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Reduction in encoding redundancy for overlapped FOVs over wireless visual sensor networks

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A B S T R A C T

With an increase in the capabilities of sensors, wireless visual sensor networks (WVSNs) are being researched to perform more complicated tasks as each visual sensor performs video capture, processing and sharing. Because each visual sensor operates by using its own resources including computation and communication under a limited power supply, it is necessary to develop an energy management scheme suitable for WVSNs. In particular, when multiple camera modules of visual sensors are aimed at some regions with different fields of views (FOVs), undesirable power consumption for encoding may occur among distributed visual sensors. Because some overlapped FOVs among captured images give rise to encoding redundancy, this leads to an increase in data quantity and power consumption for the encoding and communication. To resolve this problem, in this paper, we present a novel strategy for lifetime maximization of the WVSN. In order to estimate overlapped FOVs without using complicated procedures such as pattern or object recognition, we propose a geographical model to estimate overlapped FOVs based on location and visual direction. Based on this model, the power-rate-distortion (P-R-D) is determined and used to construct an optimization problem for minimizing the power consumption of each node. Through the proposed scheme, including distributed power allocation and node scheduling under simple information sharing, the network lifetime is maximized. Numerical results demonstrate the validity of the proposed algorithm.

1. Introduction

Wireless sensor networks (WSNs) have been developed as powerful means for observation of events and environments over long periods of time. Wireless visual sensor networks (WVSNs) have recently emerged as a new type of sensor-based intelligent system. WVSNs have significant differences with respect to other WSNs, due to the relatively large volume of data sensed by WVSNs and the associated processing overhead. Each visual sensor node in a WVSN is able to process image or video data locally using one or more cameras, and to extract detailed information for a wide range of applications such as video surveillance, emergency response, environmental tracking, and health monitoring [1–3]. This information is then gathered from multiple nodes to provide users with information-rich descriptions of captured events [4,5].

Traditionally, one of the main research issues in the design of WSNs concerns power management for data transmission; power management control signals may be sent by either synchronous or asynchronous time slot scheduling. It should be quite challenging to manage the power consumption problem for each sensor node in view of the entire network, since power control for a single node can affect the network lifetime as well as the lifetime of the node itself. Network lifetime maximization for conventional WSNs has been extensively discussed in the literature. In particular, the authors of [6] developed a maximum lifetime routing scheme, the authors of [7] solved the lifetime maximization problem with a distributed algorithm using the dual decomposition method and the subgradient method, lifetime maximization for interference-limited networks using a cross-layer approach was studied in [8], and the tradeoff between source rate allocation and network lifetime was investigated in [9] and [10].

The conventional works for WSNs, however, have limited applicability to WVSNs, which require accounting for the power consumption needed to process image or video data [11]. It may be necessary to compress large amounts of data prior to transmission by removing visual redundancy, which significantly reduces the power required for transmission, but at the cost of increasing the processing power required for the compression. Therefore, to deal with this power management issue, it is necessary to con-

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sider not only the transmission power but also the compression power, i.e., the encoding power.

In [12], the concept of accumulative visual information was introduced as a means of measuring the amount of visual information collected by a WVSN. The minimization of video distortion in WVSNs via optimizing power allocation in WVSNs was investigated in [1], while the authors investigated the resource-distortion optimization problem for video encoding and transmission over WVSNs in [13]. In order to achieve optimal power management for visual sensor nodes, it is necessary to determine rates of power consumption for the three main modules: the encoder, transmitter, and receiver. Thus the design of system protocols for WVSNs needs to take into account the power consumption of the encoding module.

Since the approaches used in [12] and [13] did not consider the factor of encoder power, there should be room for improvement in the network lifetime for WVSNs. In general, the higher the compression applied by an encoder algorithm is (resulting in lower compressed rates for a given quality), the higher the computation overhead becomes and the more processing power is required. Hence, for a given level of source distortion, the processing power can be modeled as a decreasing function of the compressed bit rate. On the other hand, in terms of transmission, it is obvious that more power is required as the number of bits representing the source information increases. Statistically, more bits are generated as the frame size increases, which in turn leads to an increase in the transmission power. Suppose that there exist overlaps among images captured by multiple cameras. For efficiency of compression, each sensor node can choose a larger or smaller frame size for image processing according to whether it covers or skips the overlapped region. In such cases, the processing and transmitting power consumption may depend on the frame size and the associated number of generated bits.

In this paper, to optimize these power consumption factors, we focus on an overlapped field of view (FOV), i.e., an overlapped region captured by multiple cameras. Since the information dimension of the WVSN consists of FOVs of multiple sensor nodes, images captured by adjacent nodes must certainly contain the spatial-temporal correlation corresponding to the FOVs. Thus, gathering of redundant information from the overlapped FOVs can control overhead by reducing the amount of data routed through the network. On the other hand, the determination of overlapped FOVs involves the use of computer vision techniques such as pattern or object recognition, and reducing the redundancy of the overlapped FOVs can be computationally burdensome. Overlapping information may be shared over the entire network, but again the burden is nontrivial.

To alleviate this computational overhead, we propose a simple geometric WVSN model for capturing the overlapped FOVs without employing vision techniques. The authors of [14] proposed a method for cooperative video processing in video sensor networks based on sensor correlations by measuring the sensing areas overlapped with each other rather than by measuring FOVs. By pairing up highly correlated nodes and dividing sensing tasks among them, each sensor node needs to cover a fraction of the targeted area. The authors of [15] proposed a novel spatial correlation model for visual information in WVSNs, which describes the correlation characteristics of visual information captured by using the cameras with overlapped FOVs. However, in [14] and [15], they did not present a distributed cooperation method for estimating correlations between sensors; therefore it is difficult to apply the proposed methods to WVSNs directly without any manipulations. Moreover, those cooperative methods assumed that high correlation occurs when the two cameras capture an object or objects regardless of the viewing directions. Since the correlation should be measured through visual processing in units of macroblocks

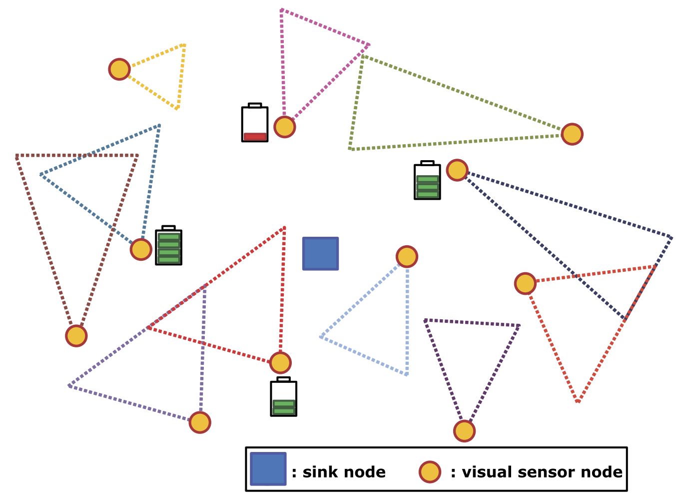

Fig. 1. An example of the visual sensor placement.

(MBs) or pixels and can be significantly changed according to the viewing direction, we detect the overlapped region by using the correlation in the unit of MBs. Thus, it is assumed that each overlapped FOV consists of multiple MBs.

The main contributions of this paper can be described as follows. First, we propose a simple estimation algorithm for identifying overlapped FOVs among visual sensor nodes, which yields the optimization problem of encoding redundancy reduction with the geometric WVSN model. Second, we investigate power minimization leading to lifetime maximization in conjunction with the joint processing and transmission of captured data based on the power-rate-distortion (P-R-D) relation. Next we describe optimization at the network level, following optimization at each sensor node, in order to prolong the network lifetime. Ultimately, we demonstrate that distributed optimization based on the sharing of small, simple sets of data, results not only in power minimization for each node but also in network lifetime maximization over the entire WVSN.

The remainder of this paper is organized as follows. In Section 2, we describe the system model including the power consumption model and the P-R-D model. The simple geometric WVSN models according to the nodes placement are presented in Section 3. The proposed algorithm for the network lifetime maximization is derived in Section 4. In Section 5, the extension of the proposed algorithm to multi-hop case is presented. In Section 6, the verification of the proposed algorithm is illustrated through a performance comparison. We provide our concluding remarks in Section 7.

2. Proposed system descriptions

2.1. Assumptions for the proposed WVSN

We assume that the WVSN consists of multiple visual sensor nodes and a sink node as shown in Fig. 1, and that each sensor node can be controlled remotely by a user. The sink node is an entity gathering information from all nodes in the WVSN. The remote user can manipulate parameters including the viewing distance, sensor node location, and direction of the camera module. Fig. 1 shows that multiple nodes may acquire visual information independently of each other; moreover, each node has its own battery (i.e., power supply), and the remaining energy level of each node may be monitored individually. Each sensor node makes an effort to extend its lifetime and to conserve energy by cooperating with adjacent nodes as much as possible. To find cooperative nodes in a distributed fashion, each node broadcasts its own location information, saves the location information received from neighboring