# Image Fusion Models and Techniques at pixel level

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***Abstract*—Information fusion consists in combining information in order to maximize the relevant information and reduce the redundancy. It is widely used in many fields, especially in image processing, for analyzing situations. Since the first use of the information fusion concept, many approaches have been introduced to define a processing model to merge information. Three basic approaches are used in information fusion: the JDL Model which is the first one used, the Intelligence Cycle Model and the DFD (Data – Features – Decision) Model. According to the field of application and the type of the information manipulated, the processing model is different. In image processing, various techniques and methods are used to perform image fusion. Many techniques are most used in research studies: PCA (Principal Component Analyses), Wavelet transform,… In this paper we present a general overview of the basic models and techniques used in image fusion.**

***Keywords—Information Fusion, Images Fusion, JDL, Fusion models***

## I. INTRODUCTION

Since the first signs of life, humans have exploited information to perform some needs. In many cases they proceed to combine some information to obtain a global vision of a situation. From day to day, life progresses, technologies evolve and the information fusion is increasingly needed. The use of big quantities of information coming from multiple sources makes the fusion process very difficult and hard.

The word fusion refers to uniting or combining things. The concept of data fusion is defined as combining data from multiple sources. In the literature, we distinguish between the word data and information. According to the field of application, the definition of the fusion concept can be different. Boström & al. [1] collected the different existing definitions of the fusion concept in many contexts.

First works in data fusion began in the 1960s, by defining mathematical models used for combining multiple data [2]. Initially, the concept of data fusion was introduced in defence and robotics fields in the 1970s. In the mid-1980s, the Joint Directors of Laboratories (JDL) of the Defence Departement of the US, formed the Data Fusion Group (which was initially named Data Fusion Sub-Panel). The main goal of establishing this group is to define the new field and unify the terminology and procedure.

Then, the importance of the idea of combining information attracts the majority of fields. In medical field, the fusion was very useful in the medical field by merging images to assist the doctor in the diagnosis phase. Economics, biology, robotics, spatial field, and more others are also taking benefits from the information fusion. But, according to the field of application of the fusion, and the type of information, the process is different.

In the image processing field, the fusion is necessary in many applications such as in medical imaging or remote sensing. Multiple research works are studying the problem of image fusion because of the complexity of its fusion process, mainly if images are taken from various sources and modalities.

In this paper we present a general survey of the principal approaches and some recent works in image fusion. First, we present the basic approaches used in information fusion. Then, we expose the common process used in the image fusion. After that, we present the basic techniques used in combining images. And finally, we expose some recent works studying the image fusion problem.

## II. THE DIFFERENT APPROACHS OF INFORMATION FUSION

### *A. The JDL Approach*

The first proposed model and the most popular architecture of data fusion is the model proposed by the JDL group. The first version was published in 1991 and contained three levels defined in the "Data Fusion Lexicon" [3]:

- Level 1: produces an entity (called object) specifications ("position, identity, amplifying kinematic, features"). These characteristics are identified as "attributes"
- Level 2: "results in a situation assessment which includes various behavioral characteristics of events and activity analysis". It specifies the relationship between entities defined in the previous level.
- Level 3: identifies "Threat assessment" by providing interpretations and analyses of the level 2 results joined

with information from "technical and doctrinal" databases.

In 1998 the JDL Model was revised. The novel model defined four levels of processing (from level 0 to level 3) and a level (level 4) for the evaluation of the entire system [4].

- The Level 0, identified as "sub-object assessment", represents a step of pre-processing of the information from sources. Its main goal is to characterize data from signals.
- The Level 1, identified as "Object Assessment", consists in "estimation and prediction of entity states on the basis of observation-to-track association"
- The Level 2, identified as "Situation Assessment", consists in "estimation and prediction of relations among entities"
- The Level 3, identified as "Impact Assessment", consists in "estimation and prediction of effects on situations of planned or estimated/predicted actions by the participants"
- The Level 4, identified as "Process Refinement"

### B. *The Intelligence cycle Model*

This model is simulated from the cyclic processing of the Economic Intelligence. The model specifies four stages [5]:

- Collection: data and information are collected from multiple sources and putted in a high level report.
- Collation: the products of the previous stage are "correlated and brought together" in order to prepare them for the fusion.
- Evaluation: performs a fusion and analyses the reports. In this stage gaps in the collection can be detected.
- Dissemination: distribution of the product of the previous stage to users concerned.

### C. *Data – Feature – Decision (DFD) Model*

Multiples research works determine a model with three levels of fusion processing:

- The low level: defines the fusion of data in the sources (such as pixels in images).
- The intermediate level: defines the fusion of features extracted from data.
- The high level: defines the fusion of decision identified from features.

## III. Image Fusion Process

The fusion process depends on the processing level. In the majority of works in image fusion, the DFD model is used. The lowest level in this model is very limited in multiple cases of image fusion. In multimodal image processing, the fusion can not be performed in the pixel level especially when manipulating complex representation such as in medical cases.

Multiple of research works, are operating in the intermediate level of the DFD model. In this level, the fusion process has three essential steps:

- Segmentation: consists in extracting regions of interest. These regions will be aligned in the next step for getting a successful merging.
- Registration: consists in searching the best alignment to much the different representations obtained from the segmentation step.
- Merging: consists in combining the different data into one representation.

A pre-processing step is usually used to facilitate the segmentation step. It consists essentially to increase the contrast or to reduce the noise in the source representation.

This process can be used for combining data from one modality. Multimodality images have not the same scale for representation, so the registration step cannot be accomplished in the best way. Some research works try to treat the registration problem of the multimodal representation by converting the 3D image to different 2D representation and then register each of the representation with the other source.

In the decision level, decisions are combined instead of features. The process changes. After the segmentation step, a classification can be operated to make a decision. Then a fusion of decisions is performed.

## IV. Basic Image Fusion Techniques

In image fusion process, the used method depends on the field of application. Fusion techniques can be classified into two groups: the spatial domain and the transform domain.

### A. *Simple Average Method*

In this method, pixels of the resulting image Ires are reconstructed by calculating the average of intensity of the corresponding pixels of input images Ii ($2 \leq i \leq n$).

$$I_{res}(i,j) = \frac{I_1(i,j) + I_2(i,j) + \cdots + I_n(i,j)}{n}$$

Where n is the number of input images.

The method is simple and easy to implement, but it is suitable only for images which are from the same modality.

### B. *Simple Maximum / Minimum Methods*

In these methods, pixels of the resulting image Ires are defined by selecting the maximum or the minimum value of the corresponding pixels intensity in the input images Ii ($2 \leq i \leq n$).

$$I_{res}(i,j) = [\mathrm{Max} / \mathrm{Min}]\,(I_1(i,j), I_2(i,j), \ldots , I_n(i,j))$$

Where n is the number of input images.

These methods can be used when input images represent the same context.

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### C. *Principal Component Analyses (PCA)*

The PCA is a mathematical method used in multiple applications for identification or recognition of patterns in data. It is based on statistical processing used mainly in data analysis. The basic idea of this method is to transform inter-correlated data in uncorrelated data called 'principal component' [6]. It reduces the data dimensions for analyses of pertinent information.

The PCA algorithm used to perform image fusion follows steps below:

- Representation of the input images as column vectors
- Calculation of the covariance matrix MC
- Calculation of the eigenvectors and eigenvalues of MC
- Normalization of column vectors and eigenvectors to calculate principle components.
- Fusion

This method is simple to implement for images from the same modality, and produces a high quality resulting image. Its main disadvantage is the spectral degradation of the resulting data compared to input data [7].

Ramandeep and Sukhpreet [8] used the PCA and the genetic algorithm for image fusion. The PCA is applied on two image to fuse them. Then a genetic algorithm is used to increase the quality of the fused image by performing a crossover and a mutation and calculating a fitness value to obtain the adequate image.

Verma and al. [9] coupled the PCA technique with the laplacian pyramid technique to fuse two images. First they applied the laplacian psyramid and select the top level for each image. Then the PCA is used to fuse the selected top levels to obtain the final image.

### D. *IHS based methods*

In the IHS (Intensity – Hue – Saturation) technique, the input images are transformed from the RGB (Red – Green – Blue) color space to the IHS space. The fusion is achieved with the Hue (H) and the Saturation (S) band. An inverse transformation is needed to reform the RGB resulting image [10]. The I, H and S parameters of each pixel are calculated by [11]:

$$\begin{bmatrix} I \\ v_1 \\ v_2 \end{bmatrix} = \begin{bmatrix} \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{3}} \\ \frac{1}{\sqrt{6}} & \frac{1}{\sqrt{6}} & -\frac{2}{\sqrt{6}} \\ \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} & 0 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

$$H = tan^{-1}\left[\frac{v_1}{v_2}\right] \qquad S = \sqrt{v_1^2 + v_2^2}$$

Changtao and al., in their study [12], have proposed a method which combined the PCA algorithm and IHS techniques to obtain a fused image that join the functional advantages of the PET image and the spatial advantages of the MRI image. The PET image is transformed from the RGB color space into IHS color space. The histogram matching algorithm is applied to this result coupled with the MRI image. The PCA algorithm is used to extract the principal components. Finally the inverse IHS transforms the IHS representation of the result into RGB representation.

### E. *Wavelet based methods*

Using wavelet method, the input images are transformed from the spatial domain to frequency domain. The image is decomposed into four sub-images in one level decomposition. Each row and each column of the original image I is filtered and its sampling rate is reduced by a lowpass filter L and a highpass filter H. The decomposition results in four matrices ILL, ILH, IHL, IHH. The ILL matrices correspond to the low frequency component of the image and the IHH corresponds to the high frequency component. The fusion step is performed in the transformed domain according to a rule defined for the fusion. The resulting image is reconstructed by applying the inverse transformation [13].

In the literature, researchers proposed multiple algorithms based on the wavelet transform. The DWT (Discreate Wavelet Transform) is commonly used in image fusion.

The method of Kanisetty and Hima [14] uses the Daubechies Complex Wavelet Transform (DCWT) to combine MRI representation with the CT representation. The DCWT method is applied to decompose representations into different levels to have the low sub band coefficients and the high sub band coefficients. Each sub band is devided into blocks. The block which has larger standard deviation value is selected to form the output coeficients. The last step consists in applying the inverse DCWT algorithm to obtain the fused image.

Singh and Khare used in same way the Daubechies Complex Wavelet Transform (DCWT) to resolve the problem of multimodal image fusion in a medical application [15].

In the research work of Dudwadkar and al. the multimodal image fusion problem is solved by applying the Bi-Orthogonal Wavelet Transform [16]. They used this method to fusion PET image with CT image.

Rodrigues and al. [17] used the Discret Wavelet Transform in the fusion of MRI images with the CT images. Nahvi and Sharma choose also the DWT method [18] to deal with the problem of the multimodal image fusion.

In the work of Pradeel and Ritesh [19] proposed a method based on the Dual Tree Discrete Wavelet Transform (DDWT) algorithm and the Particle Swarm Optimization (PSO) algorithm to combining a 3D representation (MRI) with a 2D representation (CT). The method consists in applying the DDWT algorithm respectively for the MRI image and the CT image. Then, the PSO algorithm is applied to the two results. The fused image is obtained after applying the inverse DDWT to the representation obtained from the previous step.

Advantages of using the DDWT method are essentially: direction selectivity limited redundancy and shift invariance.

Swathi and al. were also interested in the fusion of the MRI image with the CT image of the brain of the same patient [20] .They used the Lifting Wavelet Transform method coupled with the Neuro Fuzzy algorithm. Firstly, the two images are pre-processed. Then they are decomposed with the LWT algorithm. The ANFS algorithm is applied to obtain the fused coefficients. The inverse LWT is used to construct the output image.

The Discrete Wavelet Transform coupled with the Contourlet Transformation are also used in the research study of Anu Priya and RajaKumari [21]. The Contourlet Transformation is very similar to the DWT. Two components are computed from source images: a lowpass subband and a highpass subband. The Inverse Contourlet Transformation are applied to obtain the fused image.

### *F. Other methods*

Haitao and Shutao solved the multimodal image fusion problem by applying a new method [22]. Each image is divided into "patches" with chosen dimensions. Then for each set of patches of the two images, a mean value is computed. From the result three components are obtained in jointly sparsely representation: one common part (regions contained in the two images) and two novel parts (regions contained in one image sources but not in the other). Fused patches are obtained from all these results. The fused image is reconstructed from these patches.

The method proposed by Sivasangumani and al. [23] performs the fusion of multimodal sources by combining coefficients obtained from Multiscale Representations (MSR) using the Neighbouring Pixel Selection (NPS) method.

Niveditha and al. [24] used the Non-Subsampled Contourlet Transform (NSCT) method to decompose the source images into high and low bands. The fusion of the frequency components is done with congruency and directive contrast. The Inverse NSCT is applied to obtain the fused image in output.

Aiswaryalakshmi and Karthikeyan proposed a new technique to combine a CT image with MRI image [25]. The method consists in applying the non-subsampled contourlet transform (NSCT) to decompose each image to low and high frequency components. Types of frequency component of the two images are merged together by using the phase congruency for low frequencies fusion and directive contrast for the high frequencies fusion. The inverse NSCT is applied to provide the output fused image.

Priyadharsini and Mahalakshmi solve the problem of the multimodal image fusion by applying a new method [26]: the Higher Order singular value decomposition (HOSVD) method. It consists in transforming a high dimension space to a low dimension space. The given image is represented by the product of three matrices: "an orthogonal matrix U", "a diagonal matrix S", and "the transpose of an orthogonal matrix V" (USVT). A sigmoid function is used to construct the fused image.

A new approach based on Weighted Least Squares Filter was proposed by Saini and Venugopal [27]. The source images are decomposed by an average filtering algorithm into two components: "base layer" and "Detail layer" which is obtained by subtracting the "base layer" from the originally image. Laplacian filter and Gaussian low pass filter are used to build the weight map and the saliency map. The WLSF is used to refine the result and normalize the representations. The two layers are combined with the weighted averaging to obtain the final output image.

## CONCLUSION

As a discipline, information fusion resolved many challenging problems related to different fields. With the evolution of technologies and the big amount of information manipulated, the need of techniques and methods guarantying the selection of relevant information and reducing the redundancy is very required. Images are information sources widely used in many fields. That's why image fusion is much needed in many application such as medical decisions, spatial image analysis,… A model defining different processing levels for the fusion process is severely required. The information processing level affects the fusion process and the choice of the method which can be applied to obtain the best results. This paper presented a general survey of the basic models and techniques used in image fusion.

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