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Foveation image coding with fuzzy-based joint parameter selection

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This paper presents a novel method of the foveation image coding based on the fuzzy-based joint parameter selection. Our objective is to maximize foveated wavelet image quality index (FWQI) of the reconstructed image. With the foveated visual sensitivity model, image regions are first prioritized. The image regions close to foveation points have higher priorities than those far away from the foveation points. The discrete wavelet transform (DWT) is utilized to transform the considering image to the wavelet domain. The wavelet coefficients from different image regions are weighted using the foveated visual sensitivity model and then scaled down before entropy encoding. To achieve the objective, we use a fuzzy logic system and an iterative search to select image coding parameters under the bit budget constraint. The coding parameters consist of a number of weighted wavelet coefficients in the list significant pixel (LSP) of the SPIHT codec [A. Said, W.A. Pearlman, A new, fast, and efficient image codec based on set partitioning in hierarchical trees, IEEE Trans. Circuits Syst. Video Technol. 6 (3) (1996) 243–250], represented as N_{LSP}, and a scaling down factor (*QP*). There are two inputs and one output in the proposed fuzzy logic system. The inputs are N_{LSP} and targeted bit per pixel used to encode an image. The output is an interval of *QP*. The *QP* value corresponding to the input N_{LSP} giving the highest FWQI is selected from the derived interval. We iteratively search for the values of N_{LSP} and *QP* providing the highest FWQI. Then, the SPIHT codec is used to generate a scalable bitstream of the discrete wavelet coefficients with the optimal pair of N_{LSP} and *QP*. The sub-optimal search algorithm to compute both N_{LSP} and *QP* with low complexity is also proposed. Our simulation results show that the proposed scheme provides a better reconstructed image quality comparing to previous work in both objective and subjective qualities.

1. Introduction

The human visual system (HVS) plays an important role in coding image and video contents [15,23]. Human eyes are generally sensitive to different bands of frequencies and spatial resolutions of images. Several different image/video compression standards exploit the HVS properties to achieve a better compression ratio and visual quality. To give an example, H.264 high profile [23] applies quantization matrices to different discrete cosine transform (DCT) coefficients obtained from transformed blocks of pixels. Fine quantizers are applied to DCT coefficients corresponding to low frequencies, while coarse quantizers are applied to DCT coefficients corresponding to high frequencies. They customize quantization matrices with the aim to please human eyes as much as possible.

The foveation image/video processing is one of the most important techniques in exploiting the HVS system to achieve efficient image/video coding [2,6,7,9–11,16,22,26–28,30]. The foveation image/video processing is based on the fact that the spatial resolution of the HVS is highest around the foveation points and decreases rapidly with increasing eccentricity. Therefore, it is reasonable to allocate more bits to the image regions, where the human eyes are most sensitive, whereas allocates less bits to the image regions, where the human eyes are less sensitive. To determine the image regions, where human eyes are sensitive, in [2,6,11,30], they practically approximated the foveation effect of images by averaging local pixel groups and mapping them into super-pixels related to the retina sampling density. Tsumura et al. [26] proposed a multi-stage super-pixel method in creating the foveation effect in the image. Kuyel et al. [10] simulated the foveation effect by resampling uniform grid images with a variable resolution reflecting the human retina. Geisler and Perry [7] used a pyramid structure for simulating and coding images and videos. In [16], Lee and Bovik used a non-uniform filtering scheme to create the foveation effect in video contents in order to increase the compressibility of a video stream. Chang and Yap [5] proposed a wavelet-based foveation method, in which a non-uniform weighting model is applied to the original image. Their proposed system also was applied to the progressive transmission scheme. Ho et al. [9] used the foveation concept in rate shaping for MPEG video coding. The foveation concept was applied to DCT coefficients. Lee and Lee [17] proposed the concept of visual entropy for image coding, which can be computed by the visual weight over the wavelet domain. Boccignone et al. [4] used the foveation concept in shot detection for video seg-

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mentation. Arnow and Bovik [1] applied the foveation concept to the corner search problems. In [27,28], Wang et al. proposed the embedded foveation image coding (EFIC) algorithm, which orders the encoded bitstream to optimize foveated visual quality at arbitrary bit rate. In the EFIC algorithm, the discrete wavelet coefficients obtained from transforming the original image are weighted and are directly encoded with the modified SPIHT codec [25], in which the scanned order of wavelet coefficients are rearranged.

When we deal with the wavelet-based foveation image compression, some wavelet coefficients can be discarded to achieve a higher compression ratio. The more a number of wavelet coefficients to be encoded and the finer representation of wavelet coefficients, the better image quality. However, they result in a higher bit rate of the compressed bitstream. The trade-off between a number of wavelet coefficients and the coarseness level representation of wavelet coefficients should be considered jointly during encoding to achieve the best image quality under the bit rate constraint. Unfortunately, even though previous works utilize the foveation concept in coding images, the trade-off between two parameters mentioned above has not been addressed yet. To address this problem, we present a novel method of the embedded foveation image coding with a fuzzy system. The proposed system tries to search for the optimal trade-off between a number of wavelet coefficients and scaling down factor (QP), which will be used to encode images. Note that QP is used to reduce a dynamic range of wavelet coefficients reflecting the coarseness level representation of wavelet coefficients. The objective is to achieve the best image quality in terms of foveated wavelet image quality index (FWQI) [28].

Fig. 1 shows a block diagram of the proposed architecture. With the foveated visual sensitivity model, image regions of an input image are first prioritized. The image regions close to the foveation points have higher priorities than those, which are far away from the foveation points. The discrete wavelet transform (DWT) is utilized to transform the considering image to the wavelet domain. The wavelet coefficients corresponding to different image regions are weighted differently based on the distance from the foveation points by the foveated visual sensitivity model and a scaling down factor. To achieve the best image quality in terms of FWQI, we use a fuzzy logic system and an iterative search to select image coding parameters, which are a number of wavelet coefficients in the list of significant pixel of the SPIHT codec (N_{LSP}) and QP. There are two inputs and one output in the proposed fuzzy logic system. The inputs are N_{LSP} and targeted bit per pixel used to encode an image. The output is an interval of QP. The QP value corresponding to the input N_{LSP} giving the highest FWQI is selected from the derived interval. We iteratively search for the values of N_{LSP} and QP globally providing the highest FWQI. Then, the SPIHT codec is used to generate a scalable bitstream of the discrete wavelet coefficients with the optimal pair of N_{LSP} and QP.

The rest of this paper is organized as follows. Section 2 reviews a concept of the foveation-based HVS model and describes the prioritization method of wavelet coefficients in different regions. Section 3 describes the entropy coding of wavelet coefficients with the modified SPIHT codec. In Section 4, the problem formulation and the solution of jointly selecting N_{LSP} and QP to achieve the best FWQI are presented. The sub-optimal computation of N_{LSP} and QP are also presented in Section 4 to reduce complexity of the iterative search. Simulation results are shown in Section 5. The conclusion remarks are in Section 6.

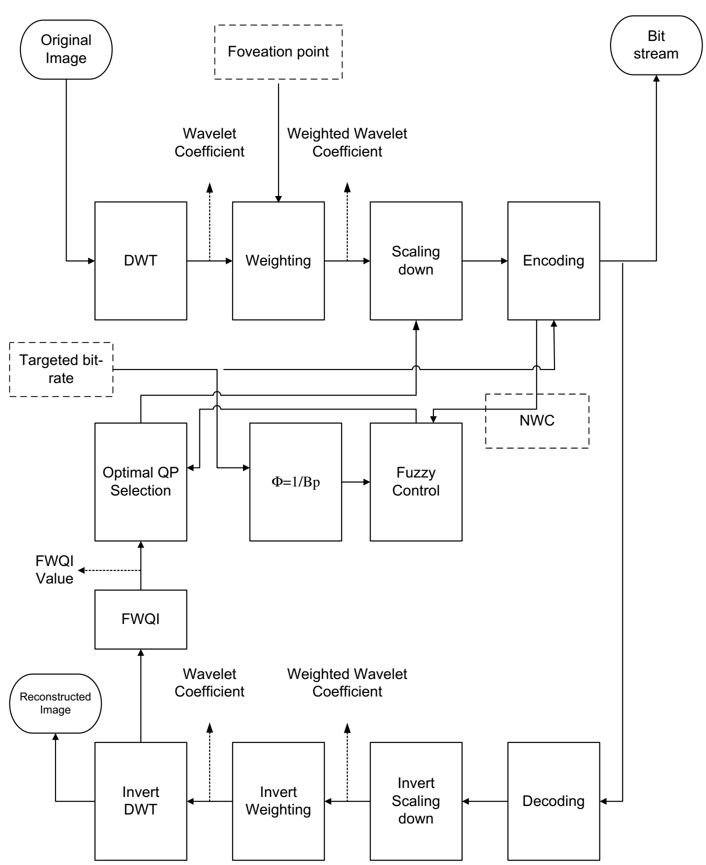

Fig. 1. General framework of the proposed foveation wavelet image coding with a fuzzy logic system.