BLOCK-WISE IMPLEMENTATION OF DIRECTIONAL GENLOT

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ABSTRACT

A block-wise implementation and directional design approach of 2-D non-separable linear-phase paraunitary filter banks (LPPUFB) are introduced.

- A boundary operation and compatibility with block-DCT are given.
- Directional transforms are given with a GenLOT-like lattice structure.

Introduction

Problems

- JPEG, MPEG-2 and H.264/AVC employ block-DCT and JPEG2000 adopts DWT for exploiting spatial redundancy. However, All these transforms are separable and weak in diagonal direction.
- Several non-separalbe transforms have been developed. However, Adaptability to local characteristics and moderate boudary operation for size-limitation are hard to be realized under perfect reconstruction.

Proposal

- A lattice structure of 2-D LPPUFB is utilized for realizing adaptive directional transforms while maintaining the orthogonality (i.e. PR).

Review of 2-D LPPUFB

Product form of 2-D LPPUFB

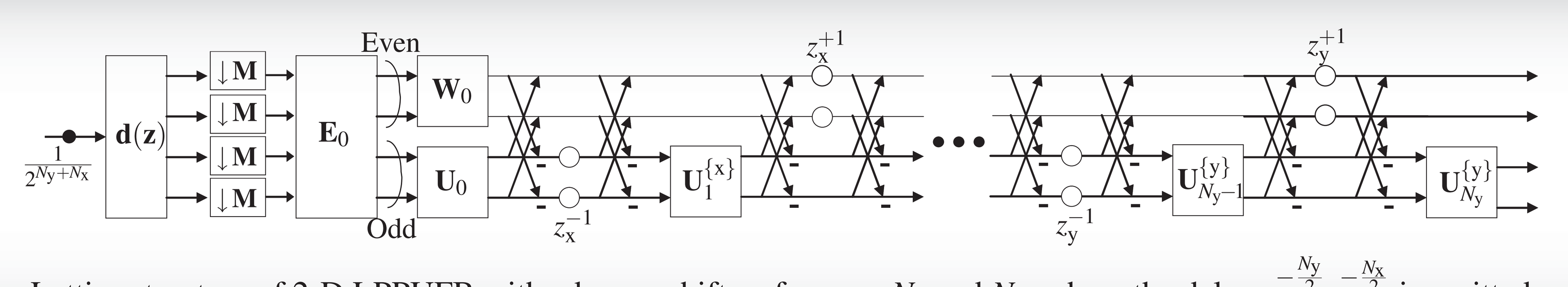
- Orthogonality and symmetry are guaranteed by the following form of polyphase Mtx. with 2-D DCT $\mathbf{E}_0$:

$$\mathbf{E}(\mathbf{z}) = \prod_{n_y=1}^{N_y} \left\{ \mathbf{R}_{n_y}^{\{y\}} \mathbf{Q}(z_y) \right\} \prod_{n_x=1}^{N_x} \left\{ \mathbf{R}_{n_x}^{\{x\}} \mathbf{Q}(z_x) \right\} \mathbf{R}_0 \mathbf{E}_0, \quad \mathbf{z} = (z_y, z_x)^T \in C^2$$

where $\mathbf{R}_0 = \begin{pmatrix} \mathbf{W}_0 & \mathbf{O} \\ \mathbf{O} & \mathbf{U}_0 \end{pmatrix}$, $\mathbf{R}_n^{\{d\}} = \begin{pmatrix} \mathbf{I} & \mathbf{O} \\ \mathbf{O} & \mathbf{U}_n^{\{d\}} \end{pmatrix}$ and $\mathbf{Q}(z_d) = \frac{1}{2} \begin{pmatrix} \mathbf{I} & \mathbf{I} \\ \mathbf{I} & -\mathbf{I} \end{pmatrix} \begin{pmatrix} \mathbf{I} & \mathbf{O} \\ \mathbf{O} & z_d^{-1}\mathbf{I} \end{pmatrix} \begin{pmatrix} \mathbf{I} & \mathbf{I} \\ \mathbf{I} & -\mathbf{I} \end{pmatrix}$

for $d \in \{y, x\}$. $\mathbf{W}_0$, $\mathbf{U}_0$ and $\mathbf{U}_{n_d}^{\{d\}}$ are parameter orthonormal matrices.

Construction with Advance Shifters



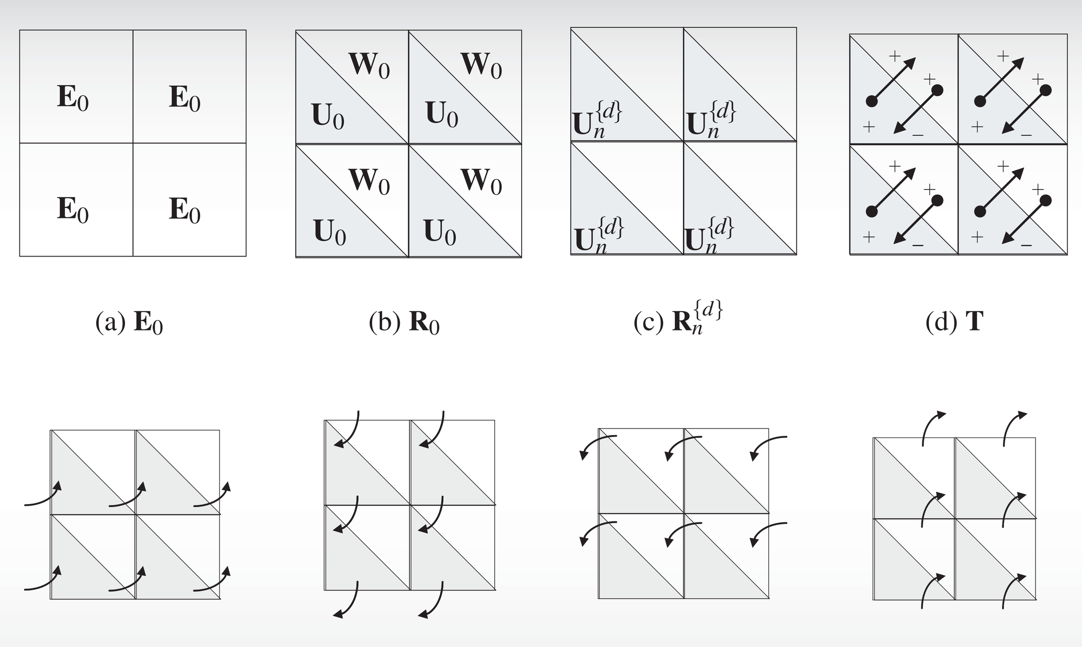
Lattice structure of 2-D LPPUFB with advance shifters for even N_y and N_x, where the delay $z_y^{-\frac{N_y}{2}} z_x^{-\frac{N_x}{2}}$ is omitted.

$$\mathbf{E}(\mathbf{z}) = z_y^{-\frac{N_y}{2}} z_x^{-\frac{N_x}{2}} \prod_{k_y=1}^{N_y/2} \left\{ \mathbf{R}_{2k_y}^{\{y\}} \bar{\mathbf{Q}}(z_y) \mathbf{R}_{2k_y-1}^{\{y\}} \mathbf{Q}(z_y) \right\} \prod_{k_x=1}^{N_x/2} \left\{ \mathbf{R}_{2k_x}^{\{x\}} \bar{\mathbf{Q}}(z_x) \mathbf{R}_{2k_x-1}^{\{x\}} \mathbf{Q}(z_x) \right\} \mathbf{R}_0 \mathbf{E}_0$$

where $\bar{\mathbf{Q}}(z_d) = z_d \mathbf{Q}(z_d)$.

Block-wise Operation

Primitive Block Operations

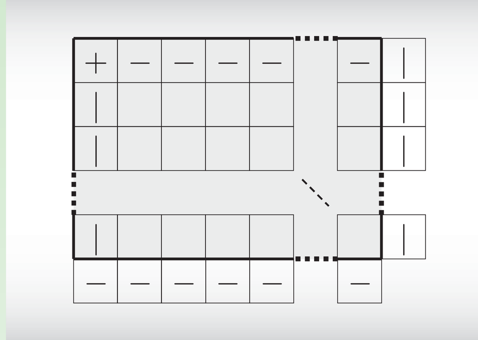


(a) $\mathbf{E}_0$ (b) $\mathbf{R}_0$ (c) $\mathbf{R}_n^{\{d\}}$ (d) $\mathbf{T}$

(e) $\Lambda(z_x)$ (f) $\Lambda(z_y)$ (g) $\bar{\Lambda}(z_x)$ (h) $\bar{\Lambda}(z_y)$

- The white and shaded triangles denote operations for upper and lower half intermediate Coefs. in the lattice structure, respectively.
- Combination of these operations allows to implement the transform, where the parameter matrices can vary block by block.

Boundary Operation



- Symmetric Ext. is not applicable.
- Overlapping can be controled by selecting $\mathbf{U}_{2k-1}^{\{d\}} = -\mathbf{I}$, for which

$$\mathbf{R}_{2k}^{\{d\}} \bar{\mathbf{Q}}(z_d) \mathbf{R}_{2k-1}^{\{d\}} \mathbf{Q}(z_d) = \begin{pmatrix} \mathbf{I} & \mathbf{O} \\ \mathbf{O} & -\mathbf{U}_{2k}^{\{d\}} \end{pmatrix}$$

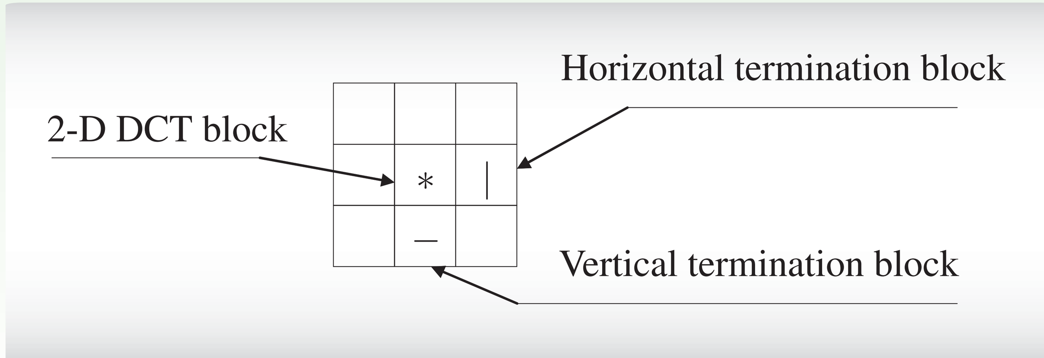
- Boundary operation with block termination: the blocks including '|', '-' and '+' denote termination blocks in the horizontal, vertical and both directions, respectively.

Compatibility with 2-D Block DCT

- 2-D DCT block can be set by selecting

$$\mathbf{W}_0 = \mathbf{U}_0 = \mathbf{I}$$

$$\mathbf{U}_n^{\{d\}} = -\mathbf{I}$$



Directional Design

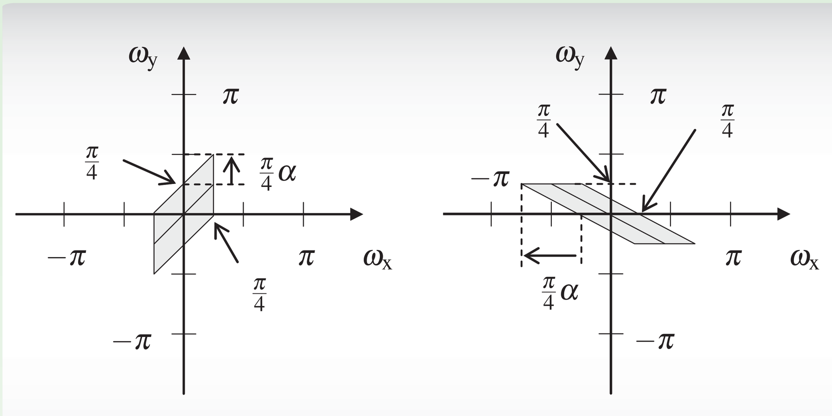
Design Specification

- Ideal lowpass filter specification: α controls the passband shape.

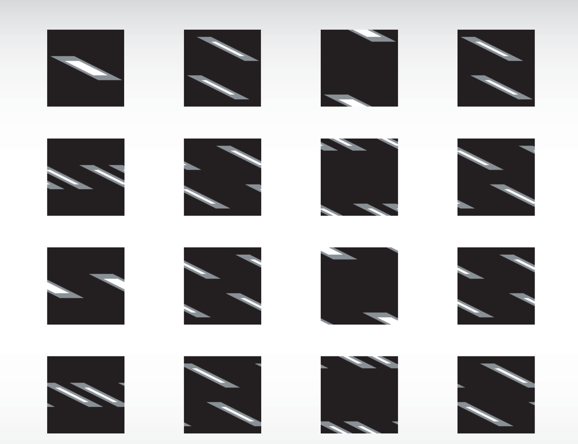
$$\mathbf{A}_d(\alpha) = \begin{cases} \begin{pmatrix} 1 & 0 \\ -\alpha & 1 \end{pmatrix}, & d = y \\ \begin{pmatrix} 1 & -\alpha \\ 0 & 1 \end{pmatrix}, & d = x \end{cases}$$

$$\left| H_{I0}\left(e^{j\omega^T}\right) \right| = \begin{cases} c_0 & \omega \in \mathrm{SPD}\left\{\pi(\mathbf{M}\mathbf{A}_d(\alpha))^{-T}\right\} \\ 0 & \omega \in [-\pi, \pi)^2 - \mathrm{SPD}\left\{\pi(\mathbf{M}\mathbf{A}_d(\alpha))^{-T}\right\} \end{cases}$$

- Examples of design specifications for $M_y = M_x = 4$.

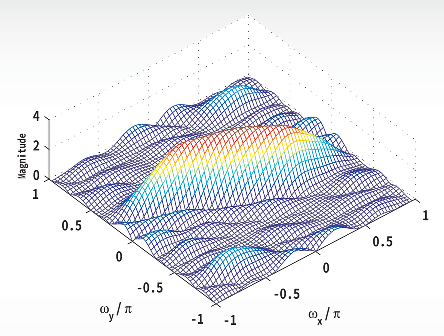


(a) $d = y, \alpha = 1.0$ (b) $d = x, \alpha = -2.0$

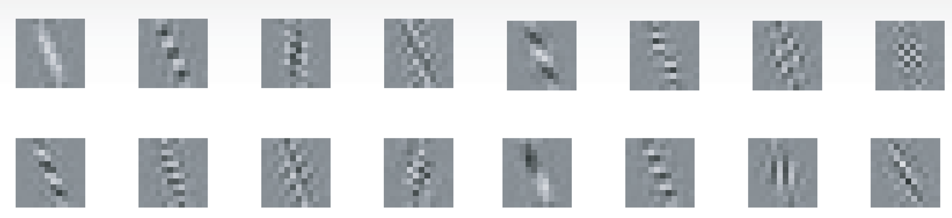


Split & Modulation

Design Example

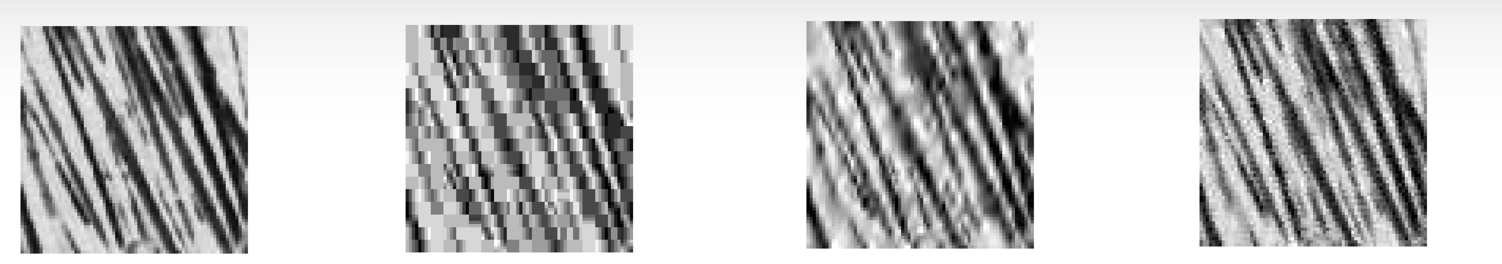


$\left|H_0\left(e^{j\omega^T}\right)\right|$



16 basis images of size 12×12 for $M_y = M_x = 4$ and $N_y = N_x = 2$

Experimental Results



Original	4×4 block DCT	2-level 9/7 DWT	DirLOT
	PSNR 28.56 [dB]	PSNR 28.43 [dB]	PSNR 28.92 [dB]

- ECSQ at 0.5bpp for 8-bit grayscale image of size 72×72, where the proposed boundary operation is applied for DirLOT.

Conclusions

- The block-wise operation serves variability of basis images without any vaiolation to the orthogonality, a boudry operation for size-limitation and the compatibility with 2-D block-DCT.
- Directional transforms can be obtained by directional specifications, and show good performance for a picture with a specific directionality.