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Hybrid WPT-BDCT transform for high-quality image compression

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Abstract: The image compression performance of transform coders highly depends on the energy compaction (EC) capability of transforms. The popular transforms such as discrete cosine transform (DCT) and discrete wavelet transform (DWT) provide decent EC; however, their capability is not enough to deliver good quality image reconstruction for higher compression levels (CLs). In this study, the authors propose a new hybrid transform which is a fusion of wavelet packet transform (WPT) and block-DCT (BDCT) transform to achieve high-quality image compression. This new hybrid WPT-BDCT transform is able to attain higher EC than the existing transforms. Further, the authors have found a new energy compaction index (ECI) to evaluate the energy compactness of the image transforms. The proposed hybrid transform has been extensively evaluated, based on proposed ECI parameter, the visual quality assessment of reconstructed images and with the standard image quality indexes peak-signal-to-noise ratio and structural similarity index measure. It is reported that the proposed hybrid transform provides higher EC and outperforms the transforms namely DCT, DWT, WPT, multi-wavelet transform and existing hybrid transforms for all the CLs.

1 Introduction

Image compression is a process of removing redundant information to utilise minimum information for its representation [1]. Among the established image compression standards, the transform coding is the most significant and popular compression technique. This technique strongly relies on the reduction of correlation between neighbouring pixels of an image by the image transformation [2, 3]. Hence, the overall performance of transform coders notably depends on the pixel-level decorrelation (PLD) or equivalently energy compaction (EC) capability of the image transforms [4].

In past few decades, several image transforms have been utilised with the transform coders to avail PLD or EC facility, including, e.g. discrete Fourier transform [5], Karhonen–Loeve transform [6], discrete cosine transform (DCT) [7, 8] and discrete wavelet transform (DWT) [9–11]. Particularly, the popular standards like JPEG [12–16], MPEG-2, H.263, H.264, and H.265 have utilised the DCT transform due to its nice EC property [17–20]. Similarly, the DWT transform is utilised by the JPEG2000 standard [21] and other compression techniques such as SPIHT [22] and EZW [23]. Next, an extension of the DWT transform, known as multi-wavelet transform (MWT) was first studied by Goodman *et al.* [24], which can offer better compression performance than the wavelets [25–27]. Further, Coifman *et al.* [28], introduced a new technique for image coding based on wavelet packet transform (WPT), which has a better ability to represent high-frequency information than the wavelets, hence provides a better alternative of DWT transform. All these image transforms reflects a long journey of this field to achieve better EC capability than the existing transforms.

On the other side, the emergence of advanced imaging standards such as HD and UHD, are now forcing the compression demands towards very high compression levels (CLs) at which the existing transforms shows poor performance, resulting a strong need to improve their EC or PLD capability. The possible solution is to combine different individual transforms and exploit their hybrid structure to achieve higher EC capability. These combined transforms are widely known as hybrid transforms and usually, differ in the way, the two individual transforms are combined or fused together. The term 'individual' used here signifies a single transform.

In past few years, mostly DCT and DWT transforms have been combined to achieve better compression compared with the individual transforms. In 2007, Elharar *et al.* [29], presented the first hybrid DWT-DCT transform for the compression of integral images. This hybrid transform offers 2–3 dB peak-signal-to-noise ratio (PSNR) gain as compared with the existing JPEG standard. The next hybrid DWT-DCT combination was proposed by Shrestha and Wahid in 2010, for the biomedical image and video applications [30]. In this technique, the higher frequency wavelet coefficients are completely neglected during compression to achieve higher compression ratio (CR), resulting significant distortion in the edges of the reconstructed images. Hence, this hybrid transform offers higher CR but at the cost of a reduction in the visual quality. To address this issue, recently, Sharmin *et al.* [31] proposed a new hybrid singular value decomposition (SVD)-DWT-DCT transform. This hybrid transform is a fusion of three individual transforms SVD, DCT and DWT. In this technique, the high-frequency wavelet coefficients are again completely removed from the compressed bit stream and hence higher CR has been achieved; however, due to the initial low-rank approximation through SVD, this technique preserves the visual quality at higher CR levels.

Although, the existing hybrid transforms offer improved image compression than the individual transforms but they have also shown following criticism related to their working and implementation:

i. The existing hybrid transforms are generally more time-consuming than the individual transforms.
ii. Mostly, the performances of the existing hybrid transforms are highly non-uniform in nature over various CLs.

To efficiently address these issues, this paper first proposes a novel low complexity hybrid WPT-block-DCT (BDCT) transform, which is a new hybrid combination of the WPT and BDCT. Next, a new energy compaction index (ECI) is also proposed to properly establish objective measurement criteria for the EC capability of the image transforms. Further, the EC capabilities of the image