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REVIEW ARTICLE

Image compression algorithms in wireless multimedia sensor networks: A survey

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KEYWORDS

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Abstract Unlike classical wired networks and wireless sensor networks, WMSN differs from their predecessor's scalar network basically in the following points; nature and size of data being transmitted, important memory resources, as well as, power consumed per each node for processing and transmission. The most effective solution to overcome those problems is image compression. As the image contains massive amount of redundancies resulting from high correlation between pixels, many compression algorithms have been developed. The main objective of this survey was to study and analyze relevant research directions and the most recent algorithms of image compression over WMSN. This survey characterizes the benefits and shortcomings of recent efforts of such algorithms. Moreover, it provides an open research issue for each compression method; and its potentials to WMSN. Reducing consumed power thus granting long life time is considered the main performance metric and will be the main target in the investigated solution.

1. Introduction

The image is the most important carrier among the information intercommunication in people's life and the biggest media containing information. It consists of pixels that are highly correlated to each other. However, due to this correlation; it contains a large amount of redundancies that occupy massive storage space and minimizes transmission bandwidth. There are three types of data redundancy that are observed. (1) Spatial Redundancy: Neighboring pixels are correlated so unnecessary repeated data within one frame need to be removed to reduce image size. (2) Temporal Redundancy: To represent image data, there is a need to reduce the number of the bits needed for image representation. (3) Spectral Redundancy: It is the correlation between different color planes. In order to overcome those redundancies, compression must be done for minimal storage and lower bandwidth while preserving acceptable visual quality of reconstructed image close enough to the original image.

Generally, compression techniques can be classified into lossy and lossless compression techniques. Benefit of lossy over lossless is to reduce encoding and decoding time, compression ratio and energy in case of power constrained applications. Moreover, image compression process includes the following:

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- **Mapper** to transform input data into a form suitable for compression to reduce spatial redundancy exists on input image.
- **Quantizer** to reduce accuracy of mapper's output.
- **Entropy encoding** to reduce quantizer's output bits.

Dequantizer output at decompression is not reversible so quantizer and dequantizer operations are omitted if lossless compression is used.

Choosing one compression technique depends upon the nature of operating platform. One of those operating platforms is wireless multimedia sensor network (WMSN). The layout of a typical WMSN consists of a large number of sensor nodes deployed in a region of interest and one or more base stations or sink. Typically, each node in WMSN has the ability to acquire, compress and transmit captured frames to the base station which acts as the main network controller or coordinator. In this role, its primary function is to coordinate the functions of the nodes. It also collects information gathered by the nodes to be stored or further processed.

WMSN has gained a wide attention as such networks have been used for many applications such as military, traffic surveillance, security monitoring, health care, machine failure diagnoses, chemical and biological detection, plant monitoring, agriculture and transportation. Compared to conventional wired networks and scalar data Wireless Sensor Networks (WSNs), WMSN encounters more problems due to their limited resources in memory, processing, bandwidth, complexity, and power consumption. As a result of massive data being transmitted over WMSN, more power dissipation per each node, and consequently data compression are needed to decrease data size. Table 1 shows the difference between scalar WSN and WMSN. WMSN differs from their predecessor's scalar WSN in the following points [1]: (1) nature and volume of visual data being manipulated which is pixel-based. On the other hand, the data manipulated by WSN are scalar such as temperature and humidity. (2) Limited resources in processing, memory and communication power to manipulate visual flow. (3) Energy dissipation by compression algorithms to handle images compared to scalar data where compression is not required. (4) Visual flow in WMSN is susceptible to information loss due to redundancy nature, but WSN data loss affects accuracy of collected data.

Therefore, the main objective of this survey was to study and analyze relevant research directions and the most recent algorithms of image compression over WMSN. It concludes the benefits and shortcomings of most recent efforts of such algorithms as well as, an open research issue for each compression method; and its potentials to WMSN. Reducing consumed power and system complexity thus granting long life time is considered the main performance metric. Also, it provides a description to different hardware platforms which allow implementation of image compression techniques.

WMSNs are divided into three parts sensing, processing and transmission. Among these operations, it is recognized that processing and transmission are the most consuming power operations. Suitable compression algorithms would reduce the data size, power consumption and increase sensors life time. A related review paper has been proposed in literature [1] surveys algorithms, protocols, hardware, and open research issues for WMSN. More precisely, power consumption is the main influencing factor in WMSN. Therefore, power consumption shortage requires compression process to be simple to achieve the highest possible compression ratio with acceptable image quality.

This paper is structured as follows: Section 2 covers performance metrics of compression with related research that contributes to enhance compression performance. Image compression techniques for WMSN are discussed in Section 3. Section 4 illustrates comparison among different lossy compression techniques. Open research areas in enhancing compression techniques for WMSN are discussed in Section 5. Finally, Section 6 concludes characteristics of image compression techniques of previous sections as well as future work.

Table 1 Comparison between scalar WSN and WMSN.

*	Scalar WSN	WMSN
Memory	Limited	Limited
Processing capability	Low	Low
Complexity	Low	High
Power consumption	High	Highest
Speed	Low	Lowest

2. Image compression performance metrics

Performance of compression techniques [2] depends on the following criteria:

- Quality of image.
- Compression ratio.
- Speed of compression.
    a. Computational complexity.
    b. Memory resources.
- Power consumption.

2.1. Image quality

There is a need for specifying methods that can judge image quality after reconstruction process and measure the amount of distortion due to compression process as minimal image distortion means better quality. There are two types of image quality [3] measures subjective quality measurement and objective quality measurement.

Subjective quality measurement is established by asking human observers to report and judge image or video quality according to their experience, and these measures would be relative or absolute. Absolute measures classify image quality not regarding to any other image but according to some criteria of television allocations study organization. On the other hand, relative measures compare image against another and choose the best one.

Objective measures are mathematical measures that measure the amount of image distortion and image quality. Those measures are:

a. Mean Square Error (MSE) which is defined as:

$$\sigma^2 = \frac{1}{N}\sum_{n=1}^{N}(x_n - y_n)^2 \quad (1)$$

where x_n is the input data sequence, y_n is the reconstructed data sequence and N is the length of data sequence.

b. Peak-Signal-To-Noise ratio (PSNR): PSNR measures the size of error relative to peak value x_{peak} (for 8 bit pixel x_{peak}^2 equals 255) of the signal and it is given by:

$$\mathrm{PSNR} = 10\log_{10}\frac{x_{peak}^2}{\sigma_d^2} \quad (2)$$

where σ_d^2 is the MSE (σ^2).

When reconstructed image is close to original one, this means that MSE between two images is low. On the other hand, higher PSNR means better image quality.

2.2. Compression ratio

Compression ratio (CR) is a term that is being used to describe ratio of compressed output sequence length (B1) to uncompressed input length (B0) and measured with bits per pixel (bpp) as described in Eq. (3).

$$\text{compression ratio (CR)} = \frac{\mathrm{B0}}{\mathrm{B1}} \quad (3)$$

CR can be used to judge how compression efficiency is, as higher CR means better compression.

2.3. Speed of compression

Compression speed depends on which compression technique can be used, as well as, the nature of platform that will host the compression technique. Compression speed is influenced by computational complexity and size of memory.

Lossy compression is a complex process that increases system complexity, storage space and needs more computational load. Therefore, the main goal was to study and analyze lossy compression techniques specifically the applicable one for WMSN. This paper also presents related efforts for enhancing performance of those techniques to achieve minimal computational load that consumes less power as possible while maintaining acceptable visual quality. WMSN differs from regular wireless sensor networks (WSNs). Where, WSNs transfer only singular data through network such as temperature [4], sound, pressure, and humidity. It requires less storage space and bandwidth compared to WMSN that have larger overhead over the network.

2.4. Power consumption

Power consumption is the main performance metric in WMSNs as it is affected by the previously mentioned metrics. The nature of multimedia requires massive storage space and large bandwidth that consumes more and more power. Transmission power is required for WMSN nodes to manipulate visual flows, and energy-aware compression algorithms that reduce network life time. Therefore, adjusting processing complexity, transmission power reduction and minimizing data size will save the energy that represents the main performance criteria on this research.

A number of related review papers have been proposed in literatures [5–10]. They contribute on enhancing compression performance. Chew et al. [5] provided 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. Authors found that Set Partitioning In Hierarchical Tree (SPIHT) is the most suitable image compression algorithm in WSN due to its high compression ratio and simplicity of computations, since WSN needs low memory, speed processing, low power consumption, high compression ratios, less complex system and low computational load.

Kumar et al. [6] 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. Their approach was based on using singular value decomposition (SVD) and block truncation coding (BTC) with Discrete Cosine Transform (DCT) in image compression technique. They depended on decision making parameter (x) which is based on observation of standard deviation (STD σ) for deciding what compression technique can be used as follows:

If $\sigma < x$ use DCT
Else if $\sigma > x$ use SVD
Else if $35 \leqslant \sigma \leqslant 45$ BTC

Nasri et al. [7] 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. Their scheme was based on wavelet image transform and distributed image compression by sharing the processing tasks between clusters to extend the overall lifetime of the network.

Ghorbel et al. [8] described robust use of DCT and Discrete Wavelet Transform (DWT) and their capabilities in WSN. They provided practical performance comparison between those techniques for various image resolutions and different transmission distances with 2 scenarios. The first scenario used two nodes only as transmitter and receiver, while, the second scenario using intermediate nodes between sender and receiver. The comparison was in terms of packet loss, reconstructed image quality, transmission time, execution time, and memory usage. They concluded that DWT is better than DCT as DWT had fewer packet losses (for Lena 32 * 32 it became clear from a distance 12 m and 7 m for Lena 64 * 64), higher image quality in terms of higher PSNR quality measure, minimal transmission time, faster execution time but large memory usage than DCT.

Ghorbel et al. [9] extended their work on their previous research [8] and made compression performance analysis for DCT and DWT with additional important parameter which is energy consumption. They measured battery life time and concluded that DWT is better than DCT in terms of image quality and energy consumption.

Ma et al. [10] surveyed multimedia compression techniques and multimedia transmission techniques and provided analysis for energy efficiency when applied to resource constrained platform. For image compression they discussed three important techniques JPEG (DCT), JPEG2000 (Embedded Block Coding with Optimized Truncation EBCOT), and SPIHT. They analyzed their work in terms of compression efficiency, memory requirement and computational load. They concluded that SPIHT is the best choice for energy-efficient compression algorithms due to its ability to provide higher compression ratio with low complexity. JPEG2000 (EBCOT) achieved higher compression ratio which mean better quality than SPHIT. However, complexity of EBCOT tier-1 and tier-2 operations caused intensive complex coding, higher computational load and more energy consumption for resource constrained systems.

3. Image compression techniques

Compression techniques can be classified into lossy and lossless compression techniques. If removing the redundancy is a reversible process and has no information loss, this is called lossless compression. On the other hand, if it has an information loss, it will be called lossy compression technique. Lossy compression techniques achieve a high compression ratio that may exceed 50:1 while preserving visual image quality of reconstructed image. Otherwise, lossless achieves a less compression ratio compared with lossy that can reach up to 3 or 4 times of original image. The benefit of lossy over lossless is to decrease encoding/decoding time, compression ratio and energy in case of power constrained applications.

Fig. 1 shows a classification of image compression techniques that will be discussed later.

3.1. Lossless image compression techniques

Lossless image compression techniques depend on two stage procedures [11]:

a. Decorrelation.
b. Entropy coding.

3.1.1. Decorrelation

In the first stage, decorrelation removes spatial redundancy between pixels by one of lossless image compression techniques. These techniques are classified into three categories prediction-based techniques [12], transform based techniques and multi-resolution based techniques [13].

3.1.2. Entropy coding

In the second stage, entropy coding which removes coding redundancy is based on Run Length Coding (*RLC*) and Statistical Coding [14,2].

Entropy definition is to identify often occurring symbols in the data stream with short code words in the compressed bit stream. Entropy coding used with some lossy compression algorithms i.e. JPEG. It reduces number of bits produced from quantizer's output for more compression.

As previously mentioned, lossless compression techniques do not lose any data that reduce compression ratio which leads image transfer over WSN to be very complicated. Lossless compressed image has a very large size compared with lossy one which consumes more power of sensor nodes and bandwidth in case of power constrained applications. Therefore, lossless compression is not preferred for image transfer over WMSN which leads us to focus on lossy compression techniques that highly encouraged in WMSN.

3.2. Lossy compression techniques

Lossy compression techniques provide high compression ratio compared with lossless compression ratio. In lossy compression, the compressed image is not usually the same as the original one, but forms a close approximation to the original image. Therefore, some form of distortion measure is required.

Distortion measure is a mathematical quantity that specifies how close an approximation to the original image. The most commonly used distortion measures in image compression are MSE and PSNR as discussed in previous section.

The most important lossy techniques used for restricted resources applications that are classified into 2 categories are discussed next as shown in Fig. 1.

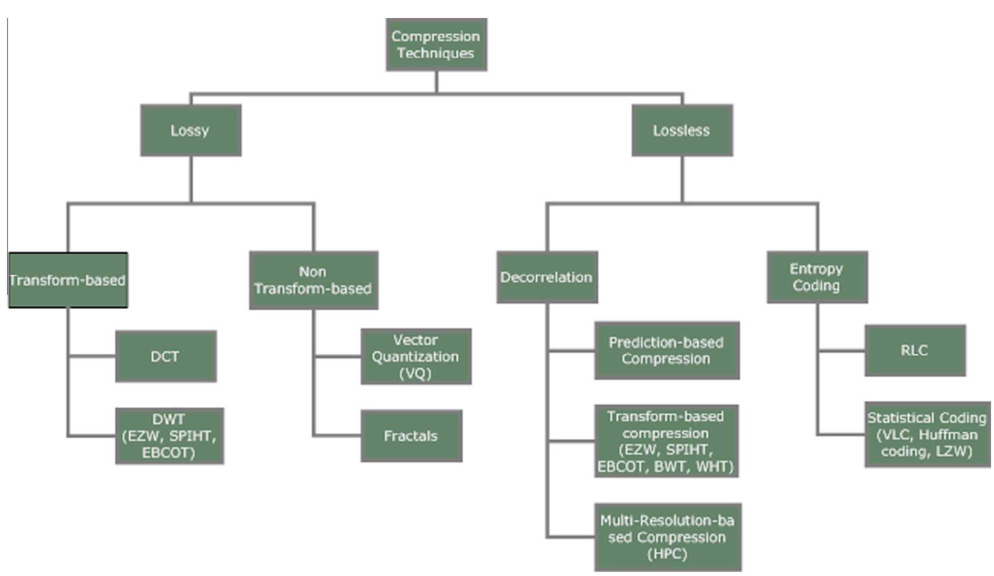

Figure 1 Classification of image compression techniques.

1. Transform-based transmission techniques.
2. Non-transform based transmission techniques.

3.2.1. Transform based techniques

Transform based techniques are based on converting input vector X (may be image) through transform T into another form Y which is less correlated than X.

Transform T does not compress any data; the compression comes from processing and quantization of Y components. For this target there is a description of Discrete Cosine Transform (DCT [15]), Discrete Wavelet Transform (DWT).

3.2.1.1. Discrete Cosine Transform (DCT). DCT [15] is the most widely used transform coding technique and the well-known compression scheme based on DCT is JPEG [5]. Fig. 2 shows lossy JPEG compression [17] scheme steps.

3.2.1.2. Discrete Wavelet Transform (DWT). Wavelet based transform [33] represented a signal with good resolution in time and frequency using a set of basis functions called wavelets. The 2D wavelets used in image compression are separable functions. Their implementation can be obtained by first applying low pass filter on rows to produce L and H subbands, then apply high pass filter on columns to produce four subbands LL, LH, HL, and HH. Then, in the second level, each of these four subbands is self-decomposed into four subbands $LL2$, $LH2$, $HL2$, $HH2$, and so on. It can be decomposed into 3, 4 ... levels. Fig. 3 illustrates the decomposition of the LL subband.

3.2.1.2.1. Set Partitioning In Hierarchal Tree (SPIHT). SPIHT [22] is a powerful wavelet based image compression algorithm that achieved very compact output bit stream than Embedded Zero Tree of wavelet coefficients (EZW) without adding an entropy encoder. This enhances its efficiency in terms of computational complexity. Moreover, progressive mode in SPIHT allows the process of coding/decoding to be stopped at any stage of the compression. Sorting pass and the refinement passes are used in coding process in SPIHT and three lists are used to store coding information, Fig. 4 shows a block diagram of SPIHT encoding steps.

3.2.1.2.2. Embedded Block Coding with Optimized Truncation (EBCOT). EBCOT is a block-based encoding algorithm, the basic idea of EBCOT is partitioning of each subband LL, LH, HL, HH produced by wavelet transform into small blocks called code blocks. Each block is coded independently. The popular image compression standard is JPEG2000 adopts the EBCOT image compression technique [5]. JPEG2000 block diagram is illustrated in Fig. 5.

3.2.2. Nontransform based techniques

Nontransform based techniques are based on vector quantizer as quantization process in lossy compression techniques has two types of quantizers scalar and vector quantizers.

3.2.2.1. Vector Quantization (VQ). As shown from VQ encoding block diagram which described in Fig. 6, the image is partitioned into blocks of pixels and each block represented by vector x. This vector compared against code words in the code book at encoder side which will get the index of the best code word match. Therefore, index stored in fewer bits will be transmitted instead of code word which achieves more compression ratio.

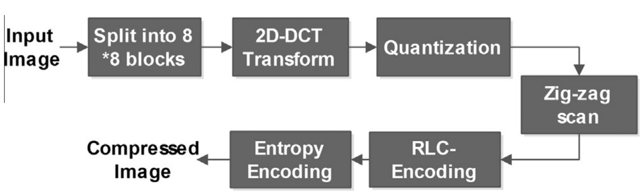

Figure 2 Lossy JPEG compression scheme.

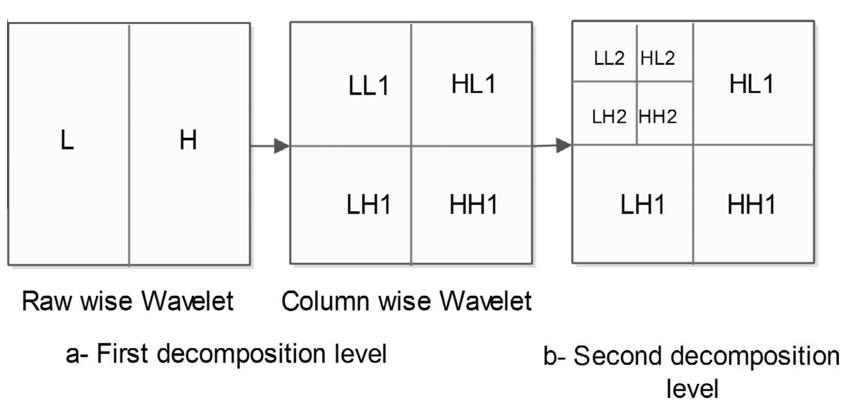

Figure 3 Two level of decomposition of 2D-DWT.

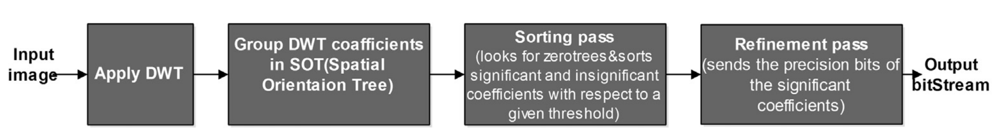

Figure 4 SPIHT encoding steps.

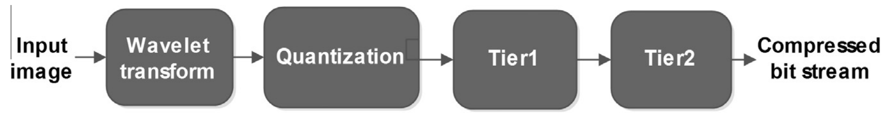

Figure 5 Block diagram of JPEG 2000.

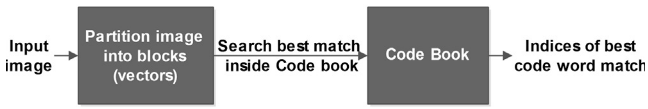

Figure 6 Block diagram of vector quantization encoder.

4. Comparative study between transform based compression techniques and non-transform based techniques

Table 2 provides a simple comparison between different transform and non-transform based compression techniques in terms of memory requirements, computational load, complexity, power consumption, compression ratio, processing speed and reconstructed image quality. Also, it specifies additional advantages/disadvantages.

By analyzing data provided in Table 2 for deciding the most suitable compression technique for WMSN, it is observed that:

Despite DCT has low memory implementation than DWT because of small block size (8 * 8), it is not the perfect choice for wireless multimedia sensor networks. Where, it consumes more power due to encoder complexity (about 60% of the whole power [16]). Ma et al. [10] showed that the floating point implementation of JPEG had the highest computational load as execution time reached to 103.12 ms which consumed most of encoder energy. DCT divides the image into blocks that cause blocks artifacts and degradation in image compression performance. Moreover, there are many attempts to decrease computational complexity in DCT, Fakhari et al. [20] introduced new high throughput architecture for DCT processor using parallelism and pipelining on Xilinx virtex5 FPGA. In addition, Zheng and Liu [21] introduced a fast DCT algorithm based on JPEG [17]. They used binary DCT on JPEG encoder, all coefficients were binary and multiplications were replaced with shifting and addition operations that are easier and faster to be performed by software and hardware. Mammeri et al. in [22] addressed the problem of adapting JPEG to energy requirement of visual sensor network (VSN). They produced an energy aware adapted version of JPEG called squared JPEG (S-JPEG) that was based on RBS notation (reduced block size (P)) and used the upper-left squared portion of each DCT block. In addition, two performance metrics were considered, image quality at the sink and energy consumption during communication. From experimental result they found that image quality and energy consumption increase with P.

There is a lot of literature based on discrete wavelet transform introducing an energy efficient technique for image compression in wireless sensor network. Ghorbel et al. in [9] proposed a performance analysis for image compression in WSN. They used DCT and DWT for their analysis and showed that DWT is better than DCT in terms of image quality and energy consumption. According to their figures, images qualities are better (for Lena 64 * 64) using DWT with PSNR reached to 33.55 db, 30.52 db using DWT, DCT respectively. On the other hand, they used rechargeable batteries Alkaline AA-NiMH 2850 mA h. They found that total batteries' lifetimes are 245.20 h, 281.34 h for DCT, DWT respectively. Nasri et al. [18] introduced an adaptive image compression scheme that minimizes computation and communication energies. This scheme is called skipped high pass sub-band "SHPS" that skips the computation of high pass coefficients as they have a very small value. Skipping is the least significant sub-band that reduces computational load and conserves energy. Additional technique beside SHPS [18], is called elimination high pass filter EHPF [19] that applied only low pass filter in the vertical direction not high pass filter thus produce only LL, LH sub-bands that contain more important image information. Actually, this is the reason that helps EHPF to achieve some saving in computation energy with less degradation in image quality, however, SHPS achieved higher energy saving with higher degradation in image quality. Those two proposed techniques create an adaptive compression technique called adaptive wavelet image compression and organization algorithm (AWICAO). Choosing the most effective technique depends on the trade-off between energy consumption and image quality.

Implementing SPIHT [23] in power constrained WMSN is an excellent choice as it achieves a higher compression ratio, less computational complexity, lower power consumption and less complex implementation over EZW [24] and DCT. SPIHT achieves very compact output bit stream without adding an entropy encoder which allows efficiency in terms of computational complexity and decreases amount of data required to be transmitted (for 512 * 512 gray scale image), the encoder speed is 7 times faster using MSPIHT [25] and the decoder is 11 times faster. MSPHIT has saved 0.5625 MB of working memory. Ma et al. in [26] proposed an improved version of SPIHT that improved PSNR by 0.2–0.4 over different techniques without arithmetic coding. On the other hand, SPIHT requires more memory storage as it has three passes that cause increase in complexity. Many researches nowadays work to adapt SPIHT for WMSN by minimizing number of passes or eliminate them using wavelet lifting based scheme instead of convolutional scheme. SPIHT has great results on achieving high compression ratios with minimal consumed power. Sun et al. [27] proposed a real time implementation of SPIHT using DSP chip which reduced memory cost by 13–14 times as well as coding time till it reached to less than 40 ms.

Chong and Ang [28] used SPIHT with image stitching to make multi-view image compression for WMSN and to remove the overlap and spatial redundancy. Certain sensor nodes had higher processing power than other nodes because they were designed to perform image stitching process. Image sensors first captured images and sent images to microprocessor (nodes with higher processing power) to perform image stitching and remove overlap redundancy. Then stitched image

Table 2 Transform and non-transform based image compression algorithms.

*	DCT	SPIHT	EBCOT	VQ	Fractals
Memory requirements	Low	Moderate	High	High	Low
Computational load	Low	Low	High	Very high	Very high
Complexity	Low	Moderate	High	High	High
Power consumption	Moderate	Low	High	High	Very high
Compression ratio	Low	High	High	Low	Very high
Processing speed	High	High	Low	Low	Low
Reconstructed image quality	Low	High	High	Moderate	Very high
Results	– Consumes about 60% of the whole power [32] – execution time of floating point implementation of JPEG reaches to 103.12 ms [10] – [9] PSNR 30.52 db for lena (64 * 64), DWT reaches to 33.55 db	– encoder speed is 7 times faster with MSPIHT [33] – SPIHT improved by 0.2 to 0.4 [34] – [35] reduces memory by 13–14 times, reduces coding time to 40 ms. Reduces transmitted data to 45% [30]	– Tier1 consumes 70% of encoding time [17]	– FRLVQ improves codebook PSNR [37]	– achieve largest compression ratio compared with JPEG [27]
Additional advantages	–	Allows coding and decoding at any stage	Robust against error transmission	Simplicity of decoder	Simple decoding process
Additional disadvantages	Consumes more power due to encoder and decoder complexity	Increases complexity due to memory storage, sorting procedures	Tier-1 is the highest computational part that consumes the most power of encoder side	Complexity increases with vector dimensionality	Decoding process is extremely computationally intensive and time consuming

was compressed with modified SPIHT coding to reduce amount of transmitted bits. Their simulation result showed that the data to be transmitted can be reduced by 10–45% using the stitched images. Fu-Xiao et al. [29] used SPIHT to minimize image distortion in WMSN based on three stages. First stage wavelet transform on original image, second stage, SPIHT of wavelet coefficients and finally context based arithmetic coding for SPIHT stage result. Also, Zhao-Jinchuang et al. in [30] introduced an image coding algorithm for separated subtree based on no list SPIHT and segment transmission for bit stream that save energy and decrease number of bits to be transmitted. In addition, Wallace et al. in [31] proposed memory-efficient implementation of the wavelet-based image coding in WSN. They studied the effectiveness of an appropriate wavelet filter type that performs best results for SPIHT algorithm in WSN. Furthermore, implementing SPIHT structure based on lifting cdf 9/7 filter with five levels of decomposition showed best results in terms of less computation and memory conservation.

EBCOT [32] is the highest algorithm in the performance of compression quality. However, the operation of Tier-1 is responsible for arithmetic encoding and context formation for encoding code block. Thus, consumed most of encoder's power and consequently increase power consumption, computational complexity, memory required and processing time. Therefore, EBCOT not very beneficial for power constrained WMSN. It was reported in [33] that Tier-1 operation consumed more than 70% of encoding time followed by the DWT stage.

Vector quantization has no transformation block, such as DCT or DWT, and entropy encoding block, which may reduce the computation complexity. This is attributed to simplicity of decoder operation which is responsible for only picking up the matching code word of vector index related to the code book at encoder side. Then reconstruct the image close to input image. Despite this, with the increase of vector dimensionality, complexity will increase and consequently an increase in power consumption and a decrease in processing speed occur. Therefore, VQ could be acceptable for power constrained WMSN with attempts focus on adapting VQ complexity with huge vector dimensionality. VQ technique was presented in [34] which used FRLVQ before applying standard VQ algorithm as preprocess. The proposed algorithm helped to design codebook in an image compression application. An improvement in resulted codebook PSNR was achieved by FRLVQ-fuzzy VQ which was approved by experimental results.

Fractals achieve higher compression ratios and good quality of reconstructed image over DCT, DWT and VQ. Jackson et al. in [35] proposed a comparative analysis of image compression techniques and showed that fractals achieved the largest compression ratios compared with JPEG. On the other hand, fractals encoding process is computationally intensive due to complex task of finding all fractals and searching for the best match thus consumes more and more power which shortens life time of WMSN. Those findings are underlined in [5,33].

5. Research area and preliminary proposal

Due to the wide range of the WMSN applications based on energy constraint, compression algorithms may be considered as an important open research. In such area, image compression through low-complexity and resource-efficient transforms needs to be addressed to continue the network lifetime where power management is realized through sharing computational load among sensor nodes. Based on the taxonomy represented in Fig. 1, it can be concluded that the most important research area in this topic is as follows:

The DCT, consumes the most power within a DCT-based compression scheme. It will be useful to decrease its computational complexity through establishing a novel algorithm that helps in: (1) Parallel and pipelined implementation of multidimensional DCT, which allows the main processing elements and arithmetic units to operate in parallel, leading to the reduction of both the computational complexity and the internal storage, as well as, the rise of throughput. (2) Working with fixed-point instead of the more complicated floating-point DCT. Comparing to fixed-point DCT, working with the floating-point DCT exhibits high energy consumption. (3) Converting the greedy operations such as multiplications into light operations. Indeed, DCT can be implemented using light operations such as shifts and additions only.

The adoption of the EZW as a compression tool in WMSN can be valuable in terms of power consumption. This is due to the relatively simple complexity of its encoder and its progressive paradigm. An open research work should be the adaptation of the EZW algorithm to the power-constrained WMSN. That can be achieved by minimizing the number of passes to reduce the memory required to store the significant wavelet coefficients found at each pass.

Implementing SPHIT on power-constrained devices is an excellent idea. Its advantages over JPEG and EZW in terms of high compression ratio, less computational complexity, and low power consumption as well as, less complex implementation make it possible to play an interesting role in image compression for power-limited applications. An open research work should be the adaptation of the SPIHT algorithm to the power-constrained WMSN. This can be done via substitution of lists by flags to reduce the memory usage, or using wavelet lifting scheme instead of the convolutional wavelet based. In addition, using one sorting list instead of three lists to store wavelet coefficients reduces memory usage.

Compared with SPIHT, implementing EBCOT on power constrained devices achieves higher compression ratio but it is more computational complex and higher power consumption. Therefore, an open research work should be the adaptation of the EBCOT algorithm to the power-constrained WMSN. This can be achieved by merging the coding passes into one pass in order to improve the overall system performance and reducing system complexity, as well as, minimizing the memory requirements.

Vector Quantization (VQ), can be an acceptable algorithm for WMSN as it achieves reasonable compression ratio and simplicity of the encoder compared with DCT or DWT. However, its complexity is increasing with vector dimensionality that consumes more power. Reducing memory required by VQ is an open research area to be acceptable for WMSN.

On the other hand, Fractals achieve the highest compression ratio compared with other compression techniques, however, fractals shorten WMSN sensors life time due to intensive complexity of the encoder. An open research issue could be the adaptation of the fractals to the power-constrained WMSN. This can be performed by integrating fractals with transformations such as DCT and DWT to decrease its computational complexity.

There are some of recent papers which introduced some of certain techniques that are suitable for implementation on the hardware platform. Kaddachi et al. [36] presented architecture of FPGA suitable for WMSN, the core is 16-bit RISC microprocessor designed to operate at low frequency. They combined normal processor and image processing functions in one system. This architecture used 2D-DWT for color image compression using lifting scheme. For system implementation they used a CMOS camera, a Spartan-3 FPGA, a WSN transceiver and a battery. They concluded that DWT core consumed only 2.68 mW in active mode which is competitively low in comparison with other COTS microprocessors. Sun et al. in [27] proposed a real time implementation using DSP chip. They chose DSP-C6201 fixed point DSP that can perform up to 1600 MIPS. Their work reduced the memory cost by 13–14 times and coding time was greatly reduced as well. Fakhari et al. [20] introduced high throughput architecture for DCT processor using parallelism and pipelining on Xilinx virtex5 FPGA. Using parallelism in calculations for 64 different parts with a pipeline for reading, calculating and writing data contributes to speed up DCT operation dramatically. FPGA based image compression for low power WCSN was introduced by [37]. They used fast zonal DCT to reduce number of DCT coefficients needed to be computed, quantized and encoded. Hardware solution depended upon FPGA Virtex V had achieved shorter processing time. It is equal to 1.45 ms for $k = 8$ and 0.99 ms for $k = 4$, where k is size of the zonal DCT. Saving in processing time can be considered (around 99% of reduction). Also, DCT approach helped in reducing the energy consumption about 21.3% when $k = 4$ and 26.18% for $k = 2$.

6. Conclusion and future work

This survey has discussed various compression techniques for WMSN with comparison among them and factors that affect compression performance. Image quality, compression ratio, speed of compression and power consumption are the most important metrics discussed for compression performance. Performance metrics differ according to operating platform. Resource constrained platforms i.e. Wireless multimedia sensor networks have some limitations on memory, power consumption, processor capabilities and life time of sensor nodes. Therefore, SPIHT is the most powerful technique that can be used due to the following reasons: SPIHT achieves very compact output bit stream and low bit rate with high compression ratio than that of its predecessor's EZW without adding an entropy encoder, which allows its efficiency in terms of computational complexity. Moreover, it uses a subset partitioning scheme in the sorting pass to reduce the number of magnitude comparisons, which also decrease the computational complexity of the algorithm. Finally, the progressive mode of SPIHT allows the interruption of coding/decoding process at any stage of the compression. Adapting SPIHT for WMSN to reduce memory required is an attractive future research area.

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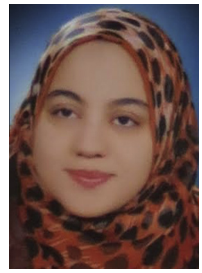

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