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Discrete Cosine Transform based fusion of multi-focus images for visual sensor networks

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ABSTRACT

This paper presents a simple and efficient multi-focus image fusion scheme explicitly designed for wireless visual sensor systems equipped with resource constrained, battery powered image sensors employed in surveillance, hazardous environment like battlefields etc. Here the fusion of multi-focus images is based on higher valued Alternating Current (AC) coefficients calculated in Discrete Cosine Transform (DCT) domain. The proposed method overcomes the computation and energy limitation of low power devices and is investigated in terms of image quality and computation energy. Simulations are performed using Atmel Atmega128 processor of Mica 2 mote to measure the resultant energy savings. The experimental results verify the significant efficiency improvement of the proposed method in output quality and energy consumption, when compared with other fusion techniques in DCT domain.

1. Introduction

Image fusion is the process of combining multiple source images from sensor network into a single one, which contains a more accurate description of the scene, more informative and suitable for both visual perception and further processing [1]. In multi-focus image fusion technique, several images of a scene captured with focus on different objects are fused such that all the objects will be in focus in the resulting image. So far, several researches have been focused on image fusion which is performed on the images in the spatial and spectral domain [2–8]. Various multi-focus image fusion algorithms in wavelet domain are available in literature [3–5]. In [3] statistical sharpness measure based on wavelet coefficients distribution is used to perform adaptive image fusion in wavelet domain. Instead of using Discrete Wavelet Transform (DWT) to decompose images into frequency domain, Discrete Stationary Wavelet transform is used in [4] to overcome the lack of translation invariance of the Discrete Wavelet Transform. Then the transformed coefficients are fused and the fused image is constructed by applying inverse Discrete Stationary Wavelet Transform. As the wavelets do not represent long edges well in the fused results, multi-focus image fusion is performed by combining both the wavelet and curvelet transforms to improve the quality [5]. But the limitation is that it consumes more time than the wavelet-based methods because two different multiscale decomposition processes are applied. However multi-focus image fusion based on DWT has its own disadvantages. DWT needs great number of convolution calculations, and it consumes much time or memory resources, which impedes its application for resource constrained battery powered visual sensor nodes.

The energy needed for DCT based fusion is less compared to the DWT based methods. Hence DCT based fusion methods are more appropriate for resource constrained devices. Since the computational energy is much less than the transmission energy, data are compressed and fused before transmission in automated battlefields, where the robots collect image data from sensor network [9]. When the source images are to be coded in Joint Photographic Experts Group (JPEG) standard or when the resultant fused

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image is to be saved or transmitted in JPEG format, the fusion methods in DCT domain will be more efficient [7,8]. Contrast sensitivity method is adopted in [7] to construct the fused image. The contrasts of the corresponding AC coefficients of different blurred images are compared and the AC coefficient with the largest contrast value is selected as the AC coefficient of the fused image. But the contrast calculation for each AC coefficient involves complex floating point computations and the fused image suffers from blocking artifacts due to diversity in the selection of DCT coefficients. In [6,7] the DCT representation of the fused image is obtained by taking the average of all the DCT representations of all the input images but the fused result has undesirable blurring effects. To overcome the undesirable side effects like blurring or blocking artifacts which reduce the quality of the fused image, multi-focus image fusion based on variance calculated in DCT domain is presented in [8]. However the mean, contrast and variance calculation for fusion [7,8] involves complex floating point arithmetic operations which incur high energy consumption in resource constrained battery powered sensor nodes.

In this paper, a simple and efficient multi-focus image fusion scheme that is suitable for resource-constrained (processing, bandwidth, memory space, battery power) sensor network is proposed. In the proposed method, the image blocks with more number of higher valued AC coefficients is absorbed into the fused image. It is extremely fast as it does not involve any complex floating point arithmetic operations like mean or variance calculation. The proposed fusion rule considerably reduces the computational complexity without compromising image quality. Since the proposed fusion scheme is performed in DCT domain, it is time-saving and simple when the fused image needs to be saved or transmitted in JPEG format [7,8]. Simulations are performed using Atmel Atmega128 processor of Mica 2 mote to measure the resultant energy savings.

2. Image fusion

In the proposed scheme, the key step is to fuse the DCT representations of multi-focus images into a single fused image. The input images are divided into blocks of size 8 × 8 and the DCT coefficients of each block is computed. Then the fusion rule is applied wherein the transformed block with more number of higher valued AC coefficients is absorbed into the fused image.

2.1. Discrete Cosine Transform

Two dimensional DCT transform of an $N \times N$ image block $f(x, y)$ [8] is given as

$$F(u,v) = \frac{2}{N} c(u)(v) \sum_{y=0}^{N-1} \sum_{x=0}^{N-1} f(x,y) \cos\left[\frac{(2x+1)u\pi}{2N}\right] \times \cos\left[\frac{(2y+1)v\pi}{2N}\right] \tag{1}$$

where $u, v = 0, 1, \ldots, N-1$ and

$$c(u) = \begin{cases} 1/\sqrt{2}, & \text{if } u = 0 \\ 1, & \text{if } u \neq 0 \end{cases} \tag{2}$$

the inverse transform is defined as

$$f(x,y) = \frac{2}{N} \sum_{v=0}^{N-1} \sum_{u=0}^{N-1} c(u)c(v)F(u,v) \cos\left[\frac{(2x+1)u\pi}{2N}\right] \times \cos\left[\frac{(2y+1)v\pi}{2N}\right] \tag{3}$$

where $x, y = 0, 1, \ldots, N-1$. Here $F(0, 0)$ is the DC coefficient and it represents the mean value of that image block. Remaining coefficients are AC coefficients.

2.2. Fusion based on variance

In [8] variance is used as the activity level for fusion criteria because in multi-focus images, the focused region is more informative and the information details of that region correspond to high variance. It is inferred that the variance of an $N \times N$ block of pixels can be exactly calculated from its DCT coefficients by computing the sum of the squared normalized AC coefficients of the DCT block.

The normalized transform coefficients are defined as

$$\hat{F}(u,v) = \frac{F(u,v)}{N} \tag{4}$$

variance (σ^2) of the image block [8] can be inferred from the transformed coefficients as follows:

$$\sigma^2 = \sum_{u=0}^{N-1} \sum_{v=0}^{N-1} \frac{F^2(u,v)}{N^2} - \hat{F}^2(0,0) \tag{5}$$

where $\hat{F}(0,0)$ is the normalized DC coefficient and other $\hat{F}(u,v)$s are the normalized AC coefficients.

2.3. Fusion criteria for the proposed AC_Max fusion

The advantage of DCT is that the energy of the original data may be concentrated in only a few low frequency components of DCT depending on the correlation in the data. Also the low-frequency components usually contain the most of the image information. Higher the value of AC coefficients implies finer image information.

Eq. (5) implies that the variance of a block of size 8 × 8 is given by the sum of the squares of the normalized 63 AC coefficients.

$$\sigma^2 = \sum_{i=1}^{63} \hat{A}i^2 \tag{6}$$

Because of the energy compaction property of AC coefficients, only few coefficients towards the top left submatrix of the DCT transformed matrix have larger values [10] and the contribution of these coefficients to variance is more compared to other AC coefficients. Hence if the AC coefficient value is high, then the variance value is also high.

Hence in our proposed method we absorb the block with more number of higher valued AC coefficients for two reasons. First is that higher the AC component value implies more fine details of the image [11]. Secondly, from