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Construction of 2-D directional filter bank by cascading checkerboard-shaped filter pair and CMFB

Zuo-feng Zhou [a,b,*], Yuan-yuan Cheng [a], Peng-lang Shui [a]

[a] National Laboratory of Radar Signal Processing, Xidian University, Xi'an 710071, PR China
[b] Xi'an Institute of Optics and Precision Mechanics, Chinese Academy of Sciences, Xi'an, 710119, PR China

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ABSTRACT

In this paper, we propose a new approach to construct a 2-dimensional (2-D) directional filter bank (DFB) by cascading a 2-D nonseparable checkerboard-shaped filter pair and 2-D separable cosine modulated filter bank (CMFB). Similar to diagonal subbands in 2-D separable wavelets, most of the subbands in 2-D separable CMFBs, tensor products of two 1-D CMFBs, are poor in directional selectivity due to the fact that the frequency supports of most of the subband filters are concentrated along two different directions. To improve the directional selectivity, we propose a new DFB to realize the subband decomposition. First, a checkerboard-shaped filter pair is used to decompose an input image into two images containing different directional information of the original image. Next, a 2-D separable CMFB is applied to each of the two images for directional decomposition. The new DFB is easy in design and has merits: low redundancy ratio and fine directional-frequency tiling. As its application, the BLS-GSM algorithm for image denoising is extended to use the new DFBs. Experimental results show that the proposed DFB achieves better denoising performance than the methods using other DFBs for images of abundant textures.

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1. Introduction

Directional information is important in many areas of image processing, such as denoising, compression, edge detection and feature extraction. During the past decade, a mass of efforts have been made to find efficient directional representations of natural images, and various directional filter banks (DFBs) have been designed [1–9]. Two-dimensional (2-D) separable wavelets are the easiest choice and have been successfully applied in image restoration and compression. However, 2-D separable wavelets are suited for representation of point singularities but unsuited for representation of line-singularities such as edges and textures in images, partly owing to their poor directional selectivity. This deficiency of 2-D separable wavelets promotes fast growing in DFBs. There exist many directional multiscale transforms, including the steerable pyramid [3], DFB [4], contourlet [5,6], DT-CWT [7], complex wavelet [8], direction-let [9], etc.

The DFBs were originally proposed by Bamberger and Smith in [4] and subsequently improved by several authors [1,10,11]. It is critically sampled and implemented by cascading two-channel diamond-shaped and parallelogram filter banks with wedge-shaped frequency partitions. Cascading the Laplacian pyramid (LP) [12] and the wedge-shaped DFB [4] generates the contourlet transform [5]. The other effective approach is to construct 2-D DFBs from 2-D separable wavelets, including the 2-D dual-tree complex wavelets [7] and the mapping-based complex wavelets [8]. The 2-D DT-CWT is the tensor product of the two 1-D DT-CWT constructed from 1-D approximate Hilbert pairs of wavelet bases [13,14]. The 2-D

* Corresponding author at: National Laboratory of Radar Signal Processing, Xidian University, Xi'an 710071, PR China.
Tel.: +86 29 88201022 8611.
E-mail addresses: ever817@126.com, plshui@xidian.edu.cn (Z.-f. Zhou).

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mapping-based complex wavelet transforms extract directional information of real-valued natural images in the two stages. A real-valued image is first decomposed into two real-valued images containing different directional information. Next, 2-D separable DWTs are applied to each of the two images to extract directional information. The 2-D mapping-based CWTs have six oriented subbands at each scale.

In this paper, following the two-stage scheme in [8], we construct new DFBs by cascading checkerboard-shaped filter pair (CSFP) and 2-D separable cosine modulated filter banks (CMFBs) that are the tensor products of two 1-D CMFBs. 1-D CMFBs are mature in theory and design algorithms [15–21] and there are many available design algorithms and numerical examples. Thus, the proposed scheme is a simple but efficient approach to construct DFBs. Similar to 2-D separable wavelets, 2-D separable CMFBs are poor in directional selectivity due to the fact that most of the subband filter's support is along the two different directions in the 2-D frequency plane. In order to improve their directional selectivity, we design a CSFP that consists of two real-valued FIR energy-complimentary filters. One is used to extract the information of a natural image in the first and third quadrants in the frequency domain, while the other is used to extract the information in the second and fourth quadrants. The CSFP followed by the 2-D separable CMFB constitutes a new 2-D DFB with a redundant ratio of only 2. The new DFBs are very efficient to represent vibrating patterns of different directions and frequencies in natural images. As its application, we use the new 2-D DFB instead of the steerable pyramids in the BLS-GSM algorithm [26] for image denoising. The experimental results show that the BLS-GSM algorithm using the proposed 2-D DFBs significantly improves the denoising performance for natural images with abundant textures.

This paper is organized as follows. Section 2 gives the structure of the new DFB by cascading CSFP and 2-D separable CMFBs. Section 3 reviews the design methods of CMFBs and gives the design algorithm for the CSFP. In Section 4, the BLS-GSM image denoising algorithm using the proposed DFBs is given, and the experimental results and performance comparison are made. Finally, we conclude our paper.

2. Structure of new directional filter banks

Many image processing tasks, such as restoration, compression and features extraction, rely on efficient representations of image features such as smooth contours, edges and textures. These image details often exhibit different directions and vibrating frequencies. Various DFBs were developed for representation of these image details. The DFBs include the steerable pyramid [3], critically sampled DFBs [4], Contourlet [5], 2-D DT-CWTs [7] and the 2-D mapping-based complex wavelets [8]. The directional selectivity of a DFB is closely related to their 2-D frequency tiling. As shown in Fig. 1, several different types of DFBs provide different frequency tiling. The 2-D separable wavelets have three oriented subbands at each scale, the contourlet transform has adjustable oriented subbands at each scale, the critically sampled DFBs have

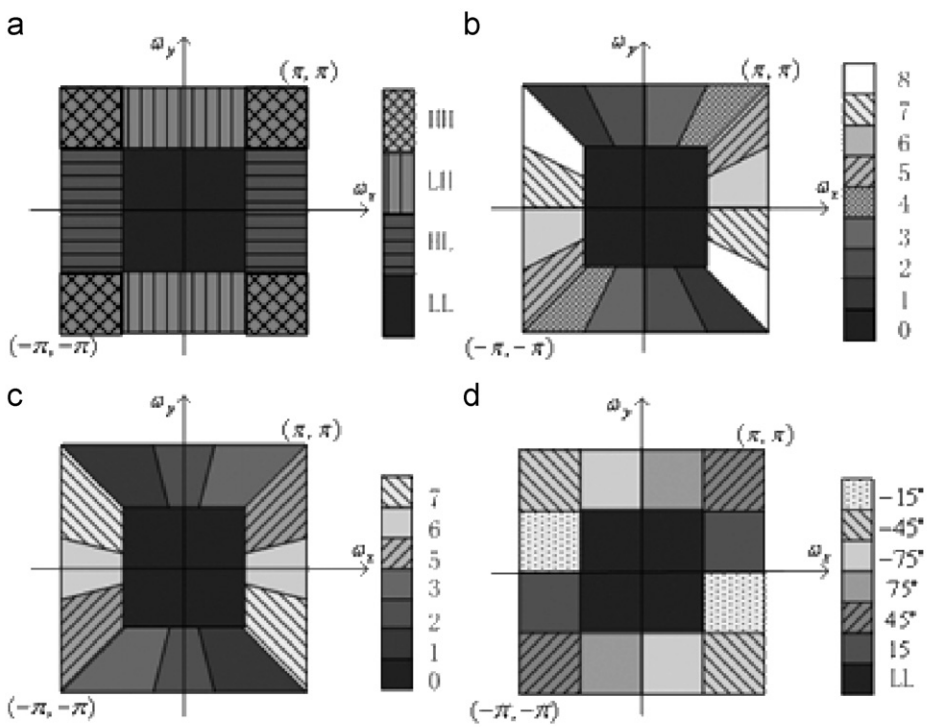

Fig. 1. Frequency tiling of the existing DFBs: (a) 2-D separable wavelets; (b) contourlet transform; (c) critically sampled DFBs; (d) 2-D DT-CWTs and mapping-based CWTs.

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