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# A novel image decomposition-based hybrid technique with super-resolution method for multi-focus image fusion

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ABSTRACT

Multi-focus image fusion combines two or more images which have different focus values of the same scene using fusion rules. The meaningful image is named all-in-focus image which is more informative and useful for visual perception. In this paper, a novel approach for multi-focus image fusion is proposed. The method is a hybrid method with super-resolution. Firstly, super-resolution method is applied to all source images to enhance information like contrast. Thus, low-resolution source images are converted to high-resolution source images. Secondly, due to decomposing these source images, Stationary Wavelet Transform (SWT) is implemented and images are divided into four sub-bands. These sub-bands are LL (low–low), LH (low–high), HL (high–low) and HH (high–high). LL is the approximation coefficient of source images and others are the detail coefficients of source images. For all these sub-bands, Principal Component Analysis (PCA) is implemented and maximum eigenvector of each sub-band of source images is selected separately to fuse images. Then, Inverse Stationary Wavelet Transform (ISWT) is used to reconstruct the fused sub-bands. Finally, to measure quality of the proposed method objectively, fused image is resized to original source image's size using interpolation based resizing method. To measure the success of method, different metrics without reference image and with reference image, are selected. Results show that the proposed method produce clear edges, good visual perception, good clarity and very few distortion. The proposed hybrid method is applied to produce better quality fused images. Results prove success of the approach in this area. Also visual and quantitative results are very impressive.

## 1. Introduction

Multi-focus image fusion can be defined as creating a meaningful image from meaningless images alone. The meaningful image is named all-in-focus image. The image contains more details and is more suitable for processing. Because of the limited focusing problem of imaging devices, combining in multi-focus images has been used by researchers a lot in recent years. Remote sensing, computer vision, monitoring applications, military affairs, health imaging etc. are some of the research areas [1].

There are two main categories in multi-focus image fusion techniques; spatial domain techniques and transform domain techniques. Spatial domain techniques select pixels or regions directly and fuse the images using either the linear or the nonlinear method. Weighted average method, Principal Component Analysis (PCA) etc. are some of the spatial domain methods [2]. The simplest way to fuse images in the spatial domain is the average method. The method has disadvantages like spatial distortion, image blurring etc. [3]. Spatial domain methods have advantages and disadvantages. For example, Brovey method, that is one of the spatial domain methods, has advantages like simplicity and less computational time but output with low quality and producing spatial distortions are disadvantages of this method [4]. To overcome these disadvantages of spatial domain methods, transform domain methods are proposed and implemented. Transform domain methods separate images into frequency components and fuse images using these components. Pyramid based and wavelet-based methods are more preferred by researchers in image fusion. Multi-scale transforms like the Laplacian Pyramid, Wavelet Transform, Counterlet Transform etc. are widely implemented because these methods have good local and multi-resolution features [3]. All of these transform domain methods have three main steps to fuse multi-focus images. Firstly, images are decomposed using multi-scale transforms. Secondly, sub-bands of decomposed images are fused using a fusion rule. And finally, fused sub-bands are reconstructed using inverse multi-scale transforms [2]. Transform domain methods have advantages and disadvantages. For example, Shearlets has advantages like output with detailed information and smaller distortions but less sharpness is the disadvantage of this method [5].

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Transform-domain methods have two main categories: pyramids and wavelets. In this paper, a wavelet-based method is implemented to decompose images. The wavelets are most preferred methods in transform-domain methods for multi-focus image fusion. Due to decreasing structural distortions, Discrete Wavelet Transform (DWT) is the most commonly applied transform domain method to fuse the images. But there are some disadvantages of DWT like not shift invariance, poor directionality and not a time-invariant transform. To decrease these disadvantages, Stationary Wavelet Transform (SWT) is implemented. SWT overcomes shift invariance disadvantage. An algorithm in which the filter is up-sampled is named as "à trous". In conventional wavelets, filters are used to convolve signal and down-sampling operation is applied to decompose signal. Because of this, the upper level signals size is quarter of the original signal size. So the wavelet is not redundant [6]. But SWT has properties like redundancy and shift invariance on the basis of multi-scale and multi-direction according to traditional wavelets. In traditional wavelets, the up-sampling and down-sampling operations are both applied to images. But SWT uses only up-sampling operation and suppress the down-sampling operation. Thereby, the original signal saves its size at upper approximation levels of signal though redundant decomposition time. Redundant decomposition keeps details of original signal, so SWT is ideal for multi-focus image fusion, image processing etc. Furthermore, SWT has low computational time because the algorithm does not need to down-sample. In SWT, filters are applied first rows and secondly to columns. Due to these advantages, SWT is selected for the proposed method [7].

Second step of the multi-focus image fusion is implementing fusion rules to decomposed images. Fusion rule is the most important part of the multi-focus image fusion. The fusion rule means that combining the feature vectors of source images using a mathematical processing effectively. Selection maximum value and averaging are the traditional ways of fusing. The averaging method carries average of the corresponding pixels of source images to fused image. The method smoothes the some features like edges, lines etc. and also reduces contrast [2]. And selecting pixel with maximum intensity from corresponding pixels of source image is named as selection maximum value. This rule produces blurring effects and spatial distortions [8]. PCA is the other fusion rule for multi-focus image fusion. PCA aims carrying the data from original space to eigenspace. Thus, the variance of data is increased and the covariance is reduced by saving the components with biggest eigenvector. In this article, PCA is applied as fusion rule. PCA presents maximum variance of data. Namely, this method reduces the redundant data and extracts the most important components of source images. Also, PCA emphasizes components that are the biggest impact and robust to noise. So the PCA reduces the blurring and spatial distortions [9].

Last step of the multi-focus image fusion is measuring the quality of proposed method. There are two main categories for measuring metrics. These are subjective quality metrics with reference image and objective quality metrics without reference image. Subjective quality metrics with reference image require an original image. The root mean square error (RMSE) and Peak-signal-to-noise-ratio (PSNR) are the most preferred metrics for subjective measuring. Objective quality metrics without reference image which is used generally in performance measuring does not require an original image. The metrics use the source images to measure quality of methods. Mutual Information (MI), Average Gradient (AG) and Petrovic's metric (QAB/F) are the most preferred quality metrics to compare methods [10].

In this paper, we proposed a hybrid technique with super-resolution. Firstly, source image's resolutions are enhanced using super-resolution method. In proposed method, super-resolution coefficient is selected as two. This value can be chosen more than two but this situation increases the computing time. With super-resolution method, information of images is enhanced. This method can be applied all source images which are low-resolution or high resolution. The purpose is to increase the information regardless of the image type. For these super resolute images, SWT is implemented. Images are decomposed using this method. SWT has advantages like low computational time because of only up-sampling. Also thanks to redundant decomposition, decomposed signal saves details of original signal. After decomposition, images are divided into four level sub-bands. Detailed and approximation coefficients are extracted. For all these coefficients, PCA is implemented as a fusion rule. Because, PCA presents data with maximum variance. Namely, this method reduces the redundant data and extracts the most important components of source images. Also, PCA emphasizes components that are the biggest impact and robust to noise [9]. After fusion rule, sub-bands which are LL (low–low) approximation coefficient, LH (low–high), HL (high–low) and HH (high–high) detail coefficients, are recreated. Fused coefficients are reconstructed and fused image is created using Inverse Stationary Wavelet Transform (ISWT). Because of the super-resolution method, the fused image's size is bigger than the original source image's size. To measure quality objectively, fused image is resized to original source image's size using interpolation based resizing method. And finally, fused image with the original size is created and is ready for comparison. Creating high-quality fused image is the purpose of the proposed method. Having more information, smoothness, good visuality and far from distortions and noises are the properties of high quality images. In these images details are seen easily from users. Most of the multi-focus image fusion methods have low spatial resolution and blurring effects. The super-resolution method has a very good impact on fused images. Because of this method, spatial resolution of fused images is enhanced successfully and high quality images are created. Also the SWT and PCA methods help producing smooth images. The visual and quantitative results show that the proposed method resolves these lacks and gets better results in quality measuring. Also, it can be seen the super-resolution method is very successful in multi-focus image fusion.

In last year's different methods are proposed for multi-focus image fusion. For example, Yin et al. proposed a new sparse representation based multi-focus image fusion approach to overcome constructing dictionary adaptive to image data. K-SVD and Batch Omp Algorithms are used to fuse images [2]. Liu et al. presented a new paper based on image decomposition. Cartoon content and texture content of images are evaluated separately [11]. Baohua et al. proposed a novel sparse decomposition and background detection based multi-focus image fusion algorithm. RPCA and Guided filter are used to preserve edges in this paper [12]. Zhang et al. made a spectrum comparison based multi-focus image fusion method. Fourier Transform and Bayesian are implemented to construct an image [13]. Chen et al. proposed multi-wavelet and DFB based multi-focus image fusion approach [14]. Hua presented a multi-focus image fusion based on random walks [15]. Li et al. made a new method which combines structure tensors of mixed order differentials and the multiscale neighborhood [16]. Zhang proposed multi-focus image fusion based on focused region extraction. Saliency analysis is used to extract focused region [17]. Proposed method is compared with literature methods which are told above [2,11,12–17].

The remainder of paper is like that; Section 2 gives the proposed fusion approach and used methods for fusion. Section 3 tells experimental results. Finally, Conclusions are given in Section 4.

## 2. The proposed fusion approach

In this paper, we proposed a super-resolution based hybrid technique to overcome spatial distortions of other algorithms. The algorithm is a novel approach in multi-focus image fusion because this hybrid technique is firstly implemented in this area. Firstly, bicubic interpolation based super-resolution method is implemented to all source images which are low-resolution or high resolution. Thus, source images have more details than original images. This method is implemented to all source images because the method can increase the