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Image fusion using intuitionistic fuzzy sets

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ABSTRACT

Image fusion is the process of combining one or more images which are obtained from different environment into a single image which is more useful for further image processing tasks. Image registration and image fusion are of great importance in defence and civilian sectors, particularly for recognizing a ground/air force vehicle and medical imaging. In this paper a new way is drawn to fuse two or more images by using maximum, minimum operations in intuitionistic fuzzy sets (IFSs). IFSs are more suitable for image processing since every digital image have lot of uncertainties. In processing phase, images are reformed into intuitionistic fuzzy images (IFIs). Entropy is employed to obtain the optimum value of the parameter in membership and non-membership function. Then the resulting IFIs are disintegrated into image blocks and the corresponding blocks of the images are reunioned by finding the count of blackness and whiteness of the blocks. This paper evaluates the performance of simple averaging (AVG), principal component analysis (PCA), discrete wavelet transform (DWT), stationary wavelet transform (SWT), dual tree complex wavelet transform (DTCWT), multi-resolution singular value decomposition (MSVD), non-subsampled contourlet transform (NSCT) and IFS (proposed method) in terms of various performance measure. The experimental and comparison results show that luminance and contrast is of great importance for image processing and prove that the proposed method is better than all other methods.

1. Introduction

Image fusion is significant in image analysis and computer vision, for more details see [1–4] and references there in. In recent days, various types of image sensors are used in satellite imaging technology, robotics, biometrics and finger print scanners. But, data obtained from these sensors are pleonastic and incompatible. Images received by employing magnetic resonance offers soft tissue details and computed tomography shows the details of bone, blood vessels and so on. In order to get an image that simultaneously renders both the soft tissue and other parts like fat, bone for assisting human visually to detect abnormalities. In this paper, images from various disciplines such as remote sensing and medicine are considered for fusion.

Spatial fusion and transform fusion are two main techniques in image fusion. Depending upon the phases of unification, fusion scheme is classified into three levels namely pixel, feature and decision level [5]. The pixel level fusion combines directly the pixel values of the fusing images and renders a composite image [6]. It is attracted by many researchers and various techniques have been developed, such as Laplacian pyramid, PCA [7], gradient pyramid and wavelet transform. Simplest image fusion method is just taking average of summed pixel values of the source images. The AVG fusion algorithm shows degraded performance. To overcome this problem many types of multi-resolution transforms emerged and are applied for image fusion. They are pyramid decomposition [8–10], wavelet transforms [11–23], MSVD [24–26], curvelet transform [27], contourlet transform (CT) [28–30] and NSCT [31–34]. Image fusion by singular value decomposition (SVD) performs almost similar to wavelets. SVD does not contain fixed set of basis vector but they depend on the data set. The fusion using SVD works very well on a pixel by pixel basis and outscores PCA. The MSVD provides an analysis tool to inquire into the properties (isotropy, sphericity, self-similarity) of signals. The MSVD is viewed as faster than the approximated SVD, for details see [24].

Zhang and Blum [12] demonstrated a fusion technique using multiscale decomposition to get a highly featured picture. Pajares and Cruz [13] have given some ideas on methods of wavelet based image fusion and they compared various resolution levels in several wavelet classes. Decomposition of wavelets and multiscale transforms have two dimensional bases which has tensors of one-dimensional basis function. To overcome such problems, few different multiscale transforms like curvelet and contourlet have been suggested in [27,28] respectively. Shifting invariance is more desirable for image denoising and image fusion, in which CT lacks. In 2006, Cunha and Zhou [31] proposed NSCT, a complete transform, since then it has been successfully utilized in various phases of image processing like image denoising, image enhancement and image fusion. NSCT outperforms wavelet based fusion algorithm

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[33]. However, in every phase of image processing, there exist many uncertainties. These uncertainties can be removed using fuzzy sets and it helps to illuminate luminance and contrast of the image.

The fuzzy set (FS) theory was proposed by Zadeh [35] in 1965, since then it is widely used in various fields. However, the membership function of fuzzy sets has only a single value. It cannot express the evidence of the support, opposition and hesitation at the same time. Atanassov [36] introduced the concept of IFS, which are development and marketing of the traditional FSs, in 1986. IFSs take into account of three aspects of information that are the degree of membership, non-membership and hesitation at the same time. Non-membership function can better describe the fuzzy concept of "non-this non-that" and more delicately portray the ambiguity nature of the objective world. Thus, the IFSs have greater flexibility and practicality in the treatment of fuzzy information and uncertainty than the traditional FSs. Every digital image have some fuzziness in it, for example poor illumination makes medical images uncertain and these can be eliminated using IFS.

This paper presents a new method for fusing two or more images. Firstly, the source images are fuzzified. Secondly, the highest value of entropy is used to find the membership and non-membership degree. This in turn employed for generating IFIs of the source images. These IFIs are disintegrated into small blocks and the total count of blackness and whiteness in each corresponding blocks are estimated. Then the blocks of fused image can be obtained by applying max, min operation based on the totality of blackness and whiteness in the image. Fused image is then reconstructed using the fused blocks having high luminance and contrast. Fused IFI is then defuzzified to get a crisp image without uncertainty. Image registration is an important requirement applied for fusion technique. In this paper, it is assumed that the source images are filed in database before commencing the fusion process.

The following renders the frame work of this paper. Section 2 deals with the preliminary details of some existing fusion algorithms along with our proposed image fusion technique. Section 3 deals with the various performance measures of the image fusion with reference and without reference images. In Section 4, the experimental results and comparisons are provided to show our fusion technique surpasses other fusion algorithms. Finally, conclusions with future directions are drawn in Section 5.

2. Fusion algorithms

The details of AVG, MSVD and proposed fusion method and their use in image fusion are described in this section.

2.1. Image fusion by AVG

This technique is a basic and straightforward technique. Fusion could be achieved by simple averaging the corresponding pixels in each input image which is described by

$$I_f = \frac{I_1 + I_2}{2}$$

where I_1, I_2 are the source images and I_f represents the fused image.

2.2. Image fusion by MSVD

Multi-resolution singular value decomposition (MSVD) is analog to that of wavelets transform. In MSVD, first level decomposition can be attained by decimating the filtered output signal by a factor of two and the second level by filtering the decimated low pass filtered output by a factor of two. This process can be repeated to get successive levels of decomposition. Here the filtering process is same as in wavelet decomposition method except the type of filter used. The idea behind MSVD is to replace the finite impulse response filters in SVD [24].

MSVD initially fragments the source images into k, $k = 1, 2, \dots, K$, levels and then fuse them by taking highest absolute value of detailed coefficients of MSVD obtained from the source images. Fusion rule at roughest stage ($k = K$) take average of approximated MSVD coefficients. Similarly, at each stage of decomposition, the fusion takes place by averaging MSVD eigen matrices obtained from source images. The fused images can be reconstructed by reversing MSVD. More details will be available in [24], which gives MSVD for a single image. In this paper, we use the same methodology to find MSVD for multiple images and they are fused as described above.

2.3. Intuitionistic fuzzy image (IFI)

Image processing by IFSs mainly needs membership and non-membership function. Now let us see briefly about the construction by initiating from FSs.

Consider a finite set $X = \{x_1, x_2, x_3, \dots, x_n\}$. A fuzzy set [37] F of X may be mathematically written as

$$F = \{(x, \mu_F(x)) | x \in X\}$$

where the function $\mu_F(x) : X \to [0, 1]$ represents the membership degree of an element x in X. Therefore, the non-membership degree of x is $1 - \mu_A(x)$.

Support of a fuzzy set F in X is defined as $Supp(F) = \{x \in X | \mu_F(x) > 0\}$. A fuzzy set is said to be a fuzzy singleton if its support is a single point.

Atanassov [36] and Atanassov and Stoeva [38] generalized fuzzy sets as IFS. An IFS F in X can be mathematically symbolized as

$$F = \{(x, \mu_F(x),\ \nu_F(x)) | x \in X\}$$

where the functions $\mu_F(x), \nu_F(x) : X \to [0, 1]$ represents the degree of membership and non-membership of an element x in X respectively, with the essential condition $0 \leqslant \mu_F(x) + \nu_F(x) \leq 1$.

On observation, it is clearly seen that FSs is a peculiar case of IFS.

A new parameter $\pi_F(x)$, which originates due to lack of knowledge called hesitation degree, has been introduced by Szmidt and Kacpryzk [39] while computing distance between FSs. IFSs is defined as follows based on the hesitation degree

$$F = \{(x, \mu_F(x), \nu_F(x), \pi_F(x)) | x \in X\}$$

where the condition $\mu_F(x) + \nu_F(x) + \pi_F(x) = 1$ holds.

Proposed method initially fuzzifies the source image. Naturally there arises a question about fuzziness in an image stated as what is fuzzy here? Various image properties like edges, brightness and so on are fuzzy due to built-in defects in imaging equipments, inherent image vagueness or by nonuniform illumination. Since a gray scale image inherits uncertainty with in pixel due to possible multi-valued levels of brightness, which is taken as fuzzy throughout this paper. There are two methods for image enhancement in the literature namely, spatial domain and frequency domain. Spatial domain method is the simple and more powerful technique in which pixels are directly manipulated. One of the significant feature for enhancing contrast in gray scale images is brightness. But due to several levels of brightness, the image pixels are uncertain. So initially images are transferred to fuzzy domain (extracted from spatial domain), which helps in stretching out the membership function over the total range of gray level. Thus, this study utilizes degree of gray levels as a membership function for fuzzification of the given source image by choosing quantized and normalized gray levels directly.

Based on fuzzy sets, an image I of $P \times Q$ dimension and L levels of grayness can be regarded as a $P \times Q$ array of fuzzy singletons