Development of Image Fusion Methods and Evaluation of Quality 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. This paper reports a detailed study performed over a set of image fusion algorithms regarding their implementation. The paper explains the theoretical and implementation issues of the efficient image fusion algorithms considered and the experimental results of the same. The fusion algorithms were assessed based on the study and development of some image quality metrics. Reported is the study and implementation of image quality metrics that were developed for assessing the image fusion algorithms implemented. The experimental results have been discussed in detail and the inference thus arrived at.

The paper, in the later section describes about the image fusion toolkit called Wavelet Fusion and Laplacian Fusion, developed using MATLAB, providing a graphical user interface for the same. A description is provided about the usage of the toolkit in order to fuse the set of input images using the various image fusion algorithms.

Index Terms: Discrete Cosine Transforms, Discrete Wavelet Transforms, Image fusion, Image processing, laplacian fusion, wavelet fusion.

I. INTRODUCTION

With the recent rapid developments in the field of sensing technologies multi-sensor 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 of 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 rapidly. Multi-sensor data often presents complementary information about the region surveyed, so image fusion provides an effective method to enable comparison and analysis of such data. The aim of image fusion, apart from reducing the amount of data, is to create new images that are more suitable for the purposes of human/machine perception, and for further image-processing tasks such as segmentation, object detection or target recognition in applications such as remote sensing and medical imaging. For example, visible-band and infrared images may be fused to aid pilots landing aircraft in poor visibility.

Multi-sensor images often have different geometric representations, which have to be transformed to a common representation for fusion. This representation should retain the best resolution of either sensor. A prerequisite for successful in image fusion is the alignment of multi-sensor images. Multi-sensor registration is also affected by the differences in the sensor images.
Image fusion is the process by which two or more images are combined into a single image retaining the important features from each of the original images. The fusion of images is often required for images acquired from different instrument modalities or capture techniques of the same scene or objects (like multi-sensor, multi-focus and multi-modal images). Image fusion is the process of combining relevant information from two or more images into a single image. The resulting image will be more informative than any of the input images. Image fusion can synthesize many images from different sensors into a picture which can meet specific application by using a mathematical model. It can effectively combine the advantages from different images and improve the analysis ability. For example, in multi-focus imaging one or more objects may be in-focus in a particular image, while other objects in the scene may be in focus in other images.

II. PREVIOUS WORK

The primitive fusion schemes perform the fusion right on the source images. This would include operations like averaging, addition, subtraction/omission of the pixel intensities of the input images to be fused. These methods often have serious side effects such as reducing the contrast of the image as a whole. But these methods do prove good for certain particular cases wherein the input images have an overall high brightness and high contrast.

III. PROBLEM DEFINITION

The relevance of the present study have suggested a multisensory image fusion using wavelet transform in which a cascaded sequence of forward and reverse wavelet transform on multimodal images produces a fused image. In Wavelet Transforms input image approximately combined and the image is obtained by taking the inverse wavelet transform of the fused wavelet co-efficient. With the availability of multisensor, data in many field such as remote sensing medical imaging, machine vision and military applications, sensor fusion has emerged as a new and promising research area.
Multisensor data often presents complementary information about the region surveyed, so image fusion provides an effective method to enable comparison and analysis of such data. The goal of image fusion is to create new images that are more suitable for the purposes of human visual perceptions object detection and target recognition. The use of multisensory data such as visible and infrared images has led to increased recognition rate in application such as automatic target recognition.

III. MOTIVATION

The motivation behind the idea is that the fusion of images is often required for images acquired from different instrument modalities or capture techniques of the same scene or objects (like multi-sensor, multi-focus and multi-modal images).

IV. PROPOSED METHOD

Image fusion is the process that combines information from multiple images of the same scene. These images may be captured from different sensors, acquired at different times, or having different spatial and spectral characteristics. The object of the image fusion is to retain the most desirable characteristics of each image. With the availability of multisensory data in many fields, image fusion has been receiving increasing attention in the researches for a wide spectrum of applications. We use the following four examples to illustrate the purpose of image fusion.

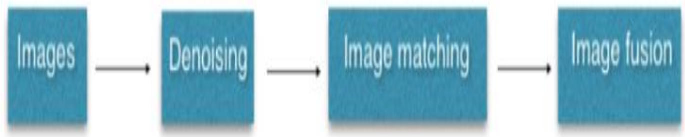

Fig.1. Steps of image fusion

A: Optical remote sensing

In Optical remote sensing fields, the multispectral (MS) image which contains color information is produced by three sensors covering the red, green and blue spectral wavelengths. Because of the trade-off imposed by the physical constraint between spatial and spectral resolutions, the MS image has poor spatial resolution. On the contrast, the panchromatic (PAN) images has high spatial resolution but without color information. Image fusion can combine the geometric detail of the PAN image and the color information of the MS image to produce a high-resolution MS image. Fig. 5.1 shows the MS and PAN images of earth observation satellite, and the resulting fused image.

B: Image fusion methods

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

- Intensity-hue-saturation (IHS) transform based fusion
- Principal component analysis (PCA) based fusion
- Arithmetic combinations
  - ➢ Brovey transform
  - ➢ Synthetic variable ratio technique
  - ➢ Ratio enhancement technique
- Multiscale transform based fusion
  - ➢ High-pass filtering method
  - ➢ Pyramid method
    - (i) Gaussian pyramid
    - (ii) Laplacian Pyramid
    - (iii) Gradient pyramid
    - (iv) Morphological pyramid
    - (v) Ratio of low pass pyramid
    - (vi) Contrast pyramid
- ➢ Wavelet transforms
  - (i) Discrete wavelet transform (DWT)
  - (ii) Stationary wavelet transform
  - (iii) Dual tree discrete wavelet transform
  - (iv) Lifting wavelet transform
  - (v) Multi-wavelet transforms
- ➢ Curvelet transform
- Total probability density fusion

- Biologically inspired information fusion

C: Image Fusion Methods
The trivial image fusion techniques mainly perform a very basic operation like pixel selection, addition, subtraction or averaging. These methods are not always effective but are at times critical based on the kind of image under consideration. Following are some of the trivial image fusion techniques studied and developed as part of the project.

➢ **Average Method**

As mentioned previously in this report, the very concept of information fusion arose from the idea of averaging the available information. Image Fusion also saw a similar background, wherein the most simplistic was 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 algorithm, being the simplest one, can be put in one-step as the following:
The proposed methods are "lossless and higher compression ratio of images" involve three techniques i) Discrete Wavelet Transform (DWT), ii) Discrete Cosine Transform (DCT), and iii) Compressive Sensing-based image de-noising using adaptive multiple sampling and optimal error tolerance.

1. Calculate the average intensity value of each corresponding pixel of the pair of input image.

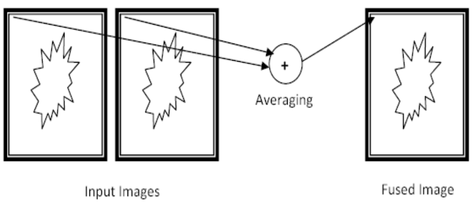

Fig.2. Pixel intensities at every position (m, n) are averaged to obtained the (m, n) pixel of the fused image.

➢ **Maximum Selection Method**

The Selection method is also one of the trivial methods of image fusion. But unlike averaging method, instead of averaging every corresponding pixel, a selection process if performed here. The criterion of selection is self-explained by the name of the method. Of every corresponding pixel of the input images, 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. A straight forward selection of the better pixel intensity is made here. 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. The stepwise description of the algorithm is as the following:

1. Compare the intensity value of the corresponding pixels of the input pair of images.
2. Generate the selection matrix based on the comparison performed in 1, assigning value 1 for condition being true and 0 otherwise
3. Multiply the corresponding value in the selection matrix with first image matrix
4. Multiply the corresponding value in the negated selection matrix with second image matrix.
5. Resultant image matrix id calculated by adding the matrices calculated in 3 and 4.

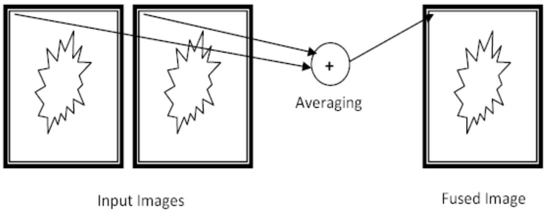

Fig.3. Pixel intensities at every position (m, n) are averaged to obtain the (m, n) pixel of the fused image.

- **Laplacian Pyramid Fusion**

The Laplacian pyramid can be understood based on the generic flow diagram of the steps involved as shown below. The stepwise description of algorithm is as follows.

Step1: Considering the pair of input image matrices as M1 and M2 respectively.
Step 2: A single dimensional filter mask is generated as

W = [1/16 4/16 6/16 4/16

Step 3: The level of fusion (decomposition and decomposition) is decided upon. Both the decomposition part and the recomposition part are iteratively executed "level" number of times.

step4: Decomposition

- The image matrices are filtered (convolved) vertically and filter mask generated, producing the filtered image matrices G1 and G2 respectively
- An additional level of filtering is performed over G1 and G2 producing filtered matrices G11 and G22.
- The difference matrix is calculated for both as (M1-G11) and (M2-G22) The difference between the original image matrices and the second level of filtered image matrices.
- The Pyramid of this level of decomposition is generated using any of the three algorithms below:
  - i. Select Maximum
  - ii. DCT Method
  - iii. Lis Method
- The pyramid thus formed is retained for the level as E[level].
- The images are decimated to half the size and the decomposition steps are iterated "level" number of times.

Step5:The finally decimated pair of images M1 and M2 is manipulated as one of the following, producing X matrix.

- Average M1 and M2
- Select Maximum in M1 and M2

- Select Minimum in M1 and M2

Step6. Recomposition

- Matrix X obtained in step 5 is un decimated by alternatively padding zero columns and rows.
- The un decimated matrix is filtered (convolved) with the doubly scaled filter mask w.
- The filtered matrix is added upon with the retained pyramid of the level E[level].
- The matrix generated in step c will act as the input matrix X to the next level of recomposition
- Recomposition steps are performed "level" number of time, eventually un decimating matrices

D: Discrete Wavelet Transforms: The DWT is similar to the DC-CWT except that the input signal is discrete. Therefore, the design rules for ψ (t), φ(t), g[k] and h[k] are similar as in the DC-CWT. The block diagram of the1-D DWT is illustrated in Fig. 4

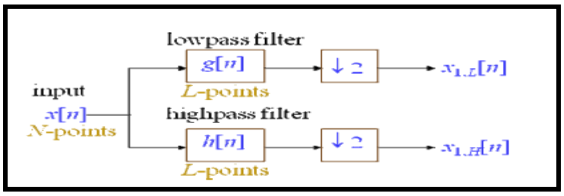

Fig. 4.The block diagram of the 1-D DWT.

- Multi-level 1-D discrete wavelet transform

Furthermore, the 1-D DWT confidents can be decomposed again using the 1-D DWT. This scheme is called multi-level 1-D DWT.

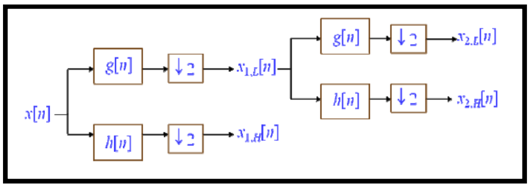

Fig. 5.The block diagram of the 2-level 1-D DWT.

Inverse discrete wavelet transforms (IDWT)

The reconstruction process from the DWT coefficients is shown in the right part of Fig.5, called inverse DWT (IDWT). The filters $h[n]$, $g[n]$, $h1[n]$ and $g1[n]$ in the figure can be design by quadrature mirror filter (QMF) method or Orthonormal filter method.

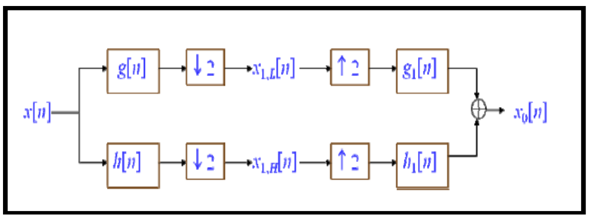

Fig.6. The block diagrams of DWT and IDWT.

- **2D discrete wavelet transform**

2-D DWT is very useful for image processing because the image data are discrete and the spatial-spectral resolution is dependent on the frequency

V. EXPERIMENTAL RESULTS

- **Optical remote sensing**

In Optical remote sensing fields, the multispectral (MS) image which contains color information is produced by three sensors covering the red, green and blue spectral wavelengths. Because of the trade-off imposed by the physical constraint between spatial and spectral resolutions, the MS image has poor spatial resolution. On the contrast, the panchromatic (PAN) images has high spatial resolution but without color information. Image fusion can combine the geometric detail of the PAN image and the color information of the MS image to produce a high-resolution MS image. Fig. 7 shows the MS and PAN images of earth observation satellite, and the resulting fused image.

Fig.7. (a) multispectral low resolution input image, (b) panchromatic high resolution input image, and (c) fused image of IHS.

(2) As the optical lenses in CCD devices have limited depth-of focus, it is often impossible to obtain an image in which all relevant objects are in focus. To achieve all interesting objects in focus, several CCD images, each of which contains some part of the objects in focus, are required. The fusion process is expected to select all focused objects from these images. An experiment is shown in Fig.8

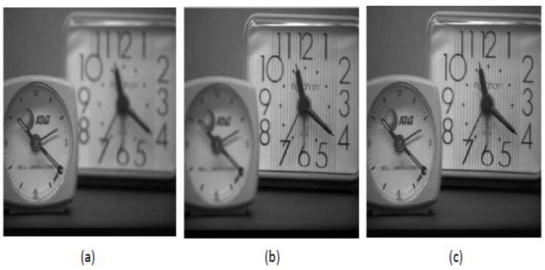

Fig.8. CCD visual images with the (a) right and (b) left clocks out of focus, respectively; (c) the resulting fused image from (a) and (b) with the two clocks in focus.

(3) Sometimes the "in focus" problem is due to the different characteristics of different types of optical sensors, such as visual sensors, infrared sensors, Gamma sensors and X-Ray sensors. Each of these types of sensors offers different information to the human operator or a computer vision system. An experiment is shown in Fig. 9. The image in Fig. 9(a), captured from a visual sensor, provides most visual and textural details, while the image in Fig. 9(b), captured from an infrared sensor, can

highlight the man hiding behind the smoke. Therefore, the image fusion process can combine all the interesting details into a composite image.

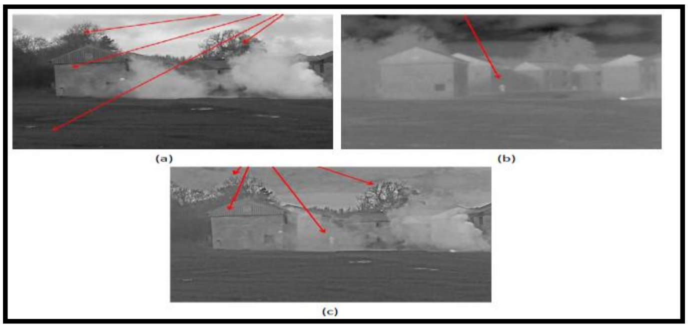

Fig.9. Images captured from the (a) visual sensor and (b) infrared sensor, respectively; (c) the resulting fused image from (a) and (b) with all interesting details in focus.

(4) In medical imaging, different medical imaging techniques may provide scans with Complementary and occasionally conflicting information, such as magnetic resonance image (MRI), computed tomography (CT), positron emission tomography (PET), and single photon emission computed tomography (SPECT). In Fig. 10, the MRI and PET images are fused. The PET is a functional image displaying the brain activity, but without anatomical information. The MRI, having higher spatial resolution than the PET, provides anatomical information but without functional activity. The object of image fusion is to achieve a high spatial resolution image with functional and anatomical information.

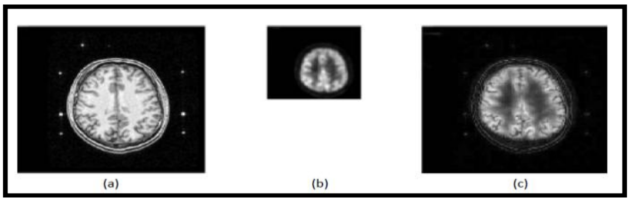

Fig.10. (a) MRI and (b) PET images; (c) fused image from (a) and (b).

VI. CONCLUSION

In this paper we have presented a method for fusing two dimensional multi-resolution 2-D images using wavelet transform under the combine gradient and smoothness criterion and DCT based Laplacian pyramid Image Fusion is discussed and performance of both schemes evaluated. The usefulness of the method has been illustrated using various experimental image pairs such as the multi focus images, multi-sensor satellite image and CT and MR images of cross-section of human brain. The results of the proposed method have been compared with that of some widely used wavelet transform based image fusion methods both qualitatively and quantitatively. Experimental results reveal that the proposed method produces better fused image than that by the latter. The use of both gradient and relative smoothness criterion ensures two fold effects. While the gradient criterion ensure that edges in the images are included in the fused algorithm, the relative smoothness criterion ensures that the areas of uniform intensity are also incorporated in the fused image thus the effect of noise is minimized.

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