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Data compression techniques in Wireless Sensor Networks

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HIGHLIGHTS

- A comprehensive literature review for data compression techniques in WSN is presented.
- DCT and DWT compression techniques are analyzed and implemented using TinyOS on a hardware platform TelosB.
- DWT has a higher PSNR and a faster compression technique than DCT.
- The experimental results show that the overall performance of DWT is better than DCT.
- As the number of intermediate nodes is increased, the performance of both techniques degrades.

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ABSTRACT

The advancement in the wireless technologies and digital integrated circuits led to the development of Wireless Sensor Networks (WSN). WSN consists of various sensor nodes and relays capable of computing, sensing, and communicating wirelessly. Nodes in WSNs have very limited resources such as memory, energy and processing capabilities. Many image compression techniques have been proposed to address these limitations; however, most of them are not applicable on sensor nodes due to memory limitation, energy consumption and processing speed. To overcome this problem, we have selected Discrete Cosine Transform (DCT) and Discrete Wavelet Transform (DWT) image compression techniques as they can be implemented on sensor nodes. Both DCT and DWT allow an efficient trade-off between compression ratio and energy consumption. In this paper, both DCT and DWT are analyzed and implemented using TinyOS on TelosB hardware platform. The metrics used for performance evaluation are peak signal-to-noise ratio (PSNR), compression ratio (CR), throughput, end-to-end (ETE) delay and battery lifetime. Moreover, we also evaluated DCT and DWT in a single-hop and in multi-hop networks. Experimental results show that DWT outperforms DCT in terms of PSNR, throughput, ETE delay and battery lifetime. However, DCT provides better compression ratio than DWT. The average media access control layer (MAC) delay for both DCT and DWT is also calculated and experimentally demonstrated.

1. Introduction

Wireless Sensor Networks (WSNs) are a group of dedicated sensors and actuators [1]. They have wireless infrastructure for communication and are used to monitor environmental changes at different locations. A network has several nodes and each node is connected to other node. The nodes may have different functions to perform such as exchanging or relaying data, sensing, among others. The node used for sensing the data is called a sensor node and the one relays the data is called a router. The one used for exchanging the data with other networks is the base station or a sink node.

Each sensor node is equipped with transducer, radio transceiver, microcontroller and power supply. The transducer produces electrical signals depending upon the physical or environmental changes. The radio transceiver is used for data transmission and reception whereas microcontroller is used for processing the data.

In many applications, sensor nodes are deployed randomly to monitor the surroundings and they do not have deterministic location. They can communicate with each other through radio transceiver. The data is collected at the sensor node and then transmitted to the sink node which in turn is connected to the

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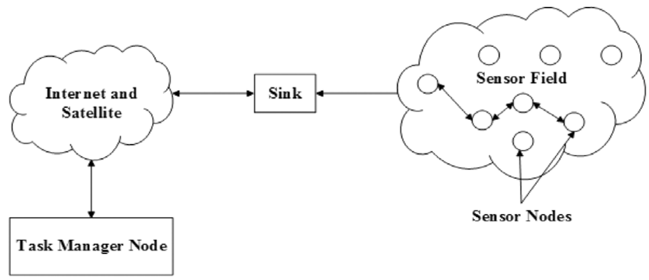

Fig. 1. Structure of typical wireless sensor network.

satellite network. The satellite network then transmits the data to the application as shown in Fig. 1.

There are several emerging applications of WSNs such as surveillance, recognition, tracking, localization and object detection that require vision capabilities [2]. WSN applications are mainly used for long-term monitoring of environments, while sensor nodes are mostly battery-powered. This makes saving the energy of those batteries with the main objective to increase the lifetime of sensors is mandatory. In sensor nodes, most energy is consumed during transmission [3]. One solution to save energy is to reduce the amount of data to be sent. This can be achieved by using data compression. The advancement in data compression algorithms has become essential in multimedia applications.

Image compression algorithms have been developed in order to reduce the size of the image [2]. The applications based on images such as medical imaging, cameras, video-on-demand systems contain large amounts of data to transmit. Thus, radio transceiver nodes consume more energy than receiving nodes. We noticed from the literature that there are many compression algorithms inapplicable for real-time environment due to resource constraints such as memory and processor speed. All of the aforementioned issues show that this is a very challenging research problem. Therefore, to overcome the issues, energy efficient compression techniques became a necessity. This paper is an effort towards this direction. In this paper, we have analyzed and implemented DCT and DWT image compression techniques on a hardware platform TelosB using TinyOS. We have evaluated both the techniques using different performance metrics. Also, we have analyzed the results that performance of DWT is better than DCT. However, changing the topology affects the performance of both DCT and DWT techniques.

The remainder of the paper is organized as follows. We describe the related work in Section 2. DCT and DWT compression techniques are described in Sections 3 and 4 respectively. Section 5 presents the experimental performance evaluation and comparison of both compression techniques. Finally, Section 6 concludes our findings of this research.

2. Related work

With the emergence of wireless technologies, WSNs have gained the interest of many researchers [4,5]. Moreover, there is a great interest in deploying WSNs for multimedia applications [5].

Wireless sensor networks in multimedia industry have different applications in various fields such as traffic surveillance, health care, security monitoring, etc. The multimedia data such as audio, video and images is normally delay sensitive and bandwidth limited. These characteristics of multimedia data require enough resources to transmit data from source to sink. Many applications are resource constraints, such as limited energy supply, limited memory and low processing speed. These constraints provide interesting challenges to achieve the desired results for specific applications [6]. Hence, in order to tackle these limitations, a number of techniques have been proposed. In this paper, we focus on DCT and DWT and described in the following subsections.

2.1. Discrete Cosine Transform (DCT)

There are several attempts by many researchers in the data compression based on DCT. The basic idea of DCT is to convert a signal into basic frequency components. For the purpose of compression, an image is divided into several blocks. Then, the sum of cosine functions on different frequencies can be mathematically used to express each block of an image. For example, Joint Photographic Experts Group (JPEG) [7] is a renowned compression scheme based on DCT.

This technique has been analyzed in different ways, including reducing the computation complexity, increasing the compression ratio, and minimizing power consumption [8]. The power consumption of DCT-based methods is more than DWT-based techniques [4]. Many researchers have attempted to decrease its computation complexity. For example, researchers in [9], have used parallel pipelined implementation of multidimensional DCT. In order to reduce computational complexity, both arithmetic units and processing elements operate in parallel in their proposed method. In [10], researchers used the same concept but with the integer cosine transform. The integer cosine transform has less computational complexity. This has been used to reduce the complexity what achieved and demonstrated in [9].

The authors in [11] have performed the evaluation on video surveillance and analyzed the trade-off between power consumption and image quality. They have used integer DCT rather than floating-point DCT and showed how image compression has an impact on image delay using automatic repeat request (ARQ). Moreover, researchers in [12] have developed image sensor network platform to transmit compressed images using multi-hop sensor network. They performed their compression on JPEG and its variant JPEG2000. Then, they showed that JPEG2000 is more appropriate than JPEG as they have compared the two on the basis of packet loss and bit errors. Since their evaluation did not consider power consumption, it would be unpractical for all multimedia sensor network applications. The work presented in [13], is an attempt to propose an algorithm that is energy efficient for the image compression. The authors have considered the problem of reducing the energy consumption as well as the trade-off between image quality and energy consumption using JPEG compression technique. The evaluation is performed experimentally using simulation and not on real-time experiments.

2.2. Discrete wavelet transform

Discrete wavelet transform is used to overcome the weakness of DCT-based techniques. Additionally, is to increase the features of DCT, i.e. frequency and localization [14]. Most of the related work in DWT is based on two-dimensional discrete wavelet transform (2D-DWT). Firstly, using one dimensional discrete wavelet transform (1D-DWT) in row wise to get low (L) and high (H) bands can do the implementation of DWT. Secondly, 1D-DWT can apply in column wise to get four sub-bands such as LL, LH, HL, and HH. Furthermore, each of these four bands can then be divided into four sub-bands. Researchers have proposed some schemes based on wavelet transform that are discussed below.

Embedded zerotrees of wavelet transform (EZW) image compression technique is introduced in [15]. It is designed for 2D dimension, but it can also be utilized in other dimensions. In EZW, encoder compresses the image into a bit stream and it is based on progressive encoding [16]. The input image decomposes into wavelet coefficients. It is multi-pass process. It has two-pass, including dominant pass and subordinate pass [17]. The work presented in [17] has also proposed another method based on EZW for image compression. In their work, EZW provides two types of resolution, namely: high and low resolution. High resolution can