Optimization of Energy Consumption in Image Transmission in Wireless Sensor Networks (WSNs) using a Hybrid Method

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Abstract. In wireless sensor networks (WSNs), sensor nodes have limited resources with regard to computation, storage, communication bandwidth, and the most important of all, energy supply. In addition, in many applications of sensor networks, we need to send images to a sink node. Therefore, we have to use methods for sending images in which the number and volume of packets are optimized to save energy. Data compression is one of the optimization methods in energy consumption. In this paper, an effective compression algorithm is proposed to reduces computational and energy consumption and eventually, increases the overall network lifetime. Here in, we use a combination of three DCT, DWT and SWT wavelet transforms to achieve our goals. Simulation results show that the proposed algorithm achieves its goals with regard to data compression and reduction of energy consumption, and improves the network lifetime.

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1   Introduction

In recent years, extensive researches have been performed in the field of wireless sensor networks, and the wireless networks could grow to such an extent, as to exert significant impact on developing and improving the telecommunications, instead of using transmission wire and radio frequency communication [15, 18]. They were first used by the military for surveillance purposes; since then, they have been largely used in industrial and civilian cases such as the weather, pollution, traffic control, and medical applications [7, 32].

Wireless sensor networks face many challenges due to their special features. These challenges are mostly related to the energy constraints, data processing, communication mechanisms, and routing. One aspect of the wireless sensor networks is the energy efficientcy of wireless sensor networks. In this manner, designing a network can be influenced by several factors, including the fault tolerance, scalability, cost of production, hardware limitations, sensor network topology, environment, transmission, power consumption, network lifetime, reliability, scalability, and some unpredictable factors. These factors are important in designing sensor network protocols [13].

A sensor network consists of many sensor nodes which are widely distributed in the environment gathering information from their environment and collectively pursuing a certain goal. In wireless sensor networks, each sensor node has limited power and the obtained information from the nodes must be transmitted to a central node [2]. The low power, low cost, small size, and distributed components in wireless sensor nodes made the local processing, wireless communications, collecting and distributing information on wireless networks do one easily, and we, effortlessly, obtain the information about where it is not accessible [5].

The energy consumption is one of the most important performance metrics for wireless sensor networks [29], because it is directly related to the lifetime of the network. The different features of the wireless sensor networks, such as the power resource, limited processing [9], density, low bandwidth, low memory sizes, and limited energy, make the network susceptible. In terms of the power consumption, the operation of a wireless sensor node can be divided into three parts: sensing, processing, and transmission. Among these three operations, the most power consuming task is the data transmission. Consequently, if we minimize the size of data by compression, it will reduce the transmission power. However, by applying the data compression, much of the processing power will be required to perform a compression algorithm. In order to reduce the total power consumption, the sum of the consumed power by transmission and processing should be reduced. The consumed power by the original data string reduces to the data string which must be smaller than the consumed energy difference transmitting between each bit of the data string. Applying the image compression before transmitting in wireless media is effective in red ucing the amount of energy, consumption. However, to select an image compression algorithm, it is crucial to have less access to the memory during the execution time [24].

The image compression is a method to reduce the size of the graphics file without losing quality [12]. The goal of the image compression is to remove the redundancies for minimizing the bit number required to represent an image [11]. The data compression can be used to

reduce the amount of the transmitted data over the wireless networks. In Figure 1, the image compression system is shown. This method leads to a reduction of the required inter-node communication, which is the main power consumption in the wireless sensor networks [25]. The compression is a process which reduces the real information amount by removing data redundancies. The data compression technique combines the related data and prevents them from sending the additional packet, so this technique can be effective in reducing the number of the sending packets. In the wireless sensor networks, many image compression algorithms are used. Indeed, the most popular methods, including JPEG and JPEG2000, can have the highest energy consumption when transmitting uncompressed images [8].
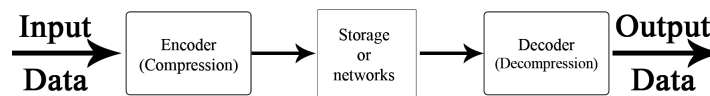

Figure 1: Image Compression System [8]

Wavelet transformation is considered to be a proper tool for signal processing applications. Take the information compression as example. It is of great importance regarding transformation of image and signal processing to possess characteristics, such as perpendicularity, symmetry (possessing the linear phase), and the high rank estimation. Although, it is impossible to simultaneously achieve all the above-mentioned conditions in the typical wavelet transformation. Multiple wavelet transformation is an extension of the scalar wavelet transformation which makes it possible to simultaneously achieve the above-mentioned conditions. In this paper, it has been attempted to introduce this kind of transform and use it in the image compression. Discrete Cosine Transform (DCT) is one of the most well-known reduced dimension-based methods and the main component-based analysis, and is one of the transforms that is frequently used in the image and the digital signal processing. The two dimensional cosine transform is a standard technique for compressing and coding the images (Figure 2).

The main idea of the discrete wavelet transform is the time-scale description of the discrete signal by means of the digital filters. In one-dimensional discrete wavelet transform system, first, the signal is transmitted from a half-band low-passed digital filter with the impulse response and, as a result of filtering, all the frequency components are removed in which their amounts are more than half of the highest frequency in the signal. Similar trend is also done using a half-band high-pass digital filter with the impulse response. As a result, two copies of the original signal, one high-pass and the other low-pass with the reduced length, are obtained from the first stage of implementing the wavelet transform. One of the most important characteristics of the DCT is that it saves most signal information in the limited coefficients found in the low frequencies. In the case of the image, most image information is saved in the matrix placed up on the left side, and it can use this information as a notable characteristic [28].

The Stationary Wavelet Transform (SWT) is a wavelet transform algorithm designed to overcome the lack of translation-invariance of the discrete wavelet transform (DWT). In the functional analysis, the DWT is one of the wavelet functions have been sampled (Figure 3). The low filters are sampled in this method, the Haar wavelet is a special series of functions which
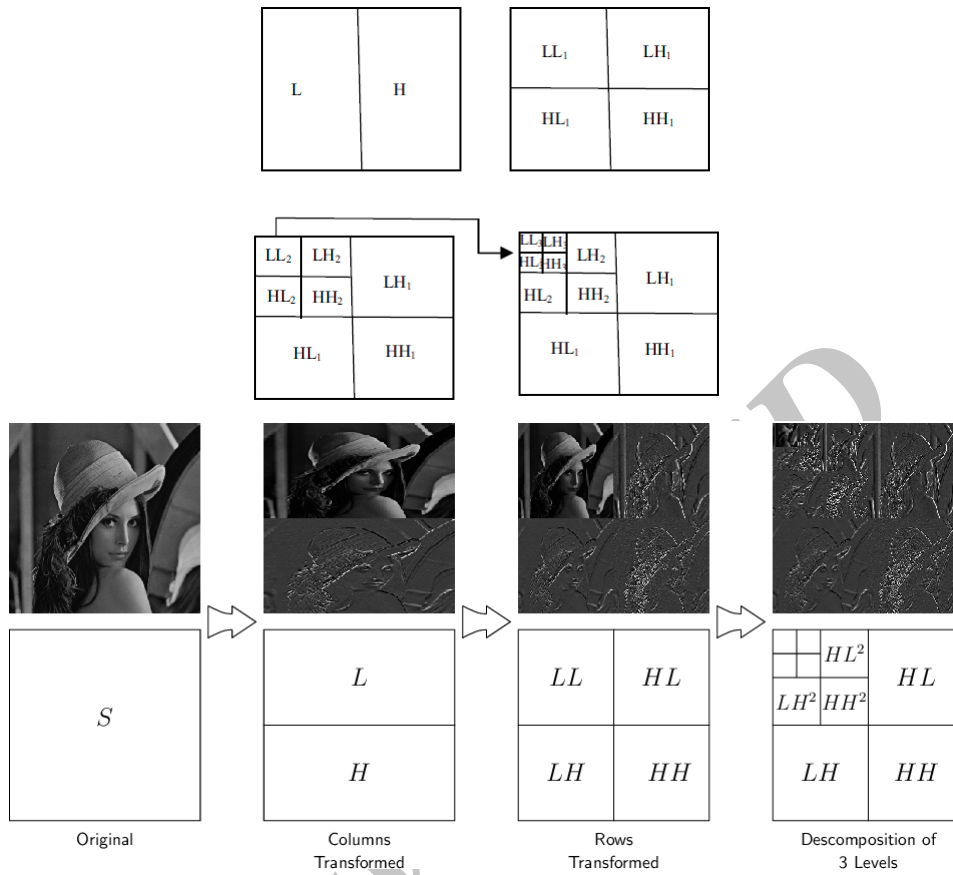
Figure 2: (a) Wavelet transform structure [15], (b) DCT structure [9]

now is known as the first wavelet proposed by Alfred Haar, a Hungarian mathematician for the first time, in 1910 [33]. The Haar wavelet is the possible simplest series. Non-continuity is the wavelet problem, and as a result, it can't be derived. The stationary wavelet transform is one of those whose most important characteristic is being time constant. This method is similar to the discrete wavelet transform, excluding that sub sampling of signal is not conducted in this method and the high filters are sampled instead [16].

The rest of this paper is organized as follows: In Section 2, a brief review of the importance of the wireless sensor networks in recent years is presented. The details and performance of the proposed method evaluated by using MATLAB simulation are explained in Section 3, and finally, the conclusions is presented in Section 4.

2   Related Works

The image compression is a well-established research field, but the sensor networks present a context in which the new design issues have to be addressed. The main characteristic of
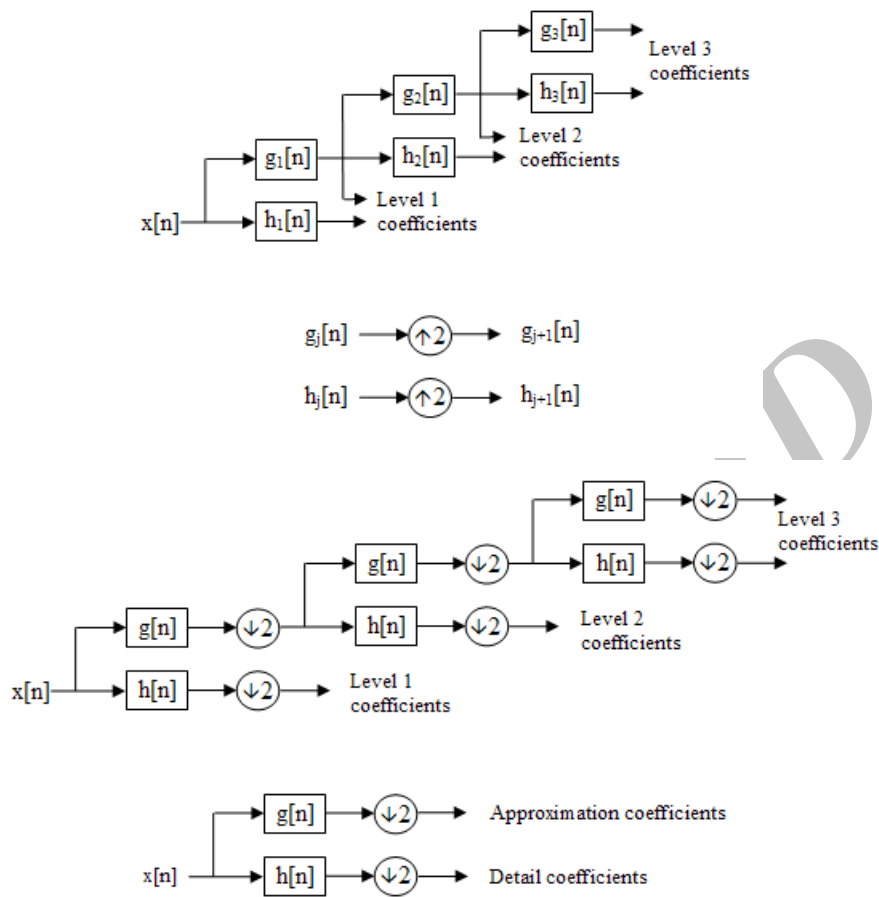
Figure 3: (a) SWT structure [19] (b) DWT structure [19]

such networks is the nodes with limited resources. In fact, the primary focus on the energy, computational power and memory allocation. In this case, a large variety of the compression algorithms have been proposed. The image compression techniques and processing algorithms in a wireless sensor network are classified in two categories: the local processing and compression as well as, the distributed processing and compression [15], [6]. When the processing is complete, the local algorithms are useful. The complete processing, including the image compression and transmission, is less energy consuming than the single transmission of uncompressed image. Some works have demonstrated that the complexity of certain compression algorithms does not lead to the greater power consumptions than the simple transmission of the uncompressed image.

For instance, [17] presents a novel method which employs the cross layer technique through the various layers as it helps achieve efficient transfer of images across the network. In [20], a novel, robust, and energy-efficient scheme, called Priority Image Transmission (PIT), in WSN is proposed. This algorithm is based on a wavelet image compression, and use various priority levels during image transmissions. Different priorities in the compressed image are consid-

ered. The information of the significant wavelet coefficients is transmitted with higher quality assurance, where as relatively less important coefficients are transmitted with lower overhead.

The mechanism proposed in [1] proposes a new image compression of grayscale technique called Adaptive Haar wavelet transform theory to provide a lossy compression. This method was introduced to overcome the drawback of the original theory by improving the compression capability. It takes into consideration the visual effect on the output image by preserving the image details. Multi scale Retinex (MSR) technique was introduced to enhance the compressed classified images from over or under-expose image contrast. This work aims to increase the lifetime of sensor by reducing the energy consumption to transfer images in WSN.

In [21], an image sensor network, with the principles of Distributed Source Coding (DSC) for efficient compression, is considered. This method relies on high correlation between the sensor nodes. The algorithm consists of two phases: the training phase and the main phase. In the Training Phase, an aggregation node or a cluster head determines the correlation of the sources, and in the Main Phase, the image is coded based on the computed correlations.

The adopted approach in [31] uses a local compression of JPEG2000 standard. In this approach, a power-aware technique that incorporates the JPEG2000 standard to compress captured images from the wireless camera nodes is introduced. They formulated the image transmission problem as an optimization problem and proposed a heuristic algorithm called MTE (Minimize Total Energy). The approach uses a technique similar to that of stereo-image compression to identify the overlap in the images of the adjacent sensor nodes.

The paper [26] estimates perceived image quality using sparse representations obtained from generic image databases through an unsupervised learning approach. A color space transformation, a mean subtraction, and a whitening operation are used to enhance descriptiveness of images by reducing spatial redundancy; a linear decoder is used to obtain sparse representations; a threshold stage is used to formulate suppression mechanisms in a visual system. This paper proposed quality estimator UNIQUE which is tested on the LIVE, the Multiply Distorted LIVE, and the TID 2013 databases and compared with 13 quality estimators. Experimental results show that UNIQUE is generally a top performing quality estimator in terms of accuracy, consistency, linearity, and monotonic behavior.

In [23], a novel method to compress the image using an improved wavelet based polyomino's is proposed for lossless compression technique. This method increases the quality of image at the receiving end. The compressed image is transmitted by Energy Efficient High Quality Image Transmission scheme (EEHQIT) to achieve energy efficient image transmissions in Wireless Sensor Networks (WSNs). However, the existence of noise makes the imaging system a complicated task. In this scenario, reducing noise using filter technique for achieving high quality compression image transmission is desired. To avoid noise in the compressed image, a scheme of spatial averaging filter is presented and tested on the transmitted compressed image.

The paper [22] presents two techniques for robust image transmission over wireless sensor networks. The first technique uses watermarking, whereas the second technique is based on the Reed Solomon (RS) coding technique which considers the distortion rate on the image while transmission for wireless sensor networks. The authors studied the image quality distortions occurring due to packet losses using two scenarios, considering watermarked and raw images to improve the Peak-Signal-to-Noise-Ratio (PSNR) rate. The paper [27] presents image filtering

techniques on larger DCT block which speeds up the operation by eliminating certain elements. This method uses simple linear operations, such as matrix multiplication, which is appropriate for efficient hardware implementations. This paper improves the compressed image quality and also aims to optimize the energy consumption using combination of the SWT, DWT, and DCT methods.

3 The Proposed Methods

Due to the limitation of the energy resources in the wireless sensor networks, energy efficiency is a key issue in wireless sensor networks [4]. The nodes in such networks face many limitations in the bandwidth and energy in terms of the processing unit, so that if the energy is over, the sensor nodes will be useless [10]. However, due to the limitation of memory and the processing speed, many compression algorithms cannot be used as well. To solve this problem, we use the DWT and DCT compression algorithms allowing an efficient trade-off between the energy consumption and the image distortion [8]. In addition, the SWT algorithm is used to improve the compressed image quality. The proposed method is the combination of DCT, SWT and DWT.

3.1 Execution Method

The following semi-code considers the generalization of the proposed algorithm execution method. This algorithm is reversible in the sink node. It means that the original image can be obtained in the sink node from compressed image.

Algorithm 1 (Proposed Algorithm): The generalization of the proposed algorithm execution method

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 1: Begin Algorithm
 2: Input Image $X = (X_1, X_2, \cdots, X_N)$
 3: if $X_i = *.Bmp$ do
 4: DCT $(X) \to I$
 5: DWT (I)+ SWT $(I) \to S$
 6: Downsampling $(S) \to X$
 7: else
 8: Back to step 2
 9: end if
10: End Algorithm

According to the generalizations noted above, at first the input image according to the simulated program is selected. The selected image suffix is *bmp*, its color depth is 8 bits and

its size is $512 * 512$. Then, the DCT is applied on the compression selected image. The DCT is popular for the image signals, because it fits well with the statistical characteristics of the existing image signals and the reason of being appropriate for the image compressing is that one block of the image usually can be shown by the DCT coefficients with the very low frequency. Thus, at first, it applies the DCT transform to the image. In the DCT, the image is subdivided in to a form of $8 * 8$ blocks and the DCT is separately implemented on each block and finally the image is created by arranging the blocks together.
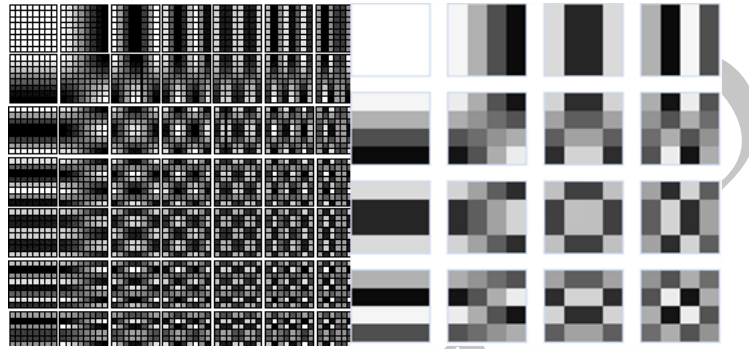

Figure 4: Fundamental block pattern according to DCT $8 * 8$ ([30]).

The DCT wavelet transform is achieved by using (1):

$$B(p,q) = a_p a_q \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} A(m,n) \cos \frac{\pi (2m+1)}{2M} \cos \frac{\pi (2n+1)}{2N} \begin{cases} 0 \leq p \leq M-1 \\ 0 \leq q \leq N-1 \end{cases} \tag{1}$$

It is noted that reducing the light contrast in the DCT leads to data loss in the second block.

in which p and q are the point numbers of the DCT from which the obtained amounts of $B(p,q)$ and the matrix coefficients of the DCT are achieved. The reverse matrix is obtained from (2):

$$A(m,n) = \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} a_p a_q B(p,q) \cos \frac{\pi (2m+1)}{2M} \cos \frac{\pi (2n+1)}{2N} \begin{cases} 0 \leq p \leq M-1 \\ 0 \leq q \leq N-1 \end{cases} \tag{2}$$

$$a_p = \begin{cases} \frac{1}{\sqrt{M}} & p = 0 \\ \sqrt{\frac{2}{M}} & 1 \leq p \leq M-1 \end{cases} \tag{3}$$

$$a_q = \begin{cases} \frac{1}{\sqrt{N}} & q = 0 \\ \sqrt{\frac{2}{N}} & 1 \leq q \leq N-1 \end{cases} \tag{4}$$

Then, the compression of the compressed image is concerned with the DCT method, using the SWT and DWT methods. The Haar wavelet is used for implementing the wavelet. It is considered that the implementation of Haar wavelet in terms of the speed is faster than the other wavelets. The Haar wavelet is defined as follows:

$$\varphi\left(t\right) = \begin{cases} 1 & 0 \leq t \leq 1/2 \\ -1 & 1/2 \leq t \leq 1 \\ 0 & \text{otherwise.} \end{cases} \tag{5}$$

and also the comparative function is equal to:

$$\phi\left(t\right) = \begin{cases} 1 & 0 \leq t \leq 1 \\ 0 & \text{otherwise.} \end{cases} \tag{6}$$

The static wavelet leads to less noise in output due to removing noise characteristic. Finally, for the output image, the frequencies, or the low-pass filter, are used. The outline of the proposed method can be seen in Figure 6.

Figure 5: Outline of the proposed method.

3.2   Simulation of the Proposed Method

The Peppers original image can be seen with the 89 kb volume in Figure 6. Obviously, the compressed file volume reaches 66 kb in the DCT, DWT and SWT methods, but the file volume is reduced to 18 kb in the proposed method. The proposed method is applied to the standard images of the gray surface. The results of Lena's image steps are presented by bitmap file format.

Figure 6: Comparison of the proposed image compression methods.

Original (input) image and the output image histograms are presented in Figure 7.

Figure 7: Original (a) and compressed (b) image histogram comparison.

4 Evaluation of the Proposed Method

In the above mentioned methods, the high-frequency characteristics of images are discarded, and the low-frequency (original) characteristics are transmitted to output images. All methods are accompanied by losses, i.e., while transforming images, some of the characteristics are discarded. As all three the DCT, the DWT and the SWT methods are combined together, it takes more time to code the program.

The compression ratio, consumed energy, quality percentage, and algorithm rank are presented the Table 1. The graphs of methods are presented in Figure 8 as well.

Table 1: Comparison of the compression ratio, consumed energy, quality percentage and algorithm rank in DCT, DWT, SWT and COMPLEX.

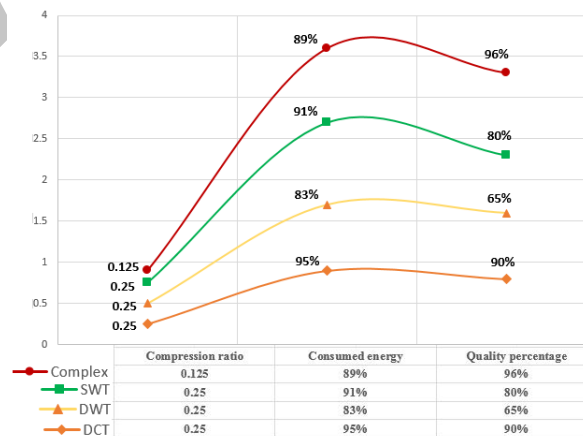| Transfer type	Input File	Output File	Compression ratio	Consumed energy	Quality percentage	Algorithm rank
DCT	Pepers.bmp	Dct.bmp	0.25	95%	90%	$8N^3$
DWT	Pepers.bmp	Dwt.bmp	0.25	83%	65%	$2N^2$
SWT	Pepers.bmp	Swt.bmp	0.25	91%	80%	$2N^2$
Complex	Pepers.bmp	Complex.bmp	0.125	89%	96%	$8N^4$

Figure 8: comparison of the compression ratio, consumed energy, quality percentage and algorithm rank in DCT, DWT, SWT and COMPLEX.

By comparing the proposed method with other methods, it is found that the proposed method is more optimized in terms of compression ratio, consumed energy, and quality.

5   Conclusions

In wireless sensor networks each sensor node limits energy and also seeks to transmit its data to a central node. Other characteristics of wireless sensor networks, includ limited processing, density, low bandwidth, and low memory sizes, limit network lifetime. The limited life time of network causes the energy consumption to become a major challenging issue. One of the most useful energy saving methods is the data compression method. By using image compression method, the consumed energy can be reduced, and this leads to removing the redundancies. In this paper, the combination of three wavelet transforms, i.e. the DCT, the DWT, and the SWT, was used to achieve the existing purposes. Some wavelet transformation methods were compared and evaluated. The network life time can be improved by limiting the size of the message sending through the network. The results show that the proposed method is more optimal in terms of the quality and the consumed energy, using the images of the gray surfaces rather than using those of the SWT, DWT or DCT methods. It is expected to implement a system having the ability to compress all the image formats in the future works.

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بهینه سازی مصرف انرژی در انتقال تصویر در شبکه های حسگر بی سیم با استفاده از روش ترکیبی

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چکیده

منابع گره های حسگر به کار رفته در شبکه های حسگر بی سیم محدود بوده و به همین دلیل توان محاسباتی، حافظه، پهنای باند و مخصوصاً باتری آنها محدود است. از طرفی در بسیاری از کاربردهای شبکه حسگر ما نیاز به انتقال تصویر به گره چاهک داریم. بنابراین ما برای کاهش مصرف انرژی باید از روش هایی برای ارسال تصویر استفاده کنیم که در آنها تعداد و حجم بسته ها کم باشد. یکی از روشهای بهینه سازی مصرف انرژی فشرده سازی اطلاعات است. در این مقاله یک الگوریتم فشرده سازی کارا پیشنهاد شده است که حجم محاسباتی کمتری داشته و مصرف انرژی آن پایین است و همین باعث افزایش طول عمر شبکه می شود. در اینجا ما از ترکیب سه تبدیل DCT ، DWT و تبدیلات موجک SWT برای دست یابی به اهداف خود استفاده می کنیم. نتایج شبیه سازی نشان می دهد که الگوریتم پیشنهاد در فشرده سازی داده ها و کاهش مصرف انرژی و بهبود طول عمر شبکه به اهداف خود می رسد.

کلمات کلیدی

شبکه های حسگر بی سیم، مصرف انرژی، فشرده سازی تصویر، تبدیل موجک گسسته، تبدیلات کسینوسی گسسته، تبدیل موجک ایستا.