International Journal of Electrical and Computer Engineering (IJECE)
Vol. 13, No. 3, June 2023, pp. 2769~2777
ISSN: 2088-8708, DOI: 10.11591/ijece.v13i3.pp2769-2777

An optimized discrete wavelet transform compression technique for image transferring over wireless multimedia sensor network

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Article Info

Article history:

Received Dec 29, 2021
Revised Jul 26, 2022
Accepted Aug 18, 2022

Keywords:

Discrete wavelet transform
Image compression
Multi-path routing ring
OpenCV
Wireless multimedia sensor network

ABSTRACT

Transferring images in a wireless multimedia sensor network (WMSN) knows a fast development in both research and fields of application. Nevertheless, this area of research faces many problems such as the low quality of the received images after their decompression, the limited number of reconstructed images at the base station, and the high-energy consumption used in the process of compression and decompression. In order to fix these problems, we proposed a compression method based on the classic discrete wavelet transform (DWT). Our method applies the wavelet compression technique multiple times on the same image. As a result, we found that the number of received images is higher than using the classic DWT. In addition, the quality of the received images is much higher compared to the standard DWT. Finally, the energy consumption is lower when we use our technique. Therefore, we can say that our proposed compression technique is more adapted to the WMSN environment.

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1. INTRODUCTION

The continuous research on electronics and semiconductors has allowed the fabrication of small and cheap sensors. These sensors can be used to collect information about the surrounding environment, process them, then communicate them wirelessly. The sensors capture the physical data from the environment (pressure, temperature, weight). Then, these data are transformed into numeric data and processed by the processor [1]. The processed data are either sent to other sensors or stored in local memory. Sensor resources are limited (memory, computation power, and battery). So, managing these resources is very important to extend the life of the network with more efficiency [2].

A wireless sensor network (WSN) is a network of several nodes. Figure 1 denotes the main components of a node. Each node makes measures from the environment and converts them into scalar data. Then, the data is sent to the main sensor (the base station). In fact, WSN is used in many fields of interest like industries [3], health care analysis [4], [5], traffic control [6], agriculture monitoring [7], and home automation [8], [9]. Nevertheless, it suffers from many constraints like limited bandwidth and resources [2]. However, the most quantity of energy in WSN is consumed by the routing protocols. As a result, the duration of the lifetime of the network depends on routing protocols. Actually, there are several routing protocols that could be used in transferring multimedia content such as low-energy adaptive clustering hierarchy (LEACH) [10], intra-cluster head (ICH)-LEACH [11], and modified (M)-LEACH [12].

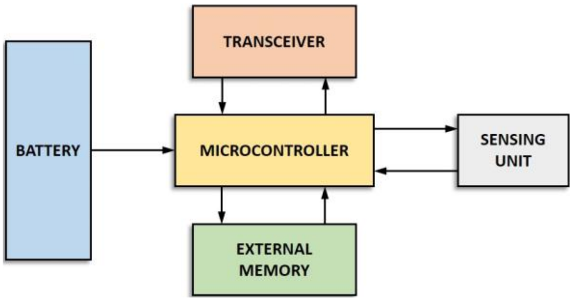

Figure 1. Internal architecture of a node

A wireless multimedia sensor network (WMSN) [13] is a network of nodes equipped with cameras. They can capture multimedia content like video and images. Then, they transmit the captured data to the network. Actually, we can find multiple architectures of WMSN. The single-tier flat is an architecture in which sensors are the same type and the data treatment is distributed. The single-tier clustered architecture which characterized by heterogeneous, nodes and concentrated processing. The last architecture is multi-tiered. In this last one, nodes are heterogeneous, and processing is distributed. In fact, transmitting multimedia content like images requires quality of service [14]: the resources of nodes in terms of processing, memory, and energy are limited, the bandwidth is limited, and the image compression techniques are used in the application layer. Actually, many compression techniques can be used in the transmission process.

Transferring multimedia content in WMSN especially images take a lot of resources. Images are big in size and detail. So, processing and transferring them can be very costly. That is why we use compression techniques before sending them to the network. Actually, they are many compression techniques like pyramidal [15], discrete cosine transforms (DCT) [16], and discrete wavelet transform (DWT) [17]. In our work, we proposed an optimization of the DWT compression technique, and we adapted it to WMSN. Moreover, we used the routing protocol multipath-routing ring [18] to test our compression method and DWT. Because it does not manage energy consumption. So, both compression techniques will be tested in energy consumption too.

This paper covers the following sections. First, we will explain our proposed compression technique. Then, we will show the results of our simulations and analyze them. Finally, we will conclude our work.

2. THE PROPOSED COMPRESSION TECHNIQUE

2.1. Generalities about image compression

Nowadays, we use digital images in almost everything. The massive use of this kind of image comes with a cost such as storing and transferring a big volume of data. Because when we keep multimedia content (graphics, audio, and video) uncompressed, we need a lot of storage to save them and bandwidth to transfer them. Nowadays, many applications use digital images like video on demand (Netflix and YouTube) [19], medical imaging [20], and satellite communication [21]. Therefore, the use of digital images needs compression to reduce the size of the storage and the bandwidth in the case of image transfer. In fact, image compression is a process that removes redundancies. As a result, we can reduce the size of an image, and keep the best quality of it. They are two categories of compression methods: lossy and lossless compression techniques. Figure 2 represents different compression techniques like lossy and lossless compression techniques. Each type contains multiple methods. In this chapter, we will see the following topics. First, we will cover some generalities about the existing compression techniques. Then we will explain the method that we proposed.

2.2. Principle of image compression

A digital image is composed of pixels, which are represented by a certain value. In general, the neighboring pixels share common characteristics. Therefore, they have redundant information. The idea behind compression is to find the common pixels. Then, we delete these redundancies. They are two main parts of compression: redundancy and irrelevancy. Redundancies consist of deleting duplications from the signal source. The irrelevancy consists of deleting the less noticeable signals received by the human eye.

2.3. Types of compression methods

They are two kinds of compression methods: lossless and lossy compression. In the first method, the decompressed image is the same as the original one. In the lossy compression method, the decompressed image loses some quality compared to the original one.

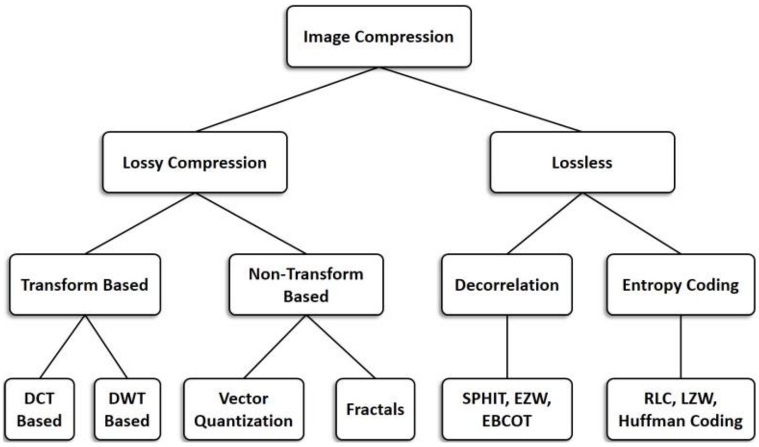

Figure 2. Image compression techniques

2.4. Lossy compression method

This method [22] is based on deleting redundant information from the original image. Because this loss of quality will not be detected by the human eye. This technique is used in JPEG compression and on the web in general. Figure 3 shows the steps of the compression and decompression process.

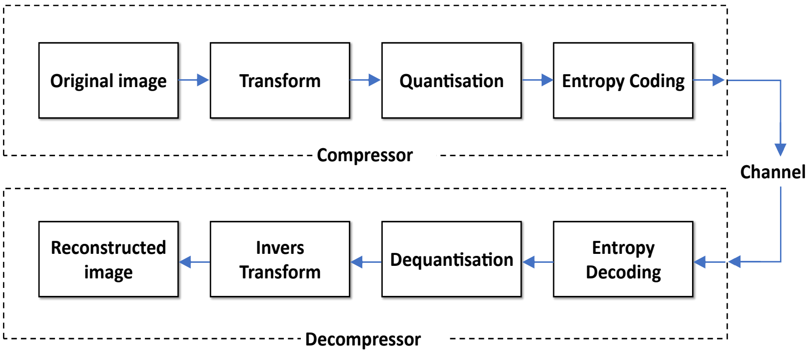

Figure 3. Lossy compression technique

2.5. Lossless methods model

This type of compression [23] uses multiple techniques:

a. The substitution model technique: This method uses the redundancy of pixels of the image that area is just to each other. Run length encoding (RLE) and bitmap compression are reused in this method.
b. The statistical model technique: This technique uses the work supported by formation theory supported by the works of Huffman [24]. It exploits the redundancy in pixels by calculating the probability of Repetition in the image. Huffman coding and arithmetic coding are the most used in this method.
c. The dictionary model technique: This technique uses a code that represents a string symbol. The encoder reads the pixels of the image and uses a dictionary. If it finds a string that exists in the dictionary, it replaces it with its code. If it does not find it, he added it to the dictionary. The LZW, LZ78, and LZ77 algorithms are the most used methods in this technique. Figure 4 shows the process of the lossless compression technique. This technique is based on doing the transform and then using the entropy coding. On the other side, we do the entropy decoding and reverse transform.

2.6. The DWT compression method

The DWT method [25] is based on the Fourier transform, which is sinusoids. The basic functions transform is characterized by short waves. They are characterized by varying frequency and limited duration. The idea behind this technique is to divide the image into four sub-bands LL, LH, HH, and HL as shown in Figure 5. In addition, the low pass sub-bands LL and LH contain more details. Therefore, we consider them and transfer them through the network. The other sub-bands HH, and HL contain minor details. So, we skip them. Figure 6 shows an image after applying a DWT compression on it.

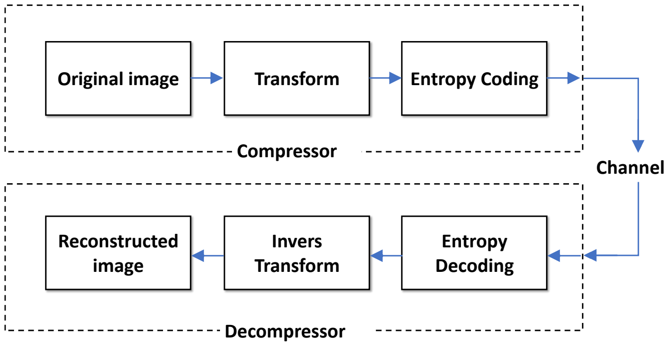

Figure 4. Lossless compression technique

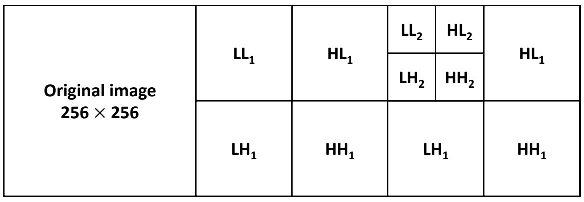

Figure 5. Division of an image into sub-bands using DWT

Figure 6. An example of appliance of DWT in an image

2.7. Run encoder length

This technique [26] uses a (length, value) instead of the data. The value is the repeated segment, and the length is how many times the value is repeated. In the case of a gray image, we apply it on one plane, but in a color image, we split the image into planes. Then, we apply it on each plane.

2.8. Performance parameters

Image compression is a process that changes the original image. Therefore, in order to measure the quality of the decompressed image compared to the original one, we use the performance parameters. They are many of them. In this paper, we are going to use two parameters: peak signal-to-noise ratio (PSNR) and mean square error (MSE) [27]. The PSNR is the measurement of the peak error between the original image and the compressed one. A higher PSNR means better quality. How to calculate the PSNR is shown in (1). In the MSE method, we do the sum of the differences between the compressed images and the original ones. Less MSE means better quality it is. To calculate MSE, we use (2). We can use the compression ratio metric to measure the quality of the decompressed image, which is expressed by (3).

$$PSNR = 10\log_{10}\left(\frac{R^2}{MSE}\right) \quad (1)$$

$$MSE = \frac{\sum_{M}^{N}[I1(m,n)-I2(m,n)]^2}{M \times N} \quad (2)$$

where R is the relative data redundancy of the representation with b bits.

$$R = 1 - \frac{1}{C}$$

where *C* is the compression ratio.

$$C = \frac{\text{CompressedImage}}{\text{OriginalImage}} \quad (3)$$

2.9. The proposed compression method

Our new protocol is based on the DWT compression technique. The purpose of this method is to minimize the number of blocks that will be sent to the network and have a decompressed image with better quality. Thus, the number of packets for each image will be less. As a result, it will be less congestion in the network and nodes will consume less energy. Our compression method, which process is explained in Figure 7, follows these steps: i) the image is divided into blocks of 32×32 pixels; ii) each block is considered a whole image. Therefore, we apply the DWT technique on each block; iii) then we take the higher value of each block and apply a quantization process. After that, we apply the RLE process and Huffman; and iv) on the other side, we apply the reverse of Huffman and the reverse RLE process. Then, we reverse the quantization process. After that, we apply the IDWT process. In the end, we put each decompressed block in its appropriate position.

Block 1 32x32	Block 4 32x32	Block 7 32x32	Block 10 32x32	
Block 2 32x32	Block 5 32x32	Block 8 32x32	Block 11 32x32	...
Block 3 32x32	Block 6 32x32	Block 9 32x32	Block 12 32x32	...
...	...	...	...	...

Figure 7. Division of an image into blocks

3. SIMULATIONS AND RESULTS

3.1. Application layer

In the application layer, we applied our optimized compression technique and DWT method to a captured image. Then, we compared the obtained results. First, we applied the optimized DWT on every block of the captured image. Then, we applied the quantization, the RLE method, and the Huffman process. After that, we send the packet containing each part through the network. When the sink receives the packet, it extracts the data and then applies the reverse Huffman, the IRLE, the reverse quantization, and the reverse optimized DWT. After that, it places the block in its position in the image. We also applied the DWT method to each captured image. Then, we took the high value of the resulting image and divided it into blocks of 8×8. Then we applied quantization, the RLE method, and the Huffman method to each block before sending it into the network. When the sink receives the packet, it extracts the data and does the same process as the optimized compression method. Figure 8 illustrates the explained process.

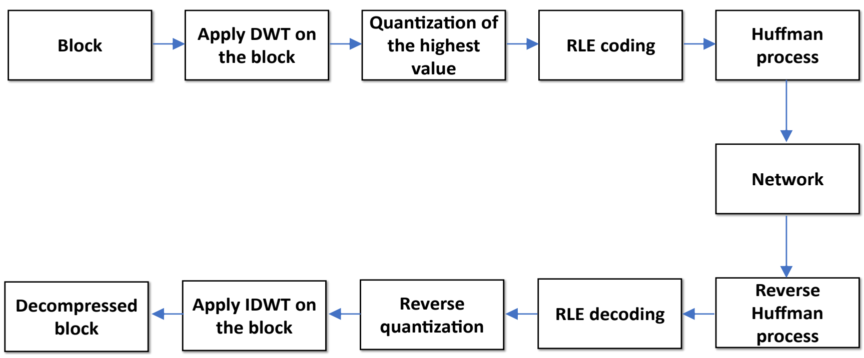

Figure 8. Compression process using our method

3.2. The routing protocol multipath routing ring

This routing protocol is based on using circles around the sink (level 0), and each circle contains some nodes. Each circle represents a superior level compared to the level before. Actually, the more levels we have, the nodes are farthest from the sink. This protocol has two phases: the construction phase and sending phase. The idea behind this protocol is that a node from level x sends packets to nodes from level x-1. Then, this node sends the packet to the inferior level until it reaches the sink, which is level 0. Figure 9 shows the structure of this protocol.

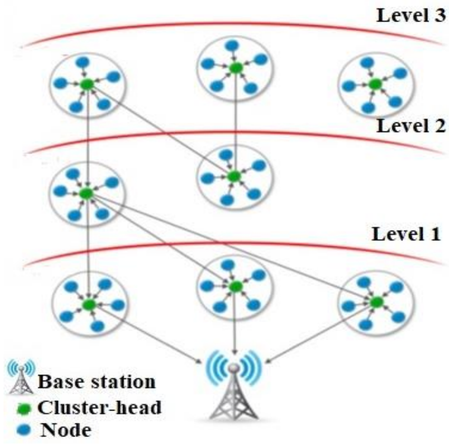

Figure 9. Multipath routing ring architecture

3.3. Simulation parameters

Table 1 shows in detail the parameters that are used in the simulation. In our simulations, we used Castalia as a simulator. We also used CC2240 as a radio model.

Table 1. Simulation parameters

Parameter	Value
Topology size	200×200 m^2
Number of nodes	200
CH probability	0.05
Number of trials	20
Initial power	200j
BS position	(0,0)
Size of image	256×256
Number of sent images	10600
Delay between images	50 s
Delay between sending packets	0.1 s
Quantization percentage	85 %

3.4. Analysis of results

The results show that our optimized compression method made many improvements compared to the DWT technique. In fact, we noticed that the total number of received images using the proposed DWT is higher by 46%. In addition, we noticed that the average PSNR of all images using our method is more than double compared to DWT. Table 2 represents the general statistics.

Table 2. General statistics

	Optimized method	DWT
Number of sent images	10600	10600
All received images	3551	2438
Complete received images	3525	2419
Average PSNR	42.71	17.21
Average compression ration	1	0.82

Figure 10 shows the number of received images per time. It shows clearly that the rate of image reception noticed in the new DWT method outcomes its counterpart using DWT. This result can be explained by the fact that the number of packets used to send an image using our method is less than the normal DWT. Thus, the possibility of reaching the sink using our optimized DWT is much higher than the standard DWT.

Figure 11 shows the dead nodes by time using both methods. It shows clearly that when we use the optimized DWT, the lifetime of the network duration is extended compared to the normal DWT. This phenomenon could be explained by the fact that when we use the optimized DWT, the number of sent packets is less compared to standard DWT. Thus, nodes send fewer packets, which means that they consume less energy. As a result, the lifetime of the network is extended.

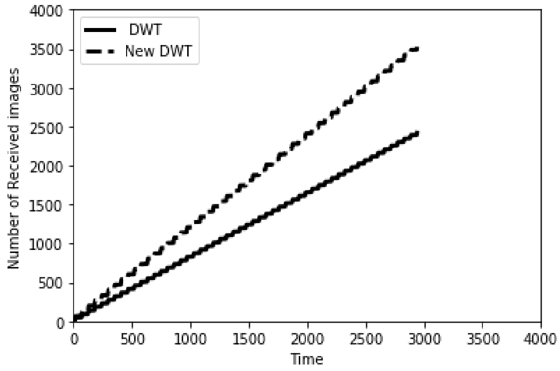

Figure 10. The number of received images per time using our proposed compression method and DWT

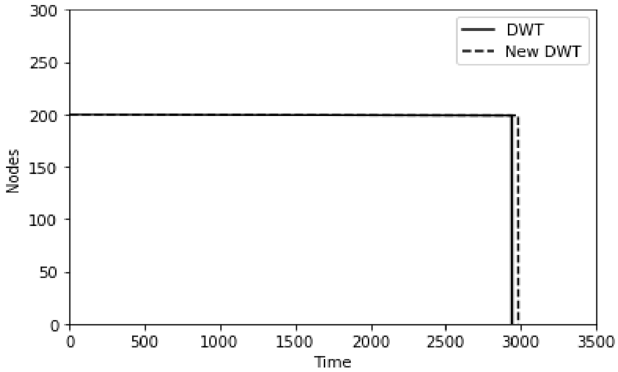

Figure 11. The dead nodes per time using DWT and new DWT

Figures 12 and 13 show respectively the number of received images per PSNR of the proposed DWT and the normal DWT. In addition, Figures 14 and 15 show respectively the number of received images per compression ratio of the proposed DWT and the normal DWT. These figures show clearly that when we use the proposed compression technique, the sink receives more complete images compared to the use of DWT method. They also showed that the quality of the received images using the modified DWT is much higher than normal DWT. These results could be explained by the fact that in our method we apply the DWT method on blocks of 32 pixels. On the other hand, DWT is applied to the whole image. This difference leads to two results. First, the number of packets generated by our method is much lesser than the normal DWT. As a result, we have more received images when we use our technique. Second, the area that we apply DWT to it in our method is small. So, we preserve the details of the image when we decompress it. However, when we use the normal DWT, we get only the highest value of the image. Thus, the quality of the decompressed images using our method is much higher than using the normal DWT.

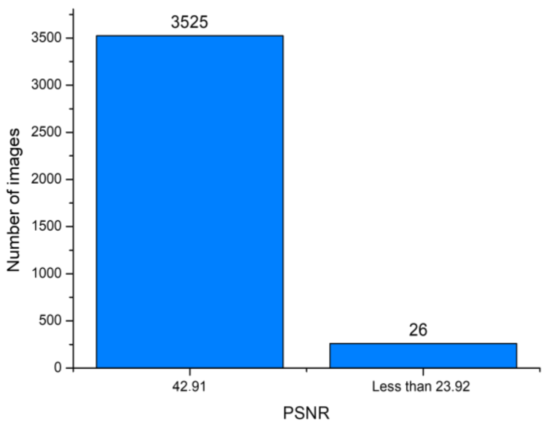

Figure 12. Number of images per PSNR using the new compression method

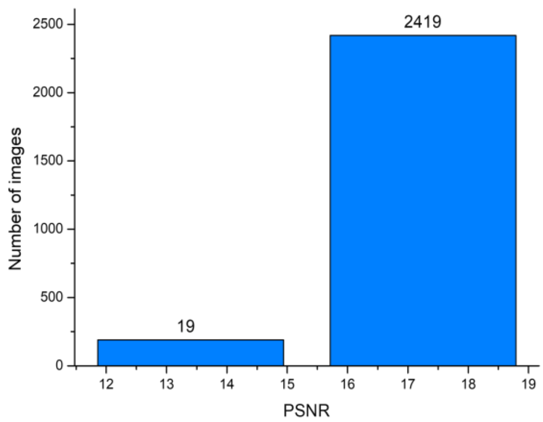

Figure 13. Number of images per PSNR using DWT

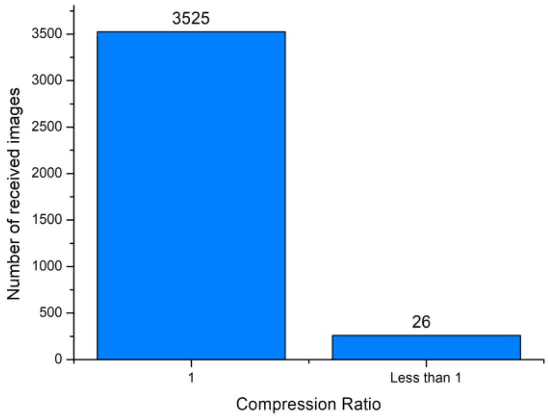

Figure 14. Number of images per compression ratio using the new compression method

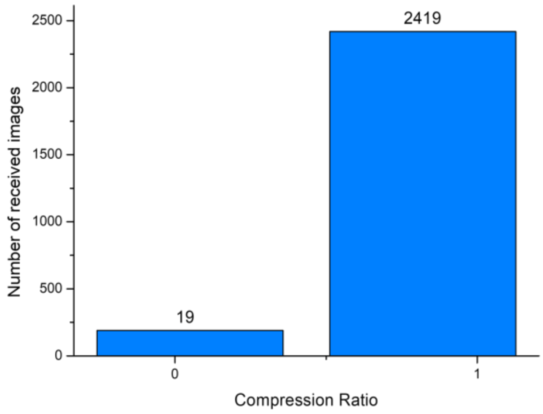

Figure 15. Number of images per compression ratio using DWT

4. CONCLUSION

In this work, we proposed an optimization of the DWT compression technique suited to WSN constraints, and we compared it with the standard DWT. In our method, we reduced the number of packets for Each image. We also got better quality after decompression by using our technique. These features could be explained by the fact that we reduce a big block of the image into a small series of binary numbers, which we put in packets. Moreover, we could extend the life of the network by reducing the number of packets per image. In a conclusion, our compression technique is more suitable for image transferring over MWSN. As a perspective, we will apply our compression technique to the video transfer.

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