Low Energy Lossless Image Compression Algorithm for Wireless Sensor Network (LE-LICA)

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Abstract: The energy consumption restricts the design of image compression algorithms in Wireless Sensor Network (WSN). The tradeoff between the decompressed image quality and energy consumption should be considered in the design. The field of image processing introduced many image compression algorithms for WSN. Joint Photographic Experts Group 2000 (JPEG2000) and Absolute Moment Block Truncation Coding (AMBTC) are examples of these algorithms. This tradeoff is considered in the design of the proposed algorithm to get Lossless image compression algorithm with a high compression rate. LE-LICA is compared with the traditional algorithms using popular metrics such as: Peak Signal to Noise Ratio (PSNR), Correlation Coefficient (CC), and energy consumption. The proposed algorithm enhances both the image quality and the energy consumption. A great challenge to reconstruct an image at the sink without lossless (the best quality) and low energy consumption at the sensor node. The results show the preference of the proposed algorithm to the others. Copyright © 2015 IFSA Publishing, S. L.

Keywords: Haar Wavelet, JPEG2000, AMBTC, PSNR, CC, Energy Consumption.

1. Introduction

The image processing is one of the most interesting fields in Wireless Multimedia Sensor Network (WMSN). Image transmission without compression consumes higher energy than the compressed energy at the transmission. So, the image compression before transmission should be considered in WMSN because of the dependence on the battery as an energy source [1]. The overall energy consumption is affected by the energy consumption of both processing circuit and the transmission circuit to send an image from the sensor node to the sink. So, it has thought to reduce the energy consumption at the transmission circuit by compressing the image at the processing circuit to reduce the overall energy consumption. The image compression field has introduced many algorithms used to compress the image such as: Joint Photographic Experts Group 2000 (JPEG2000) [2] and Absolute Moment Block Truncation Coding (AMBTC) [3].

JPEG2000 is the enhancement of JPEG [4]. The use of Haar Discrete Wavelet Transform (Haar DWT) is one of the enhancement techniques in JPEG2000. It does not provide compression, but it
enhances the compression rate at the Huffman encoding stage. It has been used to partition the image into two parts, approximation and details parts [5]. The approximation part is the average between the pixels values while the details part is the difference between them divided by 2. It is noted that, the applying of Haar DWT twice reduces the size of the approximation part to the half while the size of the details part is doubled and no change in the image size. The exceeding in the details part enhances the compression ratio at the Huffman encoding stage. So, it has thought to increase the size of the details part to enhance the compression ratio and the approach has introduced by a proposed technique namely by Haar Wavelet Image Compression Algorithm (HW-JPEG2000) [6]. HW-JPEG2000 removes the quantization stage completely which reduces the quality of the reconstructed image at the sink. Although the reduction in the details part enhances the quality of the reconstructed image as in HW-JPEG2000, it reduces the quality of the reconstructed image as in JPEG2000 enhancements which depend on multiple stages of Haar DWT because of the dependence on the quantization stage after Haar DWT multiple stages.

AMBTC is the enhancement of Block Truncation Coding (BTC) [3]. It partitions the image into blocks of size 4x4 each. It depends on the mean value of each block to compress the image rather than BTC which depends on the variance of each block beside the mean value. AMBTC technique enhances both the image quality and the energy consumption.

The paper introduces a proposed algorithm namely by Low Energy Lossless Image Compression Algorithm for Wireless Sensor Network (LE-LICA). This proposed algorithm, LE-LICA, depends only on the different between the pixels values. This approach reduces the energy consumption spent by multiple stages of Haar DWT without losses in the image quality to get low energy lossless image compression algorithm. LE-LICA is compared with the other image compression algorithms using popular metrics used in this field. The comparison is not limited to JPEG2000, AMBTC, and HW-JPEG2000, it also involves Fast Zonal Discrete Cosine Transform (Fast Zonal DCT) [7], 2D DWT-Zonal algorithms [8], and some enhancement in BTC using Clifford Algebra.

The paper is organized as follows: Section 2 introduces the related works, LE-LICA is illustrated in Section 3, the results are shown in Section 4, and section V shows the conclusions.

2. Related Works

2.1. JPEG2000

It is composed from three stages: Discrete Wavelet Transform (DWT), Quantization, and Huffman encoding [2]. Haar has introduced a simple approach in the design the filters of DWT involving transforming of the image into two parts; an approximation part and a details part. The approximation part is the average of every two adjacent pixels in the image by multiplying the two adjacent pixels as in Fig. 1. The details part is the difference between every two adjacent pixels divided by 2. Haar Wavelet does not provide compression, but it enhances the compression rate at the Huffman encoding stage. JPEG2000 has applied DWT twice to increase the details part which enhances the compression ratio at the Huffman encoding [4].

2.2. Fast Zonal Discrete Cosine Transform (Fast Zonal DCT)

Fast Zonal DCT introduces an enhancement in JPEG [7]. The encoder of Fast Zonal DCT limits the range of DCT from 0 to 3 and the decoder replaces the other values by zeros. Fast Zonal DCT increases the compression ratio at Huffman encoding stage with reduction in energy consumption, but it reduces the quality of the reconstructed image to acceptable level.

2.3. Hybrid DWT with Fast Zonal DCT in JPEG2000 (2D DWT-Zonal)

The Fast zonal DCT provides a compression in DCT stage. So, it has thought to use Fast zonal DCT stage in JPEG2000 to enhance the compression ratio [8]. Fast zonal DCT stage has been used between DWT stage and quantization stage in JPEG2000. It is applied only on the approximation part to enhance the compression ratio and to reduce the energy consumption at the Huffman encoding.
2.4. Haar Wavelet Image Compression Algorithm (HW-JPEG2000)

The quantization is the stage which reduces the pixel value from high to low using a quantization step, $\Delta$ [5]. It causes losses in the decompression process and reduces the image quality to low level. The same purpose of the quantization stage can be gotten by exceeding in the size of the details part at the expense of approximation part without losses. So, Haar DWT is applied on each row in the image until getting one pixel in the approximation part and the other pixels represent the details part for each row in the image. Fig. 2 shows the approach of HW-JPEG2000 using numerical examples [6].

2.5. Absolute Moment Block Truncation Coding (AMBTC)

AMBTC is the enhancement of BTC [3]. It has a different approach in comparison with JPEG2000 [2]. It partitions the image into blocks of size $4 \times 4$ each, and each block has its threshold. This threshold is the mean value, $x_m$, of the pixels values in each block. AMBTC uses another two mean values, $x_H$ and $x_L$. They are the mean values of the upper and lower values with respect to $x_m$ in each block.

AMBTC replaces the upper and lower values of each block by 1 or 0. The decompressed image can be reconstructed from the compressed by replacing 1 and 0 by $x_H$ and $x_L$ respectively. AMBTC does not use the quantization and Huffman encoding stages. So, no need to extra processing time and energy consumption for image compression processing.

3. LE-LICA

Instead of taking the difference between two adjacent pixels divided by 2 as in HW-JPEG2000, we will take the difference between each pixel and its neighbor without dividing by 2 for each row as shown in Fig. 3. The last pixel will be taken as its without change. So, the contents of each row will represent the difference values except the last pixel.

The contents of the final resulted image represent the difference values of the original image except the pixel of the last row and the last column. This pixel is the same as the original image. Finally, the Huffman encoding is applied on the final resulted image before the transmission.

The reconstruction of the decompressed image from the compressed one is as follows:

Step 1: Apply Huffman decoding on the received image.

Step 2: Reconstruction of the last column is done as follows:

- Apply the summation operation on the pixels values of this last column to reconstruct the first pixel in this column where: $[(A-B)+(B-C)+(C-D)+(D-E)+(E-F)+(F-G)+(G-H)+H]=A$.
- Subtract the resulting value, A, from the first pixel value, A-B, to reconstruct the second pixel value, B.
- Subtract the second resulting value, B, from the second pixel value, B-C, to reconstruct the third pixel value, C.
- Subtract the third resulting value, C, from the third pixel value, C-D, to reconstruct the forth pixel value, D.
- Repeat the same operation until obtaining G.

Step 3: after the reconstruction of the last column, repeat step 2 on each row to reconstruct the pixels values of each row.
4. Results and Discussions

The compression algorithms are applied on an image of size 512×512 as shown in Fig. 4. The reason of use this image is no flat in the image, so no 0-values is gotten approximately. The comparison of LE-LICA with the other algorithms is based on different metrics: Peak Signal to Noise ratio (PSNR) [1], energy consumption [9], Compression Ratio (CR) [1], Bit Rate (BR) [1], Correlation Coefficient (CC) [10], and Spatial Frequency (SF) [11].

4.1. Peak Signal to Noise Ratio (PSNR)

PSNR is the most commonly used as a measure of the quality of the reconstructed image, K, in comparison with the original image, X [1]. It is a qualitative measure based on the mean-square-error of the reconstructed image as shown in (1). Fig. 5 shows PSNR comparison between the image compression algorithms. PSNR comparison shows that LE-LICA is lossless image compression algorithm while the others are lossy image compression algorithms.

\[ PSNR = 20 \log \left( \frac{255 MN}{\sum_{i=0}^{N-1} \sum_{j=0}^{N-1} (K(i,j) - X(i,j))^2} \right) \]  

Fig. 4. Original image.

The attached bits (Huffman dictionary codes or the values of \( x_L \) and \( x_H \)) are considered with the compressed image in the estimations of the energy consumption, and the distance \( d \) is considered as the same as \( d_0 \). The results show that: LE-LICA consumes the least energy to compress the image in comparison with other image compression algorithms as shown in Fig. 6. The use of lossless image compression algorithm with the least energy consumption is a great addition to WSN data processing which prolong the lifetime of both sensor nodes and CH.

4.2. Energy Consumption

Compression algorithms are not applied practically, but they are programmed by MATLAB. So, the estimations of the energy consumption for addition (\( E_{add} \)), multiplications (\( E_{mul} \)), division (\( E_{div} \)), comparison (\( E_{comp} \), and round (\( E_r \)) are based on standards [9].

Each node in WSN requires transmission energy to transmit the data to the Cluster Head (CH). The distance, \( d \), between the sensor node and CH specifies the energy required to transmit the data to the sink, \( E_{TX} \), as shown in (2) [9] where: \( \epsilon_{fs} \) is the free space energy model while \( \epsilon_{mp} \) is the multipath energy model, \( B_i \) is the bits of the transmitted compressed image (compressed image with the attachment like Huffman dictionary and the averages values of AMBTC), and \( d_0 = \sqrt{\frac{\epsilon_{fs}}{\epsilon_{mp}}} \).

\[ E_{TX} = \begin{cases} B_i \cdot \epsilon_{fs} \cdot d^2, & d \geq d_0 \\ B_i \cdot \epsilon_{mp} \cdot d^4, & d < d_0 \end{cases} \]  

The attached bits (Huffman dictionary codes or the values of \( x_L \) and \( x_H \)) are considered with the compressed image in the estimations of the energy consumption, and the distance \( d \) is considered as the same as \( d_0 \). The results show that: LE-LICA consumes the least energy to compress the image in comparison with other image compression algorithms as shown in Fig. 6. The use of lossless image compression algorithm with the least energy consumption is a great addition to WSN data processing which prolong the lifetime of both sensor nodes and CH.

4.3. Compression Ratio (CR) and Bit Rate (BR)

CR is the ratio of the size of original image, \( MN \), to the size of the compressed image, \( MCNC \). BR is the ratio of the number of bits per pixel in the image to CR [1]. The size of the compressed image is measured at the transmitter. All image compression algorithms which depend on Huffman encoding require to send the dictionary of each image with the compressed image while AMBTC and its enhancement require to send the values \( x_L \) and \( x_H \) of each block with the compressed image. The attachments in the estimations of CR and BR will be considered. Table 1 shows the comparison between the compression algorithms with respect to CR and BR. LE-LICA has a higher CR value than the others except the Fast Zonal-DCT. Although LE-LICA has high CR after Fast Zonal-DCT, it scores the least energy consumption. So, this result does not change his preference to the others.
4.4. Correlation Coefficient (CC) and Spatial Frequency (SF)

CC is a parameter used to measure the matching degree between the reconstructed and original images [10] while the metric SF is used to measure the overall activity level of the image [11]. The calculated values of CC and SF ensure that LE-LICA is a lossless image compression algorithm which is matched with the original image as shown in Table 2.

### Table 1. CR and BR comparison.

<table>
<thead>
<tr>
<th></th>
<th>CR</th>
<th>BR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fast Zonal DCT</td>
<td>9.0903</td>
<td>0.8801</td>
</tr>
<tr>
<td>LE-LICA</td>
<td>7.8413</td>
<td>1.0202</td>
</tr>
<tr>
<td>AMBTC</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>2D DWT Zonal</td>
<td>3.0435</td>
<td>2.6286</td>
</tr>
<tr>
<td>JPEG2000</td>
<td>1.9050</td>
<td>4.1994</td>
</tr>
<tr>
<td>HW-JPEG2000</td>
<td>1.7204</td>
<td>4.6502</td>
</tr>
</tbody>
</table>

### Table 2. CC and SF comparison.

<table>
<thead>
<tr>
<th></th>
<th>CC</th>
<th>SF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original Image</td>
<td>1</td>
<td>53.5091</td>
</tr>
<tr>
<td>LE-LICA</td>
<td>1</td>
<td>53.5091</td>
</tr>
<tr>
<td>Fast Zonal DCT</td>
<td>0.8901</td>
<td>32.7753</td>
</tr>
<tr>
<td>AMBTC</td>
<td>0.9629</td>
<td>49.3303</td>
</tr>
<tr>
<td>2D DWT Zonal</td>
<td>0.9353</td>
<td>55.5288</td>
</tr>
<tr>
<td>JPEG2000</td>
<td>0.9941</td>
<td>60.1078</td>
</tr>
<tr>
<td>HW-JPEG2000</td>
<td>0.9991</td>
<td>54.0237</td>
</tr>
</tbody>
</table>

5. Conclusions

The reduction in the image size before the transmission prolong the sensor lifetime. Some image compression algorithms are discussed and compared with a proposed image compression algorithm using popular metrics. The estimation of the energy consumption is based on standards. 2D DWT-Zonal is one of these algorithms has suggested to add Fast Zonal-DCT stage in JPEG2000 to reduce the energy consumption. And also, HW-JPEG2000 has suggested to enhance the multi stages of Haar wavelet. All these discussed algorithms are lossy algorithms. The trade off between the energy consumption and the quality of their reconstructed image restricts their design. This paper challenges this trade off or this rules and introduces low energy lossless image compression algorithm namely by LE-LICA. LE-LICA omits the quantization stage which causes losses in the reconstruction image process. LE-LICA depends only the difference between the pixels values in addition to Huffman encoding stage. The results of the comparison between these image compression algorithms show the preference of LE-LICA to compress the images to the others.

### References


