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Multi-focus image fusion using sharpness criteria for visual sensor networks in wavelet domain☆

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ABSTRACT

The aim of multi-focus image fusion is to combine several images taken by different sensors and with different focuses to increase the perception of scene. The proposed methods suffer from some undesirable side effects like blurring artifact and/or blocking which decreases the quality of the output image. This paper presents an efficient approach for multi-focus image fusion based on variance and spatial frequency calculated in the wavelet domain. The proposed method remarkably reduces the amount of distortion artifacts and contrast loss due to the fact that variance and spatial frequency-based fusion significantly enhances reliability in feature selection and data fusion procedures. The algorithm ensures to a great extant the access to the data of the images. The experimental results verify the efficiency of the proposed method in the output image quality, as well as its lower complexity, in comparison with several recently related works.

1. Introduction

Multi-sensor methods are used in a wide range of military and civil applications such as remote sensing, machine vision, concealed weapon detection, and medical imaging in order to enhance robustness and performance. However, using more sensor data sources brings about the problem of overload information. To solve this problem, some researches have been carried out on the techniques to counteract the data overload caused by sensors without losing useful data. The aim of fusion in each application is to combine images of several sensors, which leads to the decreased amount of input image data, producing an image with more accurate data [1]. Based on information theory perspective, the fused image has better performance in data and can be used effectively for computer processing and human visual perception.

Cameras applied in visual sensor network and machine vision have limited depth of field and can focus only on the objects at the scene located within particular depth or certain distance. The main properties of such objects are high contrast and sharpness whereas objects at other distances become blurred. So it is necessary to use several cameras to extend depth of focus. Thus, multi focus image fusion techniques are appropriate for fusion of a series of images. The main challenges in image fusion process include: evaluate the blurriness of each image in an effective way, identify appropriate data of images with high focus and contrast, as well as areas with high sharpness, and combine these useful data to create an image with more information.

The simplest algorithms of image fusion perform no decomposition or transformation which results in low contrast. To tackle the problem, it is recommended to use fusion technique which is based on decomposition. Multi resolution decomposition has recently used widely in image fusion [2–6]. The key step in these approaches is to apply multi scale transform

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on each source image and then to combine their coefficients, which is done in an appropriate way to acquire the best quality in fused images. Some examples of these approaches include morphological, gradient pyramids and laplacian pyramid (LAP) and the most popular ones are discrete wavelet transform (DWT) [7] and shift invariant discrete wavelet transform (SIDWT) [8]. Most of the current pyramid transforms do not have directionality and cannot receive details and edges information; hence no high quality fusion is achieved. With the development of wavelet theory and its many advantages such as localization, direction and superb display of image information, combining images based on wavelet analysis came into attention. Using this technique provide an improved combination of fused images for human perception. These approaches achieve the best quality from the source images by monitoring a quantity called "activity level" and then fuse them. Activity level measure indicates source image's quality. Next, fusion is done according to the rules called fusion rules, two common methods of which are described as follows. In first rule which is called "choose max", coefficients with maximum "activity level" are selected and other coefficients are discarded. In the other rule, named weighted average, each multi scale discrete coefficient of the fused image is acquired from combination of weighted coefficients of the source image. It is worth mentioning that wavelet-based algorithms, using different fusion rules, can deal with various frequency bands.

An image fusion technique in wavelet area is presented in [9]. Fusion is performed by applying wavelet analysis on each source image. In this study, DWT is replaced with SIDWT to decompose the image. By observing marginal distribution of wavelet coefficients and their differences at different focus levels, a new statistical sharpness measure is presented to measure the blurredness of the image exploiting the spreading of the wavelet coefficients. In [9], wavelet coefficients distribution is evaluated using locally adaptive laplacian mixture model (LMM). With the estimation that is provided by this model, detail sub-band coefficients are fused. To combine approximation sub-band coefficients, weighted average has been used as the fusion rule. To measure information in this sub-band, the region entropy introduced in [10] has been used. Finally, the fused image is acquired by applying inverse wavelet transform. This method attempts to produce an image with high sharpness but it suffers from serious artifacts around the edges.

Another approach suggested in [11] to maintain the visual quality and the efficiency of the fused image and to reduce the complexity, is based on discrete cosine harmonic wavelet (DCHWT) which considers the fusion rule suggested in [12]. Fusion is done by calculating weights for the coefficients of every level and sub-band. However, it has some disadvantages like producing ringing artifacts.

A method of multi-focus fusion has been presented in the wavelet field in [13]. In the proposed algorithm, firstly the input images are divided into 8×8 blocks. On each block wavelet transformation is applied. Secondly, the variance of the wavelet coefficient is calculated for every sub-band. In this proposed method, variance is taken as activity level measure. Thirdly, the sub-band variances compared to each other and the coefficients with the largest variance are selected. In the final step, the inverse of wavelet transform is applied to the fused coefficients. This is done for every sub-image of 8×8. The main advantage of this method is the superb quality of the acquired image on the non-edge. This method, however, has few weaknesses in terms of fusing the areas close to the edges and boundaries and, increasing the run time due to the division of the image into small blocks.

Recently, two fusing methods have been proposed by Yu Li [14– 15]. The proposed method in [14] fuses the image using the two theories of multi scale transform (MST) and sparse representation (SR), which are widely used in image display. First MST is applied on each source image in order to obtain high pass and low pass coefficients. Then, low pass bands are fused via an approach based on SR and high pass coefficients are fused using the absolute value of coefficients. Finally, the fused image is obtained by performing inverse MST. This method works well in non-border areas but creates some artifacts in border areas. In the other method presented in [15], activity level of image patches are measured using dense scale invariant feature transform (SIFT) descriptor and the primary decision map is obtained. In the next step, the ultimate decision map is achieved by matching SIFT property.

In some earlier works, several methods suggested in DCT and gradient domain are explained to have an evaluation of the fusion. A fusion approach has been suggested in [16] in DCT domain. As the quantity of the variance is usually considered as contrast in image processing application, in [16] the variance of DCT coefficients of the 8×8 blocks of the source images are calculated, in which the variance is taken as activity level measure. Then, it uses consistency verification (CV) to discard error in block selection procedure caused by noise or undesired effects. Complexity reduction is one of this method's advantages. However, the proposed algorithm has some weaknesses in the boundaries between the fused source images, so it errors in identifying the blocks with high quality.

Tang [17] has presented two other fusion techniques in DCT domain named DCT + Average and DCT + Contrast. He has defined his proposed methods on 8×8 blocks. DCT+Average acquires the fused image by calculating the average of DCT coefficients of the input image. This method had some undesirable side effects like blurring.

In another method, DCT + Contrast, activity level is considered on the basis of contrast. Therefore, among corresponding DCT coefficients in the source image, each of them which has the most contrast is taken as the equivalent coefficient in the output image. Calculating contrast criterion in this method is very complex. In addition, this method has high blocking effects due to DCT coefficients shifts in different selection of different images.

The other method, recently introduced in [18] by Zhou, obtains fused image in gradient domain by exploiting a new multi scale method which detects definite focus regions and then identifies gradient weight near focused boundaries. This method is so complex with long run time and the contrast is decreased in the boundaries between the source images, leading to the production of some artifacts.