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Simplified Structure of Integer Lifting Wavelet Filter Banks for Lossless Image Compression

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Abstract

In this paper, a simplified structure of integer lifting wavelet filter banks for lossless image compression is proposed by shifting and merging the scaling factors of the row and the column wavelet transforms. It is implemented by reducing the numbers of scaling factors and considering the scaling lifting. The numbers of scaling factors of the 2-D wavelet transform can be reduced by shifting and merging operation, and then the computing speed can be improved. Furthermore, the scaling lifting of simplified structure can be used to reduce the computing errors and get more accurate results. Experiments show that the simplified integer lifting structure results in lesser computational steps than the standard integer lifting structure and therefore improves the speed of the image compression. Besides, using the new lossless image compression system based on simplified integer lifting wavelet, the lower bit-rates are obtained.

***Keywords**: integer lifting; lossless image compression; scaling factor; simplified structure; wavelet filter bank*

1. Introduction

Image is the most important carrier among the information intercommunication in people's life and the biggest media containing information. Generally, compression techniques can be classified into lossy and lossless compression techniques [1]. Chew *et al.*[2] provide a review for image compression algorithms and presented performance analysis between various techniques in terms of memory requirements, computational load, system complexity, coding speed, and compression quality. Kumar *et al.* [3] discussed a new approach that enhances compression performance compared with JPEG (Joint Photographic Experts Group) techniques and they used MSE and PSNR as the quality measures. Nasri *et al.* [4] introduced an efficient adaptive compression scheme that ensures a significant computational and energy reduction as well as communication with minimal degradation of the image quality. Ghorbel *et al.* [5] described robust use of DCT and Discrete Wavelet Transform (DWT) and their capabilities in WSN. Ghorbel *et al.* [6] extended their work on their previous research [5] and made compression performance analysis for DCT and DWT with additional important parameter which is energy consumption. Ma *et al.* [7] surveyed multimedia compression techniques and multimedia transmission techniques and provided analysis for energy efficiency when applied to resource constrained platform.

Over the past decades, discrete wavelet transform and perfect reconstruction filter banks have become the dominant technologies in numerous areas such as signal and image processing [8-9] and image denoising [10] and . Mallat developed a pyramidal wavelet transform using a numerical filter bank [11]. In recent years, the second-

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generation wavelets based on lifting scheme have achieved substantial recognition [12-14] especially since their integration in the JPEG2000 standard [15-16]. The lifting scheme is an efficient and powerful tool to compute the wavelet transform. It can improve the key properties of the first generation wavelet step by step. At the same time it has many advantages compared to the first generation wavelet such as in-place computation, integer-to-integer transforms and speed. Daubechies and Sweldens indicated how to factorize 1-D biorthogonal wavelet filter banks into lifting scheme [12]. The analysis part and synthesis part of the standard lifting structure are shown in Figure 1 and Figure 2 respectively.

This work aims to simplify the lifting structure by considering the scaling factors of the row and column wavelet transform. We plan to reduce the numbers of the scaling factors of the 2-D wavelet transform (row and column wavelet transforms) and therefore improve the computing speed. Furthermore, the method of scaling lifting is used to construct the simplified structure of integer lifting wavelet with scaling lifting. The scaling lifting of simplified structure can be used to reduce the computing errors and get more accurate results.

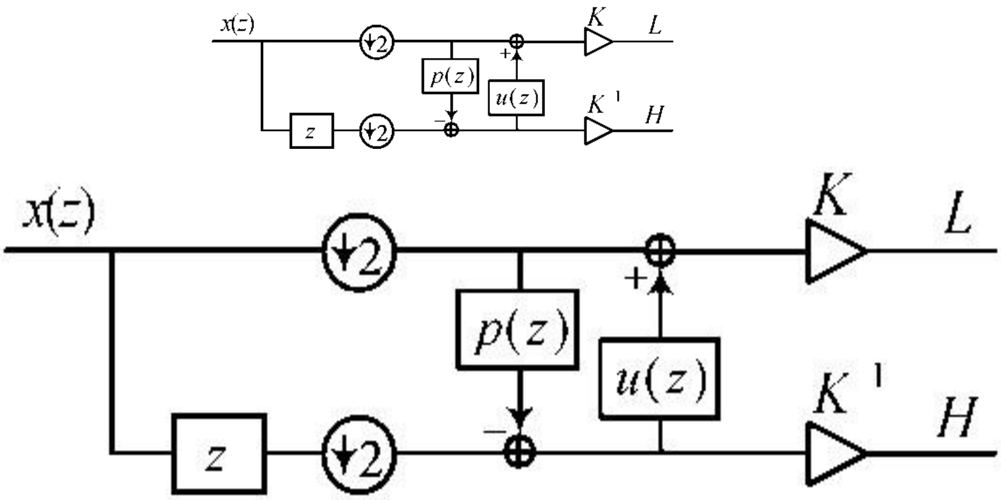

Figure 1. Analysis Part of Standard Lifting Structure

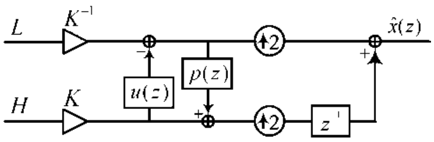

Figure 2. Synthesis Part of Standard Lifting Structure

The remainder of the paper is organized as follows. Section 2 gives a brief description of the background of integer-to-integer lifting wavelet transform. Section 3 introduces the simplified structure of integer lifting wavelet filter with scaling lifting. Section 4 and 5 give the experiments and conclusion respectively.

2. Integer-to-integer Lifting

The integer-to-integer lifting wavelet transforms are proposed in [10]. Integer-to-integer wavelet transforms have important application in lossless image compression. Their structures are shown as follows.

Figure 3 denotes the analysis part of integer lifting structure. In Figure 3, the “Round()” operations are given following the steps prediction and update respectively.

The integer value can be obtained after prediction operation and update operation. That is, if the scaling factors and are omitted, the coefficients of low-pass channel L and high-pass channel H are all integer value after wavelet transform. Therefore, the integer-to-integer lifting is achieved. Figure 4 shows the synthesis part of integer lifting structure. Using the structure in Figure 4, the original signal can be reconstructed without any information loss. Note that the scaling factors and can cause a problem of perfect reconstruction for integer-to-integer lifting, and then we will discuss the lifting of scaling factors in Section 3.2.

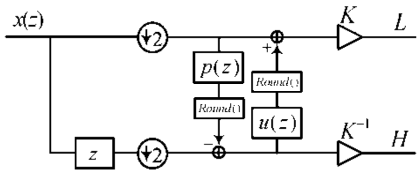

Figure 3. Analysis Part of Integer Lifting Structure

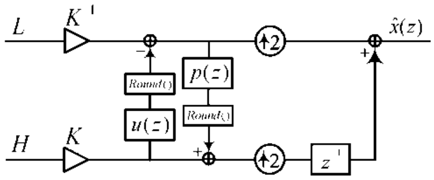

Figure 4. Synthesis Part of Integer Lifting Structure

3. Simplified Structure of Integer Lifting Wavelet with Scaling Lifting

In this section, the simplified structure of integer lifting wavelet is introduced firstly. The simplified structure is built by shifting and merging the scaling factors of the row and column wavelet transforms. Secondly, the scaling lifting for simplified structure is introduced and the perfect reconstruction is achieved. Finally, to build the lossless image compression system, the simplified structure of integer lifting wavelet with scaling lifting is proposed.

3.1. Simplified Structure of Integer Lifting Wavelet

The image compression system using integer lifting wavelet consists of analysis part and synthesis part. The analysis part is usually divided into two steps, row wavelet transform and column wavelet transform. The analysis part of standard integer lifting structure for image compression is shown in Figure 5. In Figure 5, the rows of image are decomposed using the integer lifting wavelet firstly, and the corresponding image decomposition coefficients can be obtained, L and H denote low-pass and high-pass wavelet coefficients respectively (Figure 6). Then the columns of blocks L and H (see Figure 5 and Figure 6) are decomposed using the integer lifting wavelet and the corresponding image decomposition blocks are shown in Figure 6. Comparing with the analysis part in Figure 5, the synthesis part can be obtained by flipping the signs and reversing the operations (see Figure 7).

In Figure 5 and Figure 7, the decomposition and reconstruction of image in each level are implemented by row and column operation using the same filter banks (prediction filter and update filter). In analysis part (see Figure 5), the constant scaling factors and are used three times, row decomposition once and column decomposition twice. We observe that the factors and in the front can be shifted to the end of the structure and merged with the scaling factor or in the end. This means that we can simplify the standard lifting structure by shifting and merging the scaling factors and . Therefore, the analysis part of simplified integer lifting structure is given in Figure 8. Similarly, the synthesis part of simplified integer lifting structure is shown in Figure 9, it can be obtained by flipping the signs and reversing the operations in Figure 8.

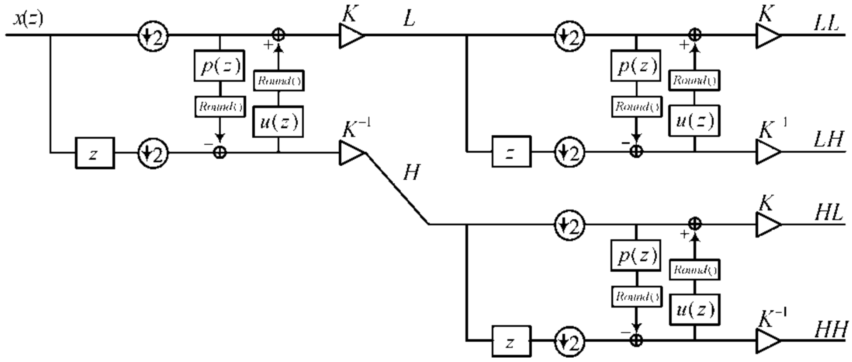

Figure 5. Analysis Part of Standard Integer Lifting Structure for Image Compression (Row and Column Lifting Wavelet Transforms)

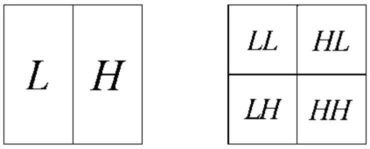

Figure 6. Wavelet Image Decomposition

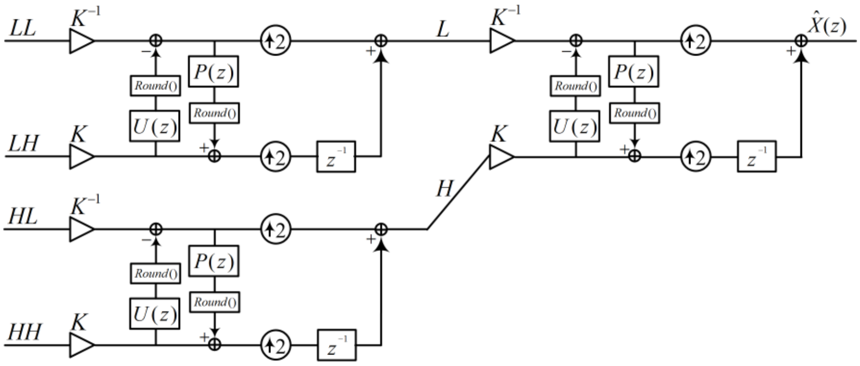

Figure 7. Synthesis Part of Standard Integer Lifting Structure for Image Compression (Row and Column Lifting Wavelet Transforms)

Comparing the analysis part of standard integer lifting structure (Figure 5) with the proposed analysis part of simplified integer lifting structure (Figure 8), we can calculate the number of multiply operation which be reduced. Letting M_1 and N_1 be the number of row and column of the image in current level respectively. Here, comparing Figure 8 with Figure 5, we find that the scaling factors in channels *L*, *H*, *LH* and *HL* in Figure 5 are eliminated in Figure 8; hence the multiply operation can be reduced about $M_1 \times N_1 / 2$ for channel *L* or *H*, $M_1 \times N_1 / 4$ for channel *LH* or *HL*. Therefore, the number of reduction of multiply operation in analysis part is $M_1 \times N_1 \times \frac{3}{2}$. The similar conclusion can be obtained in synthesis part (see Figure 9), hence the total number of reduction of multiply operation is $M_1 \times N_1 \times 3$.

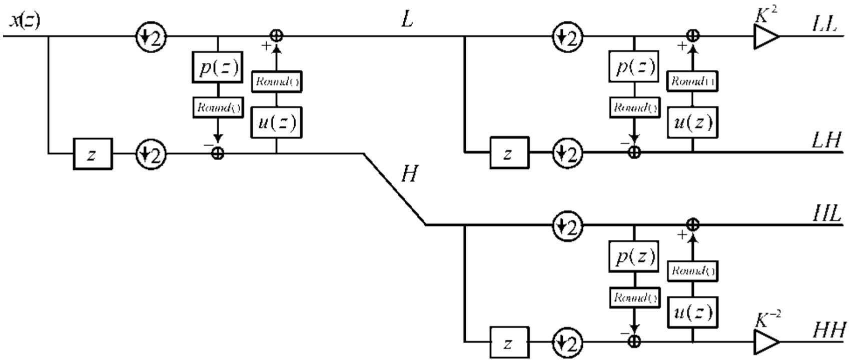

Figure 8. Analysis Part of Simplified Integer Lifting Structure for Image Compression

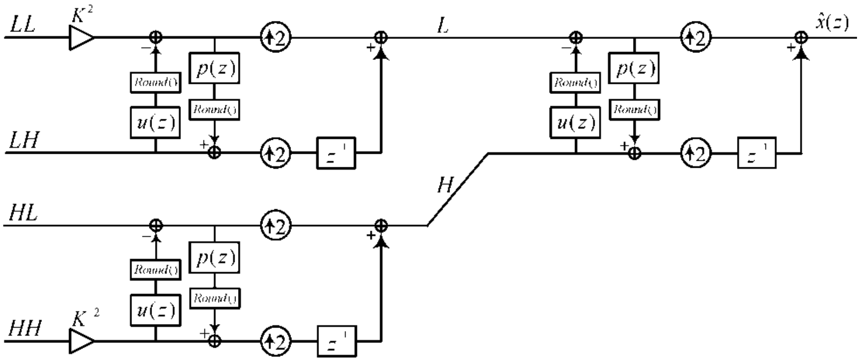

Figure 9. Synthesis Part of Simplified Integer Lifting Structure for Image Compression

Letting M and N denote the number of row and column of the original image, L stands for the decomposition level of the original image using lifting structure. Therefore, using the simplified integer lifting structure, the number of multiply operation can be reduced about $4\left(1-\frac{1}{4^L}\right)\times M\times N$ all over the whole image compression process, which including analysis part with L-level decomposition and synthesis part with L-level reconstruction.

Therefore, we conclude that the simplified structure of integer lifting wavelet can reduce the computing time and improve the computing speed.

3.2. Scaling Lifting for Simplified Structure

The simplified structure of integer lifting wavelet can be built by shifting and merging the scaling factors of row and column wavelet transform. But as mentioned above, the scaling factors (K and K^{-1} in Figure 5, or K^2 and K^{-2} in Figure 8) of integer lifting structure are difficult to be handled for integer-to-integer because they are not invertible. Fortunately, Daubechies and Sweldens introduced a method to factorize the scaling factor into four lifting steps [5]. Therefore it can be called scaling lifting. The scaling lifting is shown as follows.

$$S(z)=\begin{bmatrix}K & 0\\ 0 & 1/K\end{bmatrix}=\begin{bmatrix}1 & K-K^2\\ 0 & 1\end{bmatrix}\begin{bmatrix}1 & 0\\ -1/K & 1\end{bmatrix}\begin{bmatrix}1 & K-1\\ 0 & 1\end{bmatrix}\begin{bmatrix}1 & 0\\ 1 & 1\end{bmatrix}$$

Let $K=\sqrt{2}$,

$$S(z)=\begin{bmatrix}\sqrt{2} & 0\\ 0 & 1/\sqrt{2}\end{bmatrix}=\begin{bmatrix}1 & \sqrt{2}-2\\ 0 & 1\end{bmatrix}\begin{bmatrix}1 & 0\\ -1/\sqrt{2} & 1\end{bmatrix}\begin{bmatrix}1 & \sqrt{2}-1\\ 0 & 1\end{bmatrix}\begin{bmatrix}1 & 0\\ 1 & 1\end{bmatrix}$$

Therefore the scaling lifting, which combined with integer-to-integer, is given in Figure 10.

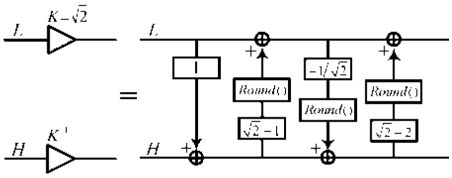

Figure 10. Scaling Lifting with $K=\sqrt{2}$

Considering analysis part of standard integer lifting structure in Figure 5 and scaling lifting with in Figure 10, then the analysis part of standard integer lifting structure with scaling lifting can be given in Figure 11.

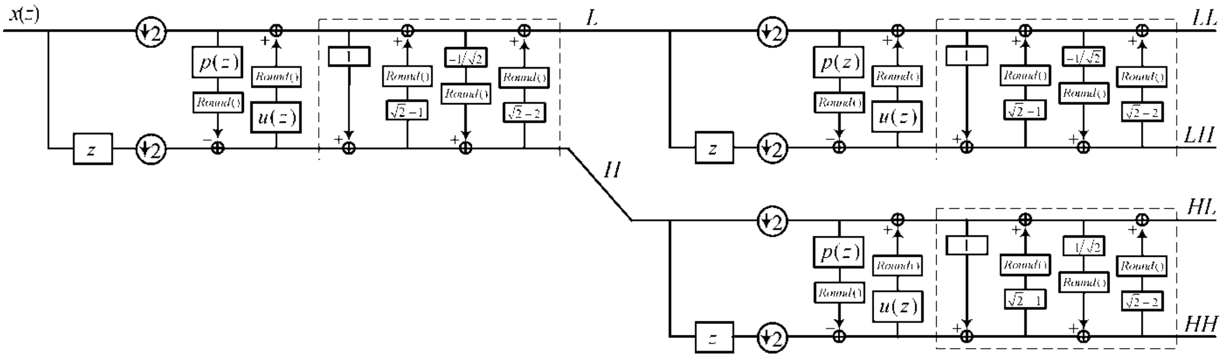

Figure 11. Analysis Part of Standard Integer Lifting Structure with Scaling Lifting

For most two-channel lifting wavelet transforms, the scaling factor usually equals to . If the simplified structure is used, we can apply the scaling lifting between channel LL and HH (see Figure 8). Therefore, we have the following equation.

$$K_{new}=K^2=2$$

$$P(z)=\begin{bmatrix}2 & 0\\ 0 & 0.5\end{bmatrix}=\begin{bmatrix}1 & -2\\ 0 & 1\end{bmatrix}\begin{bmatrix}1 & 0\\ -0.5 & 1\end{bmatrix}\begin{bmatrix}1 & 1\\ 0 & 1\end{bmatrix}\begin{bmatrix}1 & 0\\ 1 & 1\end{bmatrix}$$

Figure 12 shows the scaling lifting with $K_{new}=K^2=2$ for simplified structure. Firstly, in Figure 12, the scaling operations are based on integer values (multiplied by 1, 1, -0.5 and -2). However, in Figure 10, the scaling operations are based on infinite decimal values (multiplied by 1, $\sqrt{2}-1$, $-1/\sqrt{2}$, and $\sqrt{2}-2$), which means it must discard more decimal bits when using the "*Round*()" operation to get their integer part. Secondly, two "*Round*()" operations are eliminated in Figure 12, which means we can obtain the more accurate compute result without discard any information in these two steps (without "*Round*()" operations). Therefore, comparing Figure 12 with Figure 10, we conclude that the scaling lifting with $K_{new}=K^2=2$ can reduce the computing errors and get more accurate results.

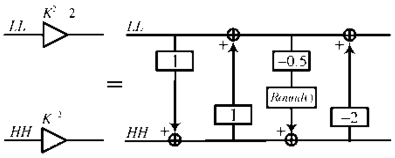

Figure 12. Scaling Lifting with for Simplified Structure

3.3. Simplified Structure of Integer Lifting Wavelet with Scaling Lifting

In this section, the simplified structure of integer lifting wavelet with scaling lifting will be built by combining the integer-to-integer lifting, simplified structure and scaling lifting. Figure 13 shows the analysis part of simplified integer lifting structure with scaling lifting, which is obtained by merging Figure 8 and Figure 12. The synthesis part can be obtained by slipping the signs and reversing the operations.

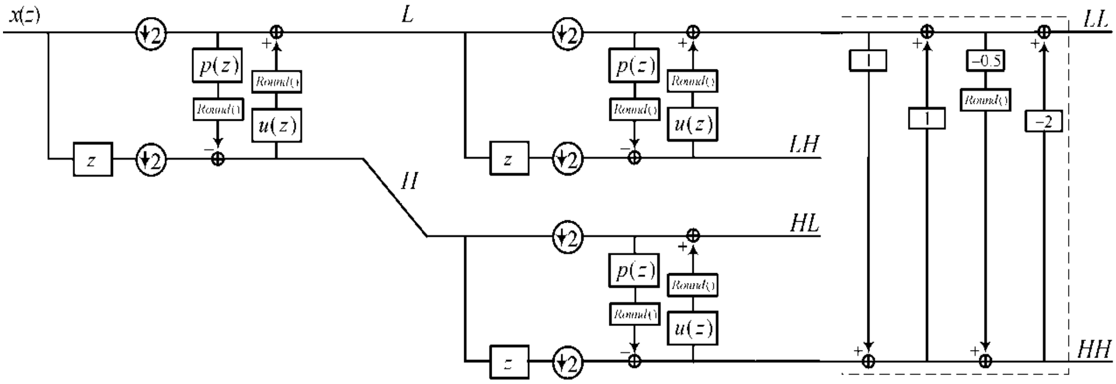

Figure 13. Analysis Part of Simplified Integer Lifting Structure with Scaling Lifting

Comparing Figure 13 with Figure 11, we find that two scaling lifting steps are reduced in Figure 13. It means that less computing errors and more accurate results to "real value" are obtained using the structure in Figure 13. Furthermore, the scaling lifting with in Figure 13 can reduce the computing errors than the scaling lifting with in Figure 11. Therefore, we conclude that the simplified integer lifting structure with scaling lifting can reduce the computing errors and get the more accurate value than standard integer lifting structure with scaling lifting. We will do some experiment comparison between simplified structure and standard structure of the 5/3 wavelet of JPEG2000 for lossless image compression in next section.

4. Experiments

In this section, the computation time of wavelet image decomposition and reconstruction using standard integer lifting structure and simplified integer lifting structure, which all do not consider the coefficients coding, is measured firstly. Furthermore, the bit-rates of image lossless compression are compared between standard integer lifting structure and simplified integer lifting structure. The SPIHT coding algorithm is employed by the two integer lifting structures when computing the bit-rates.

To measure the computation time, the standard integer lifting structures of 9/7 and 5/3 wavelet filter banks, which adopted by JPEG2000, are utilized to compare with their simplified structures. The 8-bit gray-scale images Lena, Bridge and Peppers with size are used. We employed the image compression system without considering the coefficients coding; and the results are shown in Table 1.

Table 1. Computing Time in Milliseconds of Different Lifting Structures

Wavelet filter bank	Time (ms)
9/7-standard integer lifting wavelet	469
9/7-simplified integer lifting wavelet	437
5/3-standard integer lifting wavelet	516
5/3-simplified integer lifting wavelet	406

Table 1 shows the computing time using the standard integer lifting wavelet and the simplified integer lifting wavelet respectively. In Section 3.1, we conclude that the simplified integer lifting wavelet can reduce the computing time, and now the experiments in Table 1 can give the support for this conclusion. In Table 1, we observe that the simplified integer lifting wavelet proposed in this paper gets lower computing times and they are reduced about 32ms (9/7 wavelet) and 110ms (5/3 wavelet) than the standard integer lifting wavelet.

The bit-rates (Bit/Pixel) are important to the lossless image coding, the lower bit-rate means high compression ratio. Therefore, the bit-rates of lossless image compression are given using standard integer lifting wavelet and simplified integer lifting wavelet proposed in Section 3. In this experiment, Eighteen 512×512 8-bit gray-scale images are chosen and SPIHT coding algorithm is used to test the standard and the simplified integer lifting structure of 5/3 wavelet of JPEG2000. The results are shown in Table 2.

Table 2. Bit-Rates (Bit/Pixel) of Different Lifting Structures

Image	Standard Integer Lifting Wavelet	Simplified Integer Lifting Wavelet
Baboon	6.793941	5.986946
Barbara	5.886513	5.037720
Bike	6.092491	5.626175
Bridge	6.581451	5.877102
Couple	5.549809	5.056225
Crowd	5.241467	4.421471
Elaine	5.736576	5.139389
Goldhill	5.783493	5.034573
Lake	5.963192	5.316547
Lena	5.137688	4.514534
Man	5.582668	4.869335
Milkdrop	4.938641	4.023701
Peppers	5.542747	4.823788
Plane	5.067616	4.250137
Portofino	5.583912	5.094902
Woman1	5.555542	5.101509
Woman2	4.714954	3.543446
Zelda	5.072983	4.230957

Table 2 shows the bit-rates using the standard integer lifting wavelet and the simplified integer lifting wavelet respectively. In Section 3.2 and 3.3, we conclude that the simplified integer lifting wavelet can reduce the computing errors and get the more accurate value than the standard integer lifting wavelet, now the experiments in Table 2 can give the support for this conclusion. In Table 2, we observe that the simplified integer lifting wavelet proposed in this paper gets lower bit-rates and they are reduced about 0.4 to 1.2 than the standard integer lifting wavelet.

5. Conclusion

The simplified structure of integer lifting wavelet filter banks for lossless image compression is presented in this paper. The simplified structure of integer lifting wavelet is a versatile simplification for the standard integer lifting structure, and it can be used for any second generation wavelet based on lifting to improve the computing speed and performance. It results in lesser computational steps and speed implementation than the standard integer lifting structure. Furthermore, using the new lossless image compression system based on simplified integer lifting wavelet, the lower bit-rates are obtained.

Acknowledgements

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