Image Fusion Methods and Applications: A Review

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Abstract: Image fusion is the process of fusing several input images into a single output image that better describes the scene than any of the input images could on their own. The requirement for image fusion is to achieve high resolution on panchromatic, multispectral, or actual-world images. There are numerous ways to combine images, as well as some approaches, including IHS, PCA, DWT, Laplacian pyramids, Gradient Pyramids, DCT, and SF. In a variety of applications, various digital image fusion algorithms have been created. An image that includes more information for human visual perception and is more valuable for additional vision processing is the result of image fusion, which pulls information from many images of a given scenario. Additionally, it wants to examine how image fusion methods are evaluated for quality. The concept, principles, restrictions, and benefits of each of the grey-scale picture fusion algorithms are reviewed and are then investigated at the pixel and feature levels.

Keywords: Discrete Wavelet Transform; Image Fusion; Feature Extraction; Imaging and Spatial Domain

Introduction

The process of fusing pertinent data from two or more images into one image is known as image fusion. The use of image fusion techniques is widespread in many fields, including astronomy, medicine, military, and remote sensing (Plooij et al., 2011). To improve the information content, two or more photos are combined through the technique of image fusion. By combining various satellites, aircraft, and ground-based imaging systems with other relevant data sets, image fusion approaches help object recognition systems perform better. Additionally, it aids in sharpening the images, enhancing elements that are not visible in either image, replacing inaccurate data, and completing data sets for better decision-making. To create a single image that more accurately depicts the scene and keeps the valuable information from the input photographs, it combines significant information from two or more source images. Due to the existence of both natural and artificial items in the picture, a high-resolution panchromatic image provides geometric details of the image, whilst a low-resolution multispectral image provides colour information of the source image. With multisensor image fusion, visual data from several images with various geometric representations is combined into a single final image without any information being lost. Image sharpening, feature augmentation, enhanced categorization, and the generation of stereo data sets are benefits of image fusion. The advantages of multi sensor image fusion include a wider operating window, enhanced dependability, spatial and temporal features, system performance, and reduced ambiguity. Image fusion approaches can be categorised according to the degree of processing. These are at the pixel level, feature level, and decision level. The simplest and most popular way is at the pixel level. The majority of the information from the original image is preserved while processing pixels in the source image (Deshmukh & Malviya, 2015). Pixel level image fusion provides more accurate findings when compared to the other two methods. The attributes of the raw image are processed at the feature level (Rani & Sharma, 2008). Effective image fusion can be achieved by combining this method with the decision level method. The data is simpler to compress and send due to the smaller data size. Making decisions is the highest level of image fusion. It leverages the data information extracted from the feature level fusion or pixel level fusion to achieve a given target by making the best decisions possible (Deshmukh & Malviya, 2015). Additionally, it lessens redundant and ambiguous information.

- **The goal of image fusion is typically:**

Usually, the objective of image fusion is to merge data from many images or image modalities into a single, integrated image that enhances and maintains the most important aspects from each source. The main goal is to create a fused image with more significant content, clarity, and richness than the individual input images. Whether the visual data is being used for computer vision, remote sensing, medical imaging, surveillance, or other purposes, the goal of this process is to enhance its overall quality, interpretability, and efficacy. Image fusion seeks to overcome the limits of individual photos and give a more thorough and educational portrayal of the underlying scene or phenomena by utilizing complementing details from several sources. This combined image is meant to facilitate more precise analysis, interpretation, and decision-making in several domains where visual data is essential.

- **Image Fusion Levels**

Pixel level

This is the most basic form of his image fusion technology. The final image is created by combining the values and intensities of the two input images depending on their average.

Feature level

It justifies using the characteristics of the image, such as if one image has a deformed eye while the other has a distorted head or nose. With this level of technology, it is simple to extract the features of two identical photos separately, and then a fusion algorithm produces an improved image.

Block or Region Based

According to the image's pixel blocks, region-based fusion takes place in this process. The greatest degree of method is blocks level. Measurements are computed in accordance with the areas and it is a multistage representation.

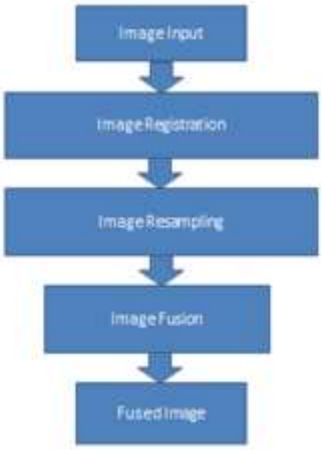

Figure 1. Pre-processing steps for image fusion

Since the middle of the 1980s, there has been a lot of study and effort done on image fusion techniques. Taking the grey scale average of the pixels from the source photos is the simplest method of fusing images. At the expense of a lower contrast level, this straight forward procedure produces good results. Depending on the geographical and temporal properties of the data sets, these image fusion algorithms can be used to various data sets. The images are combined using both spatial domain and frequency domain approaches. While frequency domain techniques first transform the image into frequency domain by applying Fourier transform, then retrieve the resultant image by applying inverse Fourier transform, spatial domain techniques manipulate image pixels to reach the desired result. Performance measurement metrics including entropy, peak signal to noise ratio (PSNR), and mean square error are used to compare these methodologies.

- **Existing Image Fusion Techniques**

The following are various image fusion methods that have been researched and created thus far.

a. IHS (Intensity-Hue-Saturation) Transform
b. Principal Component Analysis (PCA)
c. Pyramid techniques
d. High pass filtering
e. Wavelet Transform
f. Artificial Neural Networks
g. Discrete Cosine Transform
h. IHS (Intensity-Hue-Saturation) Transform

Intensity, Hue and Saturation are the three properties of a colour that give controlled visual representation of an image. The IHS transform method is the most traditional picture fusion technique. Because the IHS space holds the majority of the spectral data, hue and saturation need to be properly managed. High spatial resolution detail information is added to the spectrum information for the fusion of high resolution PAN picture and multispectral images. This study offers numerous IHS transformation methods based on various colour models. HSV, IHS1, IHS2, HIS3, IHS4, IHS5, IHS6, and YIQ are some of these methods. IHS transformation produces varied outputs based on these several formulas (Deshmukh & Malviya, 2015; Paramanandham & Rajendiran, 2016).

- **Principal Component Analysis (PCA)**

Although the PCA method and IHS approach are comparable, the PCA method has the benefit that any number of bands can be employed. One of the most widely used techniques for picture fusion is this one. Low resolution multispectral pictures are used to create uncorrelated principal components. The information that is shared by all bands used is contained in the first principal component (PC1). It has a high variance, which provides additional details about the panchromatic image.

PC1 is replaced with a high resolution PAN component that has been stretched to have a similar variance. The high resolution multispectral image is then obtained using an inverse PCA transform.

- **Pyramid Techniques**

Image pyramids can be thought of as a model for the human visual system's binocular fusion. An original image is represented at several levels by the pyramid structure. Applying a pattern-selective technique to image fusion creates a composite image. First, each source image is subjected to the pyramid decomposition process. In order to create a composite image, all of these photos are combined. The inverse pyramid transform is then used to create the final image. In this paper, the pyramid technique's MATLAB implementation is demonstrated. Each stage of decomposition involves image fusion, which results in a fused pyramid from which the fused image is generated (Wei, Dobigeon, Tourneret, Bioucas-Dias, & Godsill, 2016).

- **High Pass Filtering**

High pass filtering is used to create the multispectral images with high resolution. The low resolution multispectral image is combined with the high frequency data from the high resolution panchromatic image to create the final image. Either the original HRPI is used and the LRPI is subtracted from it, or the High Resolution Panchromatic Image is filtered with a high pass filter. This technique maintains the spectrum information present in the HRMI's low frequency data.

- **Wavelet Transform**

As an alternative to the quick Fourier transformations, there is the wavelet transform. It has an advantage over the Fourier transform in that it delivers the appropriate resolution in both the time domain and the frequency domain, whereas the Fourier transform only does so. The signal is divided into sine waves with varying frequencies in the Fourier transform, whereas the wavelet transform divides the signal into scaled and shifted versions of the mother wavelet or function. The input images are divided into approximate and informative coefficients using DWT at a certain level in the wavelet image fusion process. These two coefficients are combined using a fusion rule, and the resulting image is created by using the inverse wavelet transform (Deshmukh & Malviya, 2015).

- **Artificial Neural Networks**

Pattern recognition has found a place for artificial neural networks (ANN). A nonlinear response function is employed in this. It makes use of a feedback network called a pulse coupled neural network (PCNN). The receptive field, the modulation field, and the pulse generator are the three sections of this network. The pixel of the input image is matched with one neuron per neuron. The intensity of the corresponding pixel serves as an external input to the PCNN. In terms of resistance to noise, independence from geometric fluctuations and capacity to bridge slight intensity differences in input patterns, this technique is favourable. Due to its viability and real-time system performance, PCNN is employed in medical imaging and has biological significance (Paramanandham & Rajendiran, 2016).

- **Discrete Cosine Transform**

For the compressed images in the form of MPEG, JVT, etc., the discrete cosine transform has become important. The spatial domain image is transformed into the frequency domain image using the discrete cosine transform. The photos were split into three categories by Chu-Hui Lee and Zheng-Wei Zhou: low frequency, medium frequency, and high frequency. The DC value represents average illumination, and the AC value is the high frequency coefficient. The components that make up the RGB image have a dimension of 8x8 pixels. The image is then converted to a grey scale image by grouping it according to the red, green, and blue matrices (Wang, Ma, & Gu, 2010).

- **Types of Image Fusion**

a. Single Sensor

Real world is captured by a single sensor as a series of photos. To create a new image with the best information content, the collection of photographs is combined. A human operator, such as a detector operator, may not be able to recognise things of his interest that can be emphasised in the resulting fused image, for instance, in illumination variation and noise full environments.

The drawback of these systems is due to the imaging sensor's limits when compared to other sensing areas. The dynamic range, resolution, etc. of the system are all constrained by the capability of the sensor under the operating conditions. For instance, a visible-band sensor, like one found in a digital camera, is appropriate for images that are brightly lit during the day but is inappropriate for pictures that are dimly lit at night or in unfavourable weather, like rain or fog (Saeedi & Faez, 2012).

b. Multi Sensor

By combining the images from multiple sensors to create a composite image, a multi-sensor image fusion technique overcomes the constraints of a single sensor image fusion. An infrared camera is utilised in conjunction with a digital camera, and their distinct photos are combined to create a fused image. The previously mentioned problems are resolved by this method. The infrared camera is appropriate in dimly lit areas while the digital camera is suitable for scenes in the sunshine. It is utilised in robotics, medical imaging, and military applications of machine vision such as object detection. It is employed to resolve the information merging of many image problems orthodontics (Gong, Zhou, & Ma, 2011).

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c. Multiview Fusion

Multiple or various views of these photos are present at once. Multimodal Fusion: Images from different models like panchromatic, multispectral, visible, infrared, remote sensing. Common methods of image fusion

i) Weighted averaging pixel wise
ii) Fusion in transform domain
iii) Object level fusion

d. Multifocus Fusion:

Images captured from 3D views using its focal length. Regions of the original image can be separated so that each region is in focus in at least one channel.

Applications and Uses of Image Fusion

a) For the proper view of satellite vision, fusion is primarily used in remote or satellite areas.
b) It must be used in medical imaging, where disease should be assessed using imaging vision from the perspectives of spatial resolution and frequency.

c) Image fusion is employed in military environments where all viewpoints are used to identify threats and execute other performance-based resolution activities.
d) The two stages when the image is finished are perfectly suited for human vision and are effectively visualised for machine vision.
e) In the field of robotics, fused pictures are mostly utilised to examine frequency changes in image views.
f) In 3D artificial neural networks, focal length changes in accordance with wavelength transformation (Rani & Sharma, 2008).

e. Advantages of Image Fusion:

- It is the simplest to understand.
- Fused image has accurate colour.
- It works best for recognition and identification.
- It has a low price.
- It uses multiscale photos with a high resolution.
- Improved fused images in fog are made possible by image fusion.
- Image fusion preserves the capacity to decipher signs in all domains.
- Image fusion provides so many advantages in terms of contrast that it really should improve the image from every angle.
- It improves contextual or situational awareness.
- Image fusion decreased data transmission and storage.

f. Limitations & Challenges in Image Fusion

Notwithstanding its advantages, image fusion has a number of drawbacks and difficulties that practitioners and researchers must overcome. Among the principal difficulties are:

- Quality Degradation: Because image fusion occasionally introduces artifacts, noise, or inconsistencies into the input images, quality may suffer. The fusion process might affect the overall quality of the fused image by magnifying already-existing defects or introducing additional distortions.
- Selection of Fusion approaches: Selecting the best fusion method is a difficult process because different approaches may work better for different kinds of data or in different situations. Practitioners face hurdles due to the lack of a generally optimal fusion method and the demand for adaptation depending on application-specific criteria.
- Information Loss and Redundancy: When merging images with different resolutions, scales, or dynamic ranges, there is a chance that some information will be lost or duplicated during the fusion process. It's difficult to strike a balance between minimizing redundancy and maintaining pertinent information.
- Sensitivity to Input Variability: A lot of fusion algorithms are susceptible to changes in viewpoint, lighting, and sensor properties. One major problem that still has to be addressed is adapting fusion algorithms to handle a variety of input conditions, such as changes in ambient lighting or sensor calibration.
- Computational Complexity: A number of sophisticated fusion methods can require a lot of processing power, particularly those that rely on deep learning. It can be difficult for real-time applications to achieve the required fusion quality without sacrificing processing speed; this calls for a careful balance between efficiency and accuracy.

g. Future Trends:

Although the range of applications for the image fusion approach has increased, as was stated above, there are still some issues that are related to its use that may, in some cases, be resolved in the near future with appropriate study.

Since medical images are frequently taken using several acquisition modalities, correct registration in the field of medical diagnostics is a difficult undertaking. Above all else, identifying certain clinical issues is a difficult and complex process of medical diagnosis. The reason for this is because developing fusion techniques involves both algorithmic understanding and expertise in the relevant medical fields. The objective evaluation of the medical image fusion methods is likewise a challenging task since the required fusion performance could not be the same as that of general image fusion.

How to minimise visual distortions when combining panchromatic, hyper spectral and multi-spectral images is the main challenge in remote sensing. Additionally, even though the source images are typically taken on the same platform, different imaging sensors still have various acquisition times and do not always fully focus in the same direction. The considerable spectral and resolution differences between the input images make precise and accurate registration in this situation very difficult. Finally, because remote sensing devices are evolving quickly, it will be important to create new algorithms for fusing images taken by cutting-edge satellite or aeroplane sensors.

In the area of photography, multiple exposures and focuses are taken at various moments, which could cause moving objects to appear in various places while being recorded. Moving objects may therefore introduce ghost artefacts into the merged image. Designing approaches that are considerate of such misregistration is therefore a challenging topic in this area in order to overcome this problem. How to integrate the image fusion method into integrated consumer camera systems for useful photographic applications is another area that warrants research.

Conclusion

By merging the pertinent information from various photos, image fusion enhances the information content inside the image. As the amount of data in an image grows, so does its use in medical applications for accurate disease diagnosis. The use of image fusion is similar, including applications in the military, surveillance, remote sensing, etc. For the purpose of conducting picture fusion, numerous algorithms have been developed. Several performance indices have been used to measure the efficacy of fusion strategies. The indices gauge the combined image's information density, average intensity, contrast, and edge information. Entropy, standard deviation, correlation coefficient, and other metrics are used as indexes. Although there are more applications for picture fusion, there is still room for advancement in each application domain, which could further amplify the benefits of image fusion.

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