A novel method for progressive image transmission using blocked wavelets

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Abstract

The techniques of progressive image transmission (PIT) divide image delivery into several phases. PIT's main objective is to efficiently and effectively provide an approximate reconstruction of the original image in each phase. Therefore, this study proposes the Blocked Wavelet Progressive Image Transmission method (BWPIT) based on the wavelet transformation and the spatial similarity of pixels, to reduce the bit-rate and increase the image quality in an early phase of progressive image transmission. Experimental results show that the transmission bit-rate and the image quality of BWPIT are significantly better than those of BPM, IBPM, and WbPIT in each early phase.

Keywords: Progressive image transmission, discrete wavelet transformation, Haar

1 Introduction

Transmission of high resolution images or videos over a low speed channel, such as a telephone line, usually meets the problem of the long delivery time. Therefore, users have a high demand for recognizing the picture content or even aborting the transferring process at an early stage [6].

The technique of Progressive Image Transmission (PIT), which partitions an image into several parts to transmit phase by phase, provides an approximate result of the original image in an early transmission phase, and transmits the details progressively by the following phases. In each phase of PIT, the receiver obtains an approximate result of the original image, rather than a part of it. To reduce the transmission load, a well-designed PIT method should have a low transmission bit-rate and a high image quality in an early phase. Several research results have been presented [2, 3, 4, 6].

The Discrete Wavelet Transformation (DWT) techniques can transform the signal energy trend to cluster in the low-frequency region. A few transformed significant coefficients in the low-frequency region can efficiently reconstruct an approximate result for the original image. Therefore, the DWT techniques have been widely applied to the domains of the image compression and PIT, such as [2-4].

The pixels in an image usually resemble their neighbors. Segmenting an image into several blocks has a high possibility to result in similar pixels in blocks. Therefore, to integrate the advantages of the wavelet transformation and the spatial similarity of pixels, this study proposes the Blocked Wavelet Progressive Image Transmission method (BWPIT) by applying the Haar wavelet transformation in each small block. BWPIT more significantly improves the reconstructed image quality in each early phase than do BPM, IBPM, and WbPIT. For simplicity but without loss of generality, this study focuses on the early phases of PIT and discards related compression techniques in each phase.

2 Related work

Bit-Plane Method (BPM) is the simplest and best-known method for PIT in a spatial domain [6]. BPM uniformly partitions all pixels into several bit planes for each image. The bit plane is sorted from the most significant bit to the least significant bit. Therefore, BPM can implement PIT by sending a bit plane in each phase in order. The receiver obtains the value "0" or "1" for each pixel to recover the other bits of the corresponding pixel by using the mean value in each phase. The inaccurate prediction of BPM results in poorly reconstructed images in the first several phases.

To improve the image quality in each phase, the Improved Bit-Plane Method (IBPM) applies a tree-structured codebook to predict the original value of each pixel [1]. In each phase, IBPM sends a bit plane and several codewords of the tree-structured codebook. Although IBPM improves the reconstructed image quality in each phase, the increasing bit-rate of IBPM results in a longer transmission time than that of BPM in each phase.

Chang and Lu applied the simple and efficient Haar discrete wavelet transformation (Haar DWT) for PIT, which is also called the Wavelet-based Progressive Image Transmission method (WbPIT) [2]. Haar DWT calculates the DWT coefficients by addition and subtraction operations. Two steps of one-dimensional Haar operations compose the one-scale Haar DWT of two dimensions. In each transmission phase, besides transmitting the coefficients of the current sub-band, WbPIT transmits the half coefficients and the average value of the next sub-band to refine the reconstructed image. In an early phase of PIT, WbPIT can efficiently reconstruct a coarse image. However, the overhead of transmission rapidly increases in next phase.

3 The blocked wavelet progressive image transmission (BWPIT) method

The Haar DWT can be applied for PIT well. Moreover, from the viewpoint of the spatial domain of an image, the pixels in a smooth region of the image are slightly different to each other. Therefore, this study proposes the Blocked Wavelet Progressive Image Transmission (BWPIT) method, which utilizes the advantages of Haar DWT and the spatial similarity, to reduce the bit-rate and improve the quality of the reconstructed image in each phase for PIT.

The standard deviation, σ , is a famous measure of the statistical dispersion. The normal distribution has 95.44% of the data points distributed within two standard deviation units of the mean [5]. A low standard deviation unit means that the data are similar to each other. Therefore, this study employs the standard deviation value of each block (sub image) to distinguish the degree of smoothness of each block. BWPIT partitions an image with size $m \times n$ into $(m/w) \times (n/h)$ non-overlap blocks with size $w \times h$. Then, BWPIT calculates the standard deviation of each block and assigns its degree. BWPIT distinguishes the degree of smoothness of each block, according to the three pre-defined threshold values, T_1, T_2, and T_3. The degree value of each block is assigned as follows:

$$Degree = \begin{cases} 1 & if \quad \sigma \le T_1 \\ 2 & elseif \quad T_1 < \sigma \le T_2 \\ 3 & elseif \quad T_2 < \sigma \le T_3 \\ 4 & otherwise \end{cases}, \text{ where } 0 < T_1 < T_2 < T_3.$$

The reconstructed block with a low degree value only requires a few coefficients to effectively approximate the original block. A high degree block requires more coefficients to approximately reconstruct the block. Therefore, BWPIT terminates to transmit the coefficients in an early phase for blocks with a low degree value.

Moreover, BWPIT applies the two-scale Haar DWT to each block. In a low-frequency sub-band, the coefficients usually become very large. Therefore, to reduce the transmission cost in each phase, BWPIT quantizes each coefficient into the same number of bits as the original pixel. In the first transmission phase, BWPIT transmits the mean value of each block. Fig. 1 shows the following transmission order of each block. In the second transmission phase, BWPIT transmits the coefficients of LL_2 but skips the first coefficient to deliver, since the first coefficient can be obtained by the simple computation of the mean value with the other LL_2 coefficients. The degree value of each block is also transmitted in the second phase. According to the degree value, each distinct block terminates transmission in different phase. The termination phase ($Tphase$) is as follows:

$$Tphase = \begin{cases} 1 & if \quad Degree = 1 \\ 2 & if \quad Degree = 2 \\ 5 & if \quad Degree = 3 \end{cases}$$

If $Degree$ = 4, the block is terminated to transmit in the phase, which users accept the reconstructed quality of the image or the whole information of the original image is delivered.

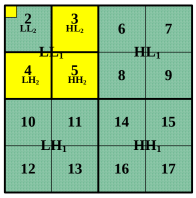


Fig. 1. The transmission order of a block

The BWPIT algorithm includes the three parts: encoding, transmission, and decoding. The users can interrupt the process in each transmission phase to reduce the transmission load. The followings describe the three parts of BWPIT.

Algorithm BWPIT_Encoding

Step 1. Decompose the image into several non-overlap blocks with size $w \times h$

Step 2. Calculate the mean and the standard deviation values of each block

Step 3. Assign the degree value to each block according to its standard deviation value

Step 4. Transform each block using the two-scale Haar DWT and quantize the coefficients with the identical number of bits.

Algorithm BWPIT_Transmission

Step 1. (Phase 1) Transmit the mean value of each block

Step 2. (Phase 2) For each block, if Degree:=1 then transmit the degree value; else transmit the degree value with the coefficients of LL_2 and skip the first coefficient

Step 3. (Phase 3-5) For each block, if Degree ≤ 2 then skip the block; else transmit the coefficients of HL_2, LH_2, and HH_2

Step 4. (Phase>6) For each block, if Degree ≤ 3 then skip the block; else transmit the coefficients of HL_1, LH_1, and HH_1

Algorithm BWPIT_Decoding

Step 1. (Phase 1) For each block, use the mean value as the value of each pixel

Step 2. (Phase 2) For each block, if Degree:=1 then skip the block; else rebuild the coefficients of LL_2, the other coefficients are set to "0", and perform the inversed DWT to reconstruct the block

Step 3. (Phase 3-5) For each block, if Degree ≤ 2 then skip the block; else set the non-received coefficients to "0" and perform the inversed DWT to reconstruct the block

Step 4. (Phase>6) For each block, if Degree ≤ 3 then skip the block; else set the non-received coefficients to "0" and perform the inversed DWT to reconstruct the block

4 Experimental results

This experiment compared the performances of BPM, IBPM, WbPIT, and BWPIT. The three 256 gray levels images, Lena, Baboon, and Toys, with size 512 × 512 were used in the simulation. For BWPIT, this experiment applied Haar DWT on the blocks with size 8 × 8, and the three standard deviations were set to 0.5, 1, and 2. The quality of the reconstructed image is evaluated by the peak signal-to-noise ratio (PSNR) value. A higher PSNR value means better image quality. This experiment applied the famous transmission rate, the bits per pixel or bit-rate (bpp), to estimate the transmission load in each phase.

Table 1 lists the PSNR and the accumulated bit-rate values that BWPIT performed on the three images in the first eight phases. In the first phase, BWPIT performed on the three images obtained the identical bit-rate. The "Baboon" image, which has less spatial similarity, required a higher bit-rate than other images in each phase. In the first phase, the PSNR value of each reconstructed image exceeded 20 dB. Therefore, the reconstructed images of BWPIT had accepted high image qualities for users in an early phase.

Fig. 2 illustrates the PSNR value over different bit-rates performed using the four algorithms, BWPIT, WbPIT, IBMP, and BPM, on the "Lena" image. In an early phase (the bit-rate value less than 3.5), BWPIT overcame the other three algorithms. BWPIT had higher PSNR values than did WbPIT at the same transmitted bit-rate.

Table 1. The PSNR and the accumulated bit-rate values in each phase of BWPIT

Image / Phase	Lena		Baboon		Toys	
	PSNR	bpp	PSNR	bpp	PSNR	bpp
1	23.97	0.13	20.77	0.13	21.77	0.13
2	27.46	0.53	22.10	0.53	24.90	0.53
3	29.93	1.03	22.76	1.03	25.87	1.03
4	31.68	1.52	24.25	1.53	28.42	1.53
5	32.53	2.02	24.95	2.03	28.70	2.03
6	33.22	2.41	25.19	2.53	29.00	2.36
7	33.99	2.80	25.44	3.03	29.39	2.69
8	34.95	3.19	25.71	3.53	29.74	3.02

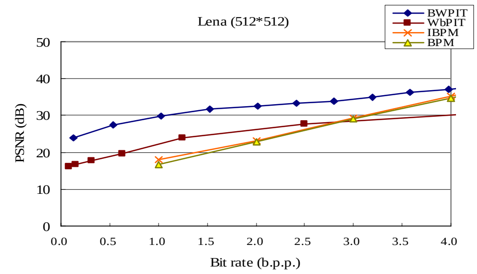
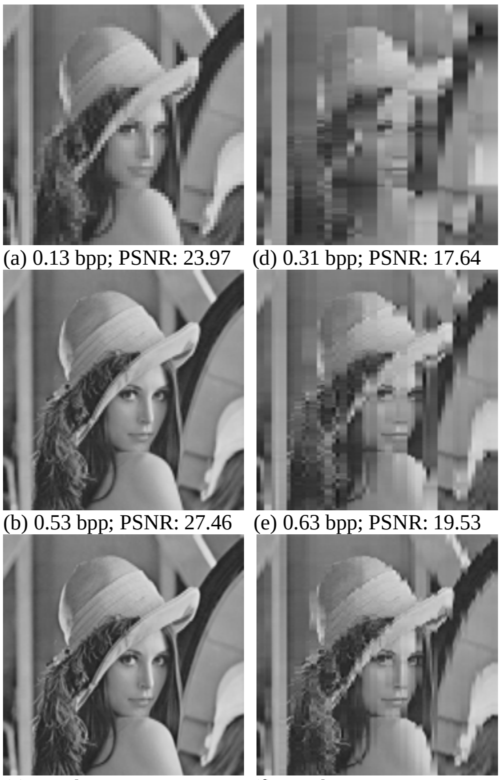


Fig. 2. The comparison of image quality over with bit-rates

Fig. 3 lists the reconstructed "Lena" images of first three phases using BWPIT and the corresponding reconstructed images using WbPIT. BWPIT required a lower bit-rate and obtained a higher PSNR value than did WbPIT. For example, in Fig. 3a, BWPIT only required 0.13 bpp to obtain the image quality with 23.97 dB. In Fig. 3d WbPIT used 0.31 bpp to get the image quality 17.74 dB. To achieve a high PSNR value (above 27 dB) for the reconstructed image, BWPIT only required 0.53 bpp, but WbPIT requires 2.50 bpp, as shown in Fig. 3b and Fig. 3e, respectively. In the three comparison phases, BWPIT had a lower transmission load and higher image qualities than that of WbPIT.

5 Conclusions

This study proposes the Blocked Wavelet Progressive Image Transmission method (WBPIT), which considers the pixel's similarity in blocks, to improve reconstructed image quality in each phase. The experimental results show that BWPIT gives significantly better reconstructed image quality in the first several phases than do BPM, IBPM, and WbPIT. BWPIT has better performance than BPM, IBPM, and WbPIT in terms of the transmission rate and the reconstructed image quality in each early phase. In the future, the authors plan to combine some efficient compress techniques with BWPIT to further reduce the data transfer rate significantly and have the same, or almost the same, quality of reconstructed image in each phase.



(a) 0.13 bpp; PSNR: 23.97 (d) 0.31 bpp; PSNR: 17.64

(b) 0.53 bpp; PSNR: 27.46 (e) 0.63 bpp; PSNR: 19.53

(c) 1.03 bpp; PSNR: 29.93 (f) 1.25 bpp; PSNR: 23.90

Fig. 3. The first three phases of “Lena” using BWPIT (a)-(c) and the corresponding phases using WbPIT (d)-(f)

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