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Image fusion based on a new contourlet packet

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ABSTRACT

Contourlet is a "true" two-dimensional transform that can capture the intrinsic geometrical structure and has been applied to many tasks in image processing. In this paper, a new contourlet packet (CP) is constructed based on a complete wavelet quadtree followed by a nonsubsampled directional filter bank (NSDFB). By combing the finer approximation characteristic of wavelet packet (WP) with the invertible characteristic of NSDFB, the proposed CP has more accurate reconstruction of images than WP. Moreover, the wavelet quadtree decomposition is implemented by the stationary wavelet transform (SWT), so the CP proves to be characteristic of shift-invariant and linear phase by choosing appropriate filters. After the proposed CP transform on the fusing images, a pulse coupled neural network (PCNN) is used to make a fusion decision, which can obtain better visual result for the global features of the original images being extracted by the output pulses of the PCNN neurons. We compare the performance of our proposed method in image fusion with that of wavelet, contourlet, wavelet packet and other contourlet packet based approaches. The experiment results show the superiorities of the method to its counterparts in image clarity and some numerical guidelines.

1. Introduction

It is well known that the commonly used separable extensions of one-dimensional transforms, such as Fourier transform (FT) and wavelet transform (WT), are limited in capturing the geometry of image edges. An efficient representation of image lies at the heart of many image processing tasks, where "efficient" refers to the ability to capture significant information about an object of interest using a compact description. Considering that wavelet fails in capturing directional information in dimensions higher than 2, in the last decade several "geometric" wavelets (e.g. ridgelet, curvelet, contourlet and bandelet) have grown in popularity motivated by the need for finding better representations of nature images. Researchers have recently considered multiscale and directional representations that can capture the intrinsic geometrical structures such as smooth contours and edges in natural images. Some examples including the steerable pyramid [1], brushlet [2], complex wavelet [3] and curvelet [4] have been studied. A striking property of these "geometric" waves is their efficiency in dealing with particular singularities in images. For example, ridgelet/frames are optimal for representing piecewise smooth signals with singularities along straight lines or hyperplane [5]. The curvelet transform, pioneered by Candès and Donoho [4], is shown to be optimal in a certain sense for functions in the continuous domain with curved singularities. Inspired by curvelet, in 2005 Do and Vetterli developed the contourlet transform (CT) [6] based on an efficient two-dimensional multiscale and directional filter bank that can deal effectively with images having smooth contours.

Contourlet is a flexible multi-resolution, local, and directional image expansion using contour segments. It can provide a multiscale and directional decomposition for images, which is more suitable for catching the features in images that are abundant in complex contours, edges and textures. A most often referred implementation scheme of contourlet is Laplacian Pyramid (LP) followed by directional filter bank (DFB) [6]. Because there exists the spectrum overlapping, some improved methods have been proposed [7,8]. However, all the variations of contourlet do not give a further decomposition of high frequency components, which may lose some details of images. The contourlet packet (CP) is a natural extension of CT, provides a level-by-level decomposition of the input image from the time domain to the frequency domain according to a full quadtree. For the further decomposition of high frequency band, it can achieve a sparse representation of images containing smooth regions as well as edges with oscillatory patterns. Wavelet based contourlet packet (WBCP) has been investigated in paper [9]. In this paper, a new contourlet packet is proposed based on a wavelet quadtree followed by a nonsubsampled directional filter bank (NSDFB), and a complete contourlet packet decomposition tree (CPDT) is constructed through a stationary wavelet transform. Because the proposed CP combines the

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characteristic of accurate approximation of complete wavelet quadtree with shift-invariant properties of stationary wavelet and NSDFB [10], it gives a more accurate representation of images than wavelet, contourlet, WP and WBCP. When a wavelet filter with linear phase is adopted, the proposed CP has linear phase and thus more robust to Gibbs effect.

In image fusion, one of the most important things for improving fusion quality is the selection of fusion rules, which influences the performance of fusion algorithm remarkably. Pulse-coupled neural network (PCNN) is a novel artificial neural network model developed recently [11], and has been efficiently applied to image processing field, such as image segmentation, image restoration, image recognition, etc. Here a new fusion method based on PCNN is employed, which uses the number of output pulses from PCNN's neurons to select fusion coefficients. The subbands coefficients corresponding to the most frequently spiking neurons of PCNN are selected to recombine a new image. Because of the global coupled property and pulse synchronization characteristic of PCNN, the selection of fusion coefficients in new algorithm utilizes the global feature in source images. So the new fusion rule can obtain better visual result than those existing fusion rules such as weighted average rule, maximum rule or region-energy-based rule that only use features of single pixel or local region to make decision and selection.

The remainder of this paper is organized as follows: Section 2 introduces the mathematical foundation of contourlet, and a complete wavelet quadtree decomposition followed by a NSDFB scheme for an implementation of contourlet packet transform is investigated. In Section 3, a PCNN is used to make a fusion decision of the decomposition coefficients and a PCNN based fusion rule is depicted in detail. Then we provide the overall structure of the fusion system and give the technical details used in this paper. In Section 4, some experiments will be conducted and their results together with relevant discussions will be reported. Concluding remarks are given in Section 5.

2. Contourlets and contourlet packet

Two-dimensional wavelets, with tensor-product basis functions, lack directionality and are only good at catching point discontinuities, but do not capture the geometrical smoothness of the contours. Contourlet is considered as an improvement over wavelets in dimension 2.

2.1. Contourlet and its implementation

Contourlet not only possess the main features of wavelets (namely, multiscale and time-frequency localization), but also offer a high degree of directionality and anisotropy, as shown in Fig. 1a and b. The primary goal of the contourlet construction is to obtain a sparse expansion for typical images that are piecewise smooth away from smooth contours. According to Do and Vetterli, contourlet transform is implemented via a two-dimensional filter bank that decomposes an image into several directional subbands at multiple scales. This is accomplished by combining LP with a DFB at each scale, which is often called pyramid directional filter bank (PDFB). First, a multiscale decomposition into octave bands by LP is computed, and then a DFB is applied to each bandpass channel, as shown in Fig. 1c.

Due to this cascade structure, multiscale and directional decomposition stages in the contourlet transform are independent with each other. The resulting transform has not only the multiscale and local time-frequency properties of wavelets, but also offers a high degree of directionality and anisotropy. Specifically, CT involves basis functions that are oriented at any directions with flexible aspect ratios. The main difference between contourlet and other multiscale directional systems is that CT allows for different and flexible number of directions at each scale, while achieving nearly critical sampling. In addition, CT uses iterated filter banks, which makes it computationally efficient; specifically, the computational complexity is of $O(N)$ for an image with N pixels.

Contourlet has many advantages in comparison with the other multiscale geometrical analysis (MGA) tools, among which the optimal theoretic approximation rate $M^{-2}(\log M)^{-3}$ and an easy implementation of PDFB are two most significant ones. However, due to the redundancy of LP, the overall transform of contourlet is redundant and so is not a good choice. The recent proposed wavelet-based contourlet transform (WBCT) is a non-redundant version of CT [12]. In the WBCT, the LP stage of CT is replaced by WT, which is by construction a non-redundant multiresolution system, and hence, this results in the non-redundant transform. One of the major advantages of WBCT is that we can construct wavelet-based contourlet packet (WBCP) in much the same way as that of wavelet packet (WP). That is, keeping in mind the anisotropy scaling law (the number of directions is doubled at every other wavelet levels when we refine the scales), we allow quadtree decomposition of both lowpass and highpass channels in wavelets and then apply the DFB to each subband [10]. However, this implementation is based on the downsample wavelet packet proposed by Mallat, and there is frequency overlapping in obtained quadrature mirror filter (QMF) filters after Wickerhause tree algorithm.

2.2. Shift-invariant wavelet packet and NSDFB based contourlet packet

Different with the method in paper [9], we propose a complete wavelet quadtree and NSDFB based implementation of CP in this paper, where a stationary wavelet packet based on stationary wavelets (or undecimated discrete wavelets, undecimated wavelet) is employed to ensure the multiscale property, and subsequently a NSDFB structure that gives directionality follows.

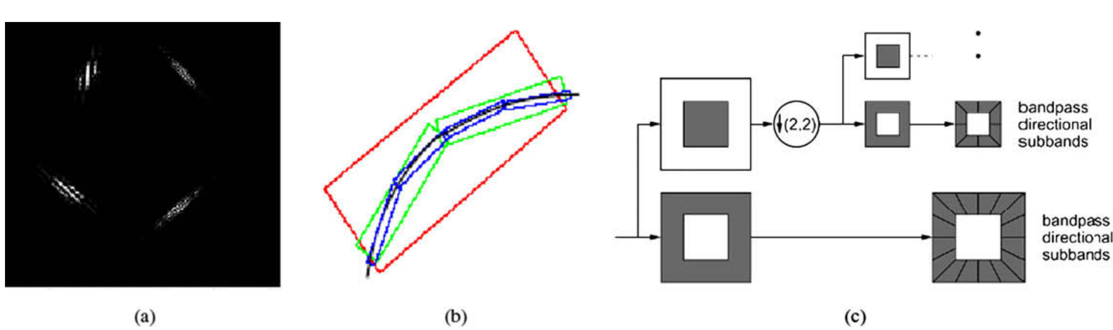

Fig. 1. (a) Four example contourlet basis images; (b) illustration showing how contourlets having elongated supports that can capture linear segments of contours; (c) implementation of pyramid directional filter bank (PDFB).