Signal Processing: *Image Communication* 29 (2014) 49–65

Contents lists available at ScienceDirect

Signal Processing: *Image Communication*

journal homepage: www.elsevier.com/locate/image

A fast hybrid Jacket–Hadamard matrix based diagonal block-wise transform☆

Moon Ho Lee [a], Md. Hashem Ali Khan [a,*], Kyeong Jin Kim [b,1], Daechul Park [c]

[a] Division Electronics and Information Engineering, Chonbuk National University, Jeonju 561-756, South Korea
[b] Mitsubishi Electric Research Laboratories (MERL), 201 Broadway, Cambridge, MA 02139, USA
[c] Department of Information and Communication Engineering, Hannam University, Daejeon 306-791, South Korea

ARTICLE INFO

Article history:
Received 23 April 2013
Received in revised form
12 November 2013
Accepted 12 November 2013
Available online 4 December 2013

Keywords:
Diagonal block (element)-wise inverse Jacket matrix (BIJM)
Sparse matrix decomposition
Successive lower order diagonal sparse matrix
Hadamard matrix

ABSTRACT

In this paper, based on the block (element)-wise inverse Jacket matrix, a unified fast hybrid diagonal block-wise transform (FHDBT) algorithm is proposed. A new fast diagonal block matrix decomposition is made by the matrix product of successively lower order diagonal Jacket matrix and Hadamard matrix. Using a common lower order matrix in the form of $\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$, a fast recursive structure can be developed in the FHDBT, which is able to convert a newly developed discrete cosine transform (DCT)-II, discrete sine transform (DST)-II, discrete Fourier transform (DFT), and Haar-based wavelet transform (HWT). Since these DCT-II, DST-II, DFT, and HWT are widely used in different areas of applications, the proposed FHDBT can be applied to the heterogeneous system requiring several transforms simultaneously. Comparing with pre-existing DCT-II, DST-II, DFT, and HWT, it is shown that the proposed FHDBT exhibits less the complexity as its matrix size gets larger. The proposed algorithm is also well matched to circulant channel matrix. From the numerical experiments, it is shown that a better performance can be achieved by the use of DCT/DST-II compression scheme compared with the DCT-II only compression method.

1. Introduction

The last decade based on orthogonal transform has been seen a quiet revolution in digital video technology such as Moving Picture Experts Group (MPEG)-4, H.264, and high efficiency video coding (HEVC) [1–7]. Digital video is everywhere such as DVD, gaming players, computers and mobile handsets. Nowadays, many of the coexisting heterogeneous systems [7,8] are likely to catch the latest news on the web as on the smart TV and iPhone. Video compression is essential to all these applications. The discrete cosine transform (DCT)-II is popular compression structures for MPEG-4, H.264, and HEVC, and is accepted as the best suboptimal transformation since its performance is very close to that of the statistically optimal Karhunen–Loeve transform (KLT) [1–5]. For practical consideration, the underlying H.264-advanced video coding (AVC) intra mode dictates the transform coding implementation within a block coder with a typical block of size up to 16 × 16. However, since a DCT-based block coder suffers from blocking effect, i.e., a disturbing discontinuity at the block boundaries,

☆ This work was supported by the MEST 2012-002521, NRF, Korea.
* Corresponding author: Tel.: +82 632702463; fax: +82 632704166.
E-mail addresses: moonho@jbnu.ac.kr (M. H. Lee), hashem05ali@jbnu.ac.kr (M. H. A. Khan), kyeong.j.kim@hotmail.com (K. J. Kim), fia4joy@yahoo.co.kr (D. Park).
[1] This work was done when he was with Inha University, Incheon, Korea.

0923-5965/$ - see front matter
http://dx.doi.org/10.1016/j.image.2013.11.002

Table 1
The comparison of computation complexity of conventional independent the DCT-II, DST-II, DFT, Haar transform and hybrid DCT-II/DST-II/DFT/HWT.

References number	Conventional		Proposed	
	Addition	Multiplication	Addition	Multiplication
W. H. Chen at el [18]				
DCT-II	$3N/2(\log_2 N-1)+2$	$N\log_2 N-(3N/2)+4$	$N\log_2 N$	$\frac{N}{2}(\log_2 N+1)$
Z. Wang [13]				
DST-II	$N(\frac{7}{4}\log_2(N)-2)+3$	$N(\frac{3}{4}\log_2(N)-1)+3$	$N\log_2 N$	$\frac{N}{2}(\log_2 N+1)$
Cooley & Tukey [21]				
DFT	$N\log_2 N$	$(N/2)\log_2 N$	$N\log_2 N$	$(N/2)\log_2 N$
Andrews &Caspari [22]				
HWT	$2(N-1)$	N	$\sum_{i=1}^{h-1}\frac{N}{2^i},\ h=\log_2 N$	$\sum_{i=1}^{h-2}\frac{N}{2^i},\ h=\log_2 N$*

* Addition count $= N/2^{n-1}+N/2^{n-2}+\ldots+N/2=\sum_{i=1}^{n-1}N/2^i$
Multiplication count $= N/2^{n-2}+N/2^{n-2}+\ldots+N/2=\sum_{i=1}^{n-2}N/2^i$.

Table 2
Computational complexity: DCT-II/DST-II/DFT/HWT.

Matrix size	**Conventional**				**Proposed**			
	DCT-II	DST-II	DFT	HWT	DCT-II	DST-II	DFT	HWT
Addition								
$N=4$	8	9	8	6	8	8	8	2
$N=8$	26	29	4	14	24	24	24	6
$N=16$	74	83	64	30	64	64	64	14
$N=32$	194	219	160	62	160	160	160	30
$N=64$	482	547	384	126	384	384	384	62
$N=128$	1154	1315	896	254	896	896	896	126
$N=256$	2690	3075	2048	510	2048	2048	2048	254
Multiplication								
$N=4$	6	5	4		6	6		×
$N=8$	16	3	12	8	16	16	12	4
$N=16$	44	35	32	16	40	40	32	12
$N=32$	116	91	80	32	96	96	80	28
$N=64$	292	227	192	64	224	224	192	60
$N=128$	708	547	448	128	512	512	448	124
$N=256$	1668	1283	1024	256	1152	1152	1024	252

much research efforts have been leveraged to reduce the blocking effect. In [4,7], a first-order Gauss–Markov model was assumed for the images, and then it was shown that the image can be decomposed into a boundary response and a residual process given the closed bound boundary information. The boundary response is an interpolation of the block content from its boundary data, whereas the residual process is the interpolation error. An approach in [4] showed that the KLT of the residual process became discrete sine transform (DST) and DCT when the boundary conditions are available in vertical and horizontal directions [4,6,7].

The discrete signal processing based on the discrete Fourier transform (DFT) is popular in orthogonal frequency division multiplexing (OFDM) wireless mobile communication systems [3] such as 3rd generation partnership project long-term evolution (3GPP-LTE), mobile worldwide interoperability for microwave access (WiMAX), international mobile telecommunications-advanced (IMT-Advanced) as well as wireless local area network (WLAN). In addition, wireless personal area network (WPAN), and broadcasting related applications (digital audio broadcasting (DAB), digital video broadcasting (DVB), digital multimedia broadcasting (DMB)) are based on DFT. Furthermore, the Haar-based wavelet transform (HWT) is also very useful in the joint photographic experts group committee in 2000 (JPEG-2000) standard [2,9]. Thus, different applications require different types of unitary matrices and their decompositions. From this reason, in this paper we will propose a unified hybrid algorithm which can be used in the mentioned several applications in different purposes.

Compared with the conventional individual matrix decompositions, our main contributions are summarized as follows:

- We propose the diagonal sparse matrix factorization for a unified hybrid algorithm based on the properties of the Jacket matrix [10,11] and the decomposition of the sparse matrix. It has been shown that this matrix decomposition is useful in developing the fast algorithms and characters [20]. Individual DCT-II [1–3,6,7,12], DST-II [4,6,7,13], DFT [3,5,14], and HWT [9]