensions. In recent years, multivariate imaging techniques have become an important source of information to aid diagnosis in many medical fields. Early work in image fusion can be traced back to the mid-eighties. Burt [1] was one of the first to report the use of Laplacian pyramid techniques in binocular image fusion and later on Burt and Adelson[2] later introduced a new approach to image fusion based on hierarchical image decomposition at about the same time Adelson disclosed the use of a Laplacian technique in construction of an image with an extended depth of field from a set of images taken with a fixed camera but with different focal lengths. Later Toet [3] used different pyramid schemes in image fusion which were mainly applied to fuse visible and IR images for surveillance purposes. Some other early image fusion work are due to Liljestedt[4] disclosing an apparatus for composite visible/thermal infrared imaging. Ajjimarang[5] see suggesting the use of neural networks in fusion of visible and infrared images, Nandhakumar and Aggarwal [6] providing an integrated analysis of thermal and visual images for scene interpretation, and Rogers et al. [7] describing fusion of LADAR and passive infrared images for target segmentation. Use of the discrete wavelet transform (DWT) in image fusion was almost simultaneously proposed by Li and Chipman et al. [8] at about the same time Koren et al. [9] described a steerable dyadic wavelet transform for image fusion and also around the same time Waxman and colleagues developed a computational image fusion methodology based on biological models of color vision and used opponent processing to fuse visible and infrared images. The need to combine visual and range data in robotics navigation and to merge images captured at different locations and modalities for target localization and tracking in defense applications prompted further research in image fusion. Many other fusion techniques have been developed during the last decade. Today, image fusion algorithms are used as effective tools in medical, remote sensing, industrial, surveillance, and defense applications that require the use of multiple images of a scene. For recent surveys of image fusion theory and applications, readers are referred to a paper by Smith and Heather and a collection of papers edited by Blum and Liu.

III. IMAGE FUSION TECHNIQUES

Image fusion techniques can enhance a digital image without spoiling it. The enhancement methods are of two types namely Spatial domain methods and frequency domain methods. In spatial domain techniques, we directly deal with the image pixels. The pixel values are manipulated to achieve desired enhancement. The fusion methods, such as averaging, the Brovey method, principle component analysis (PCA), and IHS based methods fall under the spatial domain approaches. In frequency domain methods, the image is first transferred in to frequency domain. It means that, the Fourier Transform of the image is computed first. All the enhancement operations are performed on the Fourier transform of the image and then the Inverse Fourier transform is performed to get the resultant image. These enhancement operations are performed in order to modify the image brightness, contrast or the distribution of the grey levels. As a consequence the pixel value (intensities) of the output image will be modified according to the transformation function applied on the input values. Pyramid Fusion Algorithm is a fusion method in the transform domain.

Image Fusion techniques can be sub divided in three different types of techniques including Simple fusion techniques, Principal Component Analysis (PCA) based Fusion, Pyramid based image fusion methods and Discrete Wavelet Transform (DWT) based fusion as shown in figure 1.1 below.

Figure 1.1 Categorization of Image Fusion Techniques

3.1 Simple Image Fusion/ PCA based fusion

Simple Fusion Algorithms mainly perform a very basic operation like pixel selection, addition, subtraction or averaging shown in Figure 1.1 are Average Method, Select maximum, Select minimum, PCA. These methods are not always effective but are at times critical based on the kind of image under consideration. The trivial image fusion techniques studied and developed are average method in which the resultant image is obtained by averaging every corresponding pixel in the input images. This technique is a basic and straightforward technique and fusion could be achieved by simple averaging corresponding pixels in each input image. The most straightforward way to build a fused image of several input images is performing the fusion as a weighted superposition of all input images. Select Maximum/Minimum Method is a selection process if performed here wherein, for every corresponding pixels 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. \( I_{f} = \max\{I_{1}, I_{2}\} \). In Principal Component Analysis (PCA) is a vector space transform often used to reduce multidimensional data sets to lower dimensions for analysis. It reveals the internal structure of data in an unbiased way. Principal component Analysis is a mathematical tool which transforms a number of correlated variables into a several uncorrelated variables. PCA is widely used in image classification. The PCA image fusion method simply uses the pixel values of all source images at each pixel location, adds a weight factor to each pixel value, and takes an
average of the weighted pixel values to produce the result for the fused image at the same pixel location. The optimal weighted factors are determined by the PCA technique. The PCA technique is useful for image encoding, image data compression, image enhancement, pattern recognition (especially for object detection), and image fusion. It is a statistical technique that transforms a multivariate data set of inter-correlated variable into a data set of new un-correlated linear combinations of the original variables. It generates a new set of axes which is orthogonal. By using this method, the redundancy of the image data can be decreased.

3.2 Pyramid Decomposition based fusion

Pyramid Fusion Algorithm is a fusion method in the transform domain. Various Pyramid based fusion techniques are FSD Pyramid, Laplacian Pyramid, Ratio-of-low-pass Pyramid, Gradient Pyramid, Morphological Pyramid contrast can be used for the image fusion using different fusion rules. In pyramid approach, pyramid levels obtained from the down sampling of source images are fused at pixel level depending on fusion rules. The fused image is obtained by reconstructing the fused image pyramid. An image pyramid consists of a set of low pass or band pass copies of an image, each copy representing pattern information of a different scale. At every level of fusion using pyramid transform, the pyramid would be half the size of the pyramid in the preceding level and the higher levels will concentrate upon the lower spatial frequencies. The basic idea is to construct the pyramid transform of the fused image from the pyramid transforms of the source images and then the fused image is obtained by taking inverse pyramid transform. In Filter Subtract Decimate Pyramid as suggested by the very name of this algorithm, the decomposition phase consists of Low pass filtering, subtract the low pass filtered input images and form the pyramid and 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 undecimating the image matrix by duplicating every row and column, Low pass filtering with $2^W$ and matrix addition of the same with the pyramid formed in the corresponding level. The Laplacian Pyramid method is identical to FSD pyramid except for an additional low loss filtering performed with $2^W$. All the other steps are followed as in FSD pyramid. The Ratio 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. In Gradient Pyramid the decomposition process would include two low pass filters, additional to this four directional filters (horizontal filter, vertical filter, diagonal filter) are applied on to the input image matrices .The rest of the steps are similar to that of FSD pyramid method. In Morphological Pyramid the decomposition phase in this method consists of two levels of filtering are performed on the input image matrices – image opening and image closing. Image opening is a combination of image erosion followed by image dilation. Image closing is the other 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. The Laplacian pyramid fusion consists of an iterative process of calculating the Gaussian and Laplacian pyramids of each source image, fusing the Laplacian images at each pyramid level by selecting the pixel with the larger absolute value, combining the fused Laplacian pyramid with the combined pyramid expanded from the lower level, and then expanding the combined pyramids to the upper level. The fusing step above can also be done using a PCA-based weighted averaging technique. A gradient pyramid is obtained by applying a set of 4 directional gradient filters (horizontal, vertical, and 2 diagonal) to the Gaussian pyramid at each level. At each level, these 4 directional
IV. COMPARATIVE STUDY OF VARIOUS IMAGE FUSION TECHNIQUES

On the basis of the study only few comparisons between the different existing fusion techniques have been made and are analyzed theoretically which are shown in Table 1 as below.

<table>
<thead>
<tr>
<th>S.NO</th>
<th>Fusion Technique/Algorithm</th>
<th>Domain</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Simple Average</td>
<td>Spatial</td>
<td>This is the simplest method of image fusion.</td>
<td>The main disadvantage of Pixel level method is that this method does not give guarantee to have a clear objects from the set of images.</td>
</tr>
<tr>
<td>2.</td>
<td>Simple Maximum</td>
<td>Spatial</td>
<td>Resulting in highly focused image output obtained from the input image as compared to average method.</td>
<td>Pixel level method are affected by blurring effect which directly affect on the contrast of the image</td>
</tr>
<tr>
<td>3.</td>
<td>PCA</td>
<td>Spatial</td>
<td>PCA is a tools which transforms number of correlated variable into number of uncorrelated variables, this property can be used in image fusion.</td>
<td>But spatial domain fusion my produce spectral degradation.</td>
</tr>
<tr>
<td>4.</td>
<td>DWT</td>
<td>Transform</td>
<td>The DWT fusion method may outperform the slandered fusion method in terms of minimizing the spectral distortion. It also provide better signal to noise ratio than pixel based approach.</td>
<td>In this method final fused image have a less spatial resolution.</td>
</tr>
<tr>
<td>5.</td>
<td>Combine DWT, PCA</td>
<td>Transform</td>
<td>Multi level fusion where the image undergoes fusion twice using efficient fusion technique provide improved result output image contained both high spatial resolution with high quality spectral content.</td>
<td>This method is complex in fusion algorithm. Required good fusion technique for better result.</td>
</tr>
<tr>
<td>6.</td>
<td>Combination of Pixel &amp; Energy Fusion rule</td>
<td>Transform</td>
<td>Preserves boundary information and structural details without Introducing any other inconsistencies to the image.</td>
<td>Complexity of method increases.</td>
</tr>
</tbody>
</table>
V. OBSERVATION

The different pyramid schemes have been used in image fusion method which are mainly applied to fuse visible and IR images for surveillance applications. Discrete wavelet transform for image fusion where two different fusion rules are used for approximation image and detail image respectively. Most of multiresolution (MR) based image fusion approaches deal with the issues

- the selection of specific type of MR decomposition like pyramid, wavelet, linear, morphological etc.
- the appropriate number of decomposition level which facilitates the selection and combination of salient features. More decomposition levels do not necessarily produce better result because by increasing the analysis depth the neighboring features of lower band may overlap. This gives rise to discontinuities in the composite representation and thus introduces distortions, such as blocking effect or ringing artifacts into the fused image. The considerable work has been done in case of pixel based image fusion; but less work has been explored at feature level and region level image fusion.

VI. CONCLUSION

This paper performs the Comparative study of Image fusion techniques Here, various techniques of Image Fusion that are useful in image fusion is to create a single enhanced image more suitable for the purpose of human visual perception, object detection and target recognition has been discussed. On the basis of the study we have find out various issues in different techniques and to remove them various techniques are proposed for fusion of different images. This review presents that which approach is better among all the existing Image Fusion techniques. Although selection of fusion algorithm is problem dependent but this review results that spatial domain provide high spatial resolution but spatial domain have image blurring problem. The Wavelet transforms is the very good technique for the image fusion provide a high quality spectral content. But a good fused image have both quality so 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. Finally this review concludes that hat a image fusion algorithm based on combination of DWT and PCA with morphological processing may be the future trend of research regarding image fusion.

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REFERENCES