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Fusion of multifocus images by lattice structures ☆

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ABSTRACT

Image fusion methods based on multiscale transform (MST) suffer from high computational load due to the use of fast Fourier transforms (ffts) in the lowpass and highpass filtering steps. Lifting wavelet scheme which is based on second generation wavelets has been proposed as a solution to this issue. Lifting Wavelet Transform (LWT) is composed of split, prediction and update operations all implemented in the spatial domain using multiplications and additions, thus computation time is highly reduced. Since image fusion performance benefits from undecimated transform, it has later been extended to Stationary Lifting Wavelet Transform (SLWT). In this paper, we propose to use the lattice filter for the MST analysis step. Lattice filter is composed of analysis and synthesis parts where simultaneous lowpass and highpass operations are performed in spatial domain with the help of additions/multiplications and delay operations, in a recursive structure which increases robustness to noise. Since the original filter is designed for the undecimated case, we have developed undecimated lattice structures, and applied them to the fusion of multifocus images. Fusion results and evaluation metrics show that the proposed method has better performance especially with noisy images while having similar computational load with LSWT based fusion method.

1. Introduction

Digital cameras, focused at a specific distance, yields sharper objects in the focused area and blurry objects otherwise. Multifocus image fusion is the process of obtaining a new and improved image from different forms of the same image [1–3]. The goal of fusion is to include all the important information from input images in the fused image, while avoiding artifacts and noise [4–6].

The simplest fusion method takes the average of the pixel values of the source images. However, this approach yields reduced contrast in the fusion result. Multiscale transforms (MST) such as Laplacian pyramid, gradient pyramid, morphological pyramid, discrete wavelet transform (DWT), and stationary wavelet transform (SWT) have been widely used in image fusion tasks [7–12]. In these methods, the source images are decomposed into their subbands (named as lowpass and highpass subbands) by the MST. Then the subbands are merged by a predefined rule, and finally the fused image is obtained by the inverse MST. The most popular MST methods are based on DWT. In DWT based methods, the calculation cost is very high due to the convolution operation which requires the use of ffts. To make the calculations faster, some methods are developed, such as the lifting wavelet transform (LWT) [13]. Because of the decimation process during decomposition, both DWT and LWT are not shift-invariant, thus affecting the quality of the fused image [14]. To overcome this problem, the lifting stationary wavelet transform (LSWT) is used for image fusion processes [8,9]. Recently, multidirectional MST methods such as curvelets, or nonsubsampled contourlet method (NSCT) based fusion methods have been proposed [15–17]. Although, their performance is better than the method with LSWT due to multidirection information, their complexity prevents them to be appropriate for real time implementations. Another approach for fast processing of image sequences is by parallel implementation in many core processor systems [18,19].

In this paper, a new image fusion algorithm based on the subband decomposition of the source images using 1-D lattice filter structures is proposed. Lattice filters are used in digital filter implementations because they have a number of interesting and important properties including modularity, low sensitivity to parameter quantization effects and a simple stability test [20]. Two channel QMF (quadrature mirror filter) bank with lattice structure has perfect reconstruction property, and it guarantees good stopband attenuation for each of the analysis filters. A higher order QMF

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bank with lattice structure may be obtained from a lower order one simply by adding more lattice sections. The analysis section of the complete filter bank is represented by a lattice filter while the synthesis part is represented by the inverse lattice filter [20].

The lattice filters described above also includes decimation process, as in DWT and LWT, with similar problems. So, an undecimated lattice structure is proposed in this paper to avoid this problem.

In MST based methods, another important problem is the rule selection for merging the subbands. The basic method is averaging lowpass subbands and using the absolute maximum of the highpass subbands. Taking into consideration the human vision system (HVS), local luminance contrast is measured by rationing the highpass subband to the local luminance [7]. Variations of this contrast measure are also proposed [16,17]. However, these measures use a single pixel value. A single pixel is usually not enough to determine whether it represents enough information about the subbands, and is also not good enough to eliminate the effects of noise. In wavelet subbands, there are dependencies between the scales, i.e., a large magnitude in finer scale yields a large magnitude in coarser scale. If the pixel is affected by noise, the magnitude decays. So, multiscale products (MSP), which is the multiplication of adjacent subbands, is used to eliminate effects of noise [21,22].

The paper is organized as follows: Section 2 reviews the background of the lifting wavelet transform and 1-D filter bank with attice structure. In Section 3, the new undecimated case for 1-D lattice structures is developed, and a new fusion method based on the proposed undecimated lattice structures is presented. Fusion results and evaluation metric results are given in Section 4. General conclusions are provided in Section 5.

2. Background information

In Section 2.1, the LWT method for signal decomposition and reconstruction is reviewed. In Section 2.2, signal decomposition and reconstruction with the lattice filterbank with the perfect reconstruction (PR) is reviewed.

2.1. Background on lifting wavelet transform

The lifting wavelet transform (LWT), also known as the second generation wavelet transform, consists of split, predict and update steps [13]. Since it requires only shifts, additions and scalar multiplications instead of fft operations required for the convolution steps of the classical wavelet transform, it leads to an easier hardware implementation, as well as less storage space and computation time [13]. The lifting steps for decomposition in the decimated case are as follows:

2.1.1. Split

The original signal $s(n)$ is divided into an even and an odd array as

$$x_e(n) = s(2n), \qquad x_0(n) = s(2n+1) \tag{1}$$

2.1.2. Predict

The odd array is predicted by the even array using a prediction operator $P[\cdot]$. The detail information is obtained between $x_0(n)$ and its predicted signal $P[x_e(n)]$ as

$$d_1(n) = x_0(n) - P[x_e(n)] \tag{2}$$

The predicted signal $P[x_e(n)]$ is obtained as follows:

$$P[x_e(n)] = \sum_{-M/2+1}^{M/2+1} p_r x_e(n+r) \tag{3}$$

where p_r is the prediction coefficients of the lifting scheme and M is the number of the coefficients.

2.1.3. Update

An approximate signal is obtained by using the detail signal $d_1(n)$ to update the even array $x_e(n)$ using an update operator $U[\cdot]$ as

$$s_1(n) = x_e(n) - U[d_1(n)] \tag{4}$$

$s_1(n)$ is again divided into even and odd arrays, and the recursion steps are repeated until we obtain $s_j, d_j, d_{j-1}, \ldots, d_2, d_1$ The inverse lifting scheme is obtained by reversing the order of the decomposition steps and changing + by − and vice versa. The split step is replaced by a merge step where the odd and even signals are fused together at each resolution level.

2.1.4. Undecimated case

The undecimated lifting scheme [23] consists only of two stages predict and update where the filter weight vectors are extended by inserting 2^{j-1} zeros between their samples at each level j as

$$\begin{aligned} P^j &= \{P_0^0, 0, \ldots, 0, P_1^0, 0, \ldots, 0, P_2^0, 0, \ldots, 0, P_{M-1}^0\} \\ U^j &= \{U_0^0, 0, \ldots, 0, U_1^0, 0, \ldots, 0, U_2^0, 0, \ldots, 0, U_{N-1}^0\} \end{aligned} \tag{5}$$

where M and N are the numbers of weight coefficients for filters P and U, respectively.

In the reconstruction step, similar to the decimated case, the order of the steps are reversed, the signs are changed, and the merging step is replaced by an averaging step.

2.2. Background on 1-D PR filter bank with lattice structure

A two channel filterbank is composed of analysis and synthesis sections. In the analysis section, the input signal is split into low and high pass components, and in the synthesis section, it is reconstructed from its components. Vaidyanathan [20] has proposed the use of quadrature mirror filters (QMF) with lattice structure for the design of two channel filterbanks with perfect reconstruction. The hierarchical property of lattice structures enables the design of higher order perfect reconstruction quadrature mirror filter banks (PR-QMFB) from lower order PR-QMFB simply by adding more lattice sections.

QMFB with lattice structure involves a cascade of lattice structures, and each lattice structure is associated with a lattice coefficient. They have two special characteristics:

- In each stage of the lattice, one coefficient is positive and the other one is negative, but both have the same magnitude.
- All coefficients with even valued indices are zero.

Analysis and synthesis lattice structures used in the single level decomposition and reconstruction for 1D signals are shown in Fig. 1a and b, respectively. As seen in Fig. 1a, the analysis lattice structure divides the input signal $x(n)$ into its low-pass and high-pass components: $x_L(n)$ and $x_H(n)$. The synthesis structure reconstructs the signal $x'(n)$ from these components. In Table 1, the lattice parameters determined for given stopband frequencies and corresponding average stoppand powers are shown.

The average stoppand power decreases with the increase of lattice order. Using (8), it is possible to find lattice parameters corresponding to different stopband frequencies and to construct different lattice structures.

The input output relations for the first stage and succeeding stages are given by