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Video Compressed Sensing framework for Wireless Multimedia Sensor Networks using a combination of multiple matrices ☆

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ABSTRACT

Wireless multimedia sensor networks (WMSNs) have been used for sensitive applications such as video surveillance and monitoring applications. In a WMSN, storage and transmission become complicated phenomena that can be simplified by the use of compressed sensing, which asserts that sparse signals can be reconstructed from very few measurements. In this paper, memory-efficient measurement matrices are proposed for a discrete wavelet transform (DWT)–discrete cosine transform (DCT) hybrid approach based video compressed sensing (VCS). The performance of the framework is evaluated in terms of PSNR, storage complexity, transmission energy and delay. The results show that the proposed matrices yield similar or better PSNR and consume less memory for generating the matrix when compared with a Gaussian matrix. The DWT–DCT based VCS yields better quality and compression when compared with DCT and DWT approaches. The transmission energy is 50% less and the average delay is 52% less when compared to raw frame transmission.

1. Introduction

A WMSN consists of simple and low-cost sensor nodes that are used for a variety of applications, such as environmental monitoring, healthcare monitoring and surveillance applications. In the case of surveillance applications, sensor nodes with multimedia capability are deployed in the area of interest to detect anomalies. These sensor nodes will capture and transmit the surveillance video wirelessly to the network operator. Transmission of multimedia data that range from several megabytes to a few gigabytes is a challenging task because it imposes requirements for large amounts of storage and high bandwidth for transmission. These challenges can be overcome by using an emerging technique called compressed sensing (CS), which asserts that the original signal can be reconstructed from a small number of measurements [1]. CS can be applied to sparse signals or compressible signals. The original signal is made sparse using a transform basis, and a measurement matrix is applied to the sparse signal to obtain the measurements. These measurements are transmitted for reconstruction at the receiver side. There are many reconstruction algorithms, such as basis pursuit, greedy algorithms and iterative algorithms, for reconstructing the original signal from the measurement vector.

The objective of this paper is to implement VCS based on a DWT–DCT hybrid approach and to propose efficient measurement matrices for VCS. This VCS framework is based on a block-based approach; CS is applied to all of the blocks to obtain

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the measurements. The performance of the system with the proposed measurement matrices is evaluated by analysing the PSNR, percentage of reduction in samples, storage, energy complexity, transmission energy and end-to-end delay.

The rest of the paper is organized as follows. Section 2 provides a brief survey of related works. Section 3 provides a brief description of the CS technique, and Section 4 provides details about VCS based on the DCT, DWT and DWT–DCT hybrid approach. This section also explains in detail the proposed measurement matrices and orthogonal matching pursuit (OMP) algorithm, whereas Section 5 discusses the simulation and experimental results in detail; finally, Section 6 gives the conclusions and proposed future work.

2. Related works

This section provides a brief discussion of works related to VCS along with the advantages and limitations of each technique.

Akyildiz et al. [2] provided a survey of techniques used in the algorithms, hardware and protocols for WMSNs. Different architectures of WMSNs are explored along with their advantages and disadvantages. Different varieties of low-resolution and medium-resolution image sensor nodes and their collaborative processing are also explained. The authors have also discussed the working of wireless nodes in different layers of transmission. The network management and security used for multimedia transmission purposes are also emphasized.

In [3,4], the authors have explained in detail the basics, theorems and mathematics involved in CS and how the mathematics can be implemented in real time. They have motivated the design of new sampling schemes and devices that provide information required for signal recovery using the smallest possible representation.

Gan [5] has proposed block-based CS for natural images, in which image acquisition is conducted in a block-by-block manner. The image reconstruction algorithm includes both linear and nonlinear operations such as Wiener filtering, projection onto the convex set and hard thresholding in the transform domain. The results show comparable performances between block-based CS systems and current CS schemes, but the former have much lower implementation costs.

Han et al. [6] have proposed an image representation scheme using CS because it reduces the computational complexity of the image/video encoder used in the compression process. The encoder first divides the image into two parts, dense and sparse components, where the sparse component alone is encoded using CS. The number of random measurements needed and the decoding complexity are reduced considerably. Yu et al. [7] proposed a method to construct a Toeplitz-structured matrix with chaotic sequences for CS and proved that the Toeplitz-structured Chaotic Sensing Matrix retains the Restricted Isometry Property (RIP), which guarantees exact recovery. The results show similar or better performance compared with the Chaotic Sensing Matrix and the Gaussian Sensing Matrix.

Gleichman and Eldar [8] stated that the necessity of prior knowledge of the sparsity of the signal can be avoided by using blind CS. They have proven that under some unique constraints, their methods could produce comparable results to those of conventional CS techniques. Jain and Tewari [9] slightly modified OMP to generate Orthogonal Matching Pursuit with Replacement (OMPR), which replaces an existing support element with a new one. They have explained different methods for faster implementation of OMPR algorithms, such as using a hash function. Additionally, performance for noisy samples was also analysed.

Schaeffer et al. [10] presented a method to predict the optimal real-time compression rate for videos. During the acquisition of input data, the video is spatially compressed. Simple filters and polynomial fittings are used so that the hardware implementation is easy. The quality of the reconstructed video can also be improved without increasing the amount of video stored.

Schenkel et al. [11] proposed a scheme for wireless video multicast based on CS. When multicasting video signals, CS is applied to generate measurements of equal importance from a video such that a receiver with a better channel will naturally have more information to reconstruct the content effectively. They have also examined how the properties of the natural image can be exploited to improve the reconstruction performance by adding small side information. They experimented with different matrices to improve performance, not only on the receiver side but also on the transmitter side.

Jiang et al. [12] proposed a method to separate moving objects from the background in a surveillance video. Low rank and sparse decomposition of the matrix was used to reconstruct the video acquired by compressive measurements. The low rank matrix was used to identify the background, and the sparse matrix represented any moving objects present in the video. The experimental results showed that very few measurements were needed to extract moving objects in the surveillance video.

In [13], Balouchestani et al. provided the most recent survey of CS theory applied to wireless sensor networks (WSNs). The authors also proposed new sampling methods for information, data networks and a new recovery algorithm. In [14], Pudlewski et al. explained compressive video streaming for WMSN. They found that new cross-layered network protocols combined with video encoders based on CS can provide solutions to the problems caused by encoder complexity and limited resiliency to channel errors. The surveillance image when CS is used shows better reconstruction results compared to the same surveillance image reconstructed using JPEG for bit error rates (BERs) to the powers of -5, -4 and -3.

In [15] and [16], Zhang et al. proposed a new framework for image CS recovery via collaborative sparsity and structural group sparse representation (SGSR) modelling, respectively. An efficient augmented Lagrangian-based technique and an iterative shrinkage/thresholding algorithm-based technique were also developed to solve the optimization problem. The experimental results showed that this novel CS recovery strategy increased the image quality by a large margin compared with current state-of-the-art schemes.