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A novel approach for extracting spatial correlation of visual information in heterogeneous wireless multimedia sensor networks

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ABSTRACT

In applied wireless multimedia sensor networks, heterogeneous camera nodes with different sensing capabilities are usually deployed due to their role in enhancing the overall network performance and lifetime. Exploiting the correlation characteristics of the overlapping fields of view of different camera nodes would enable very efficient collaborative in-network processing algorithms. This paper introduces a novel geometrical model to extract the spatial correlation characteristics of heterogeneous camera nodes in wireless multimedia sensor networks, taking into consideration the different sensing radii and the angles of view of the camera nodes. The novelty in the proposed model is in using *virtual* cameras at the two far ends of the camera's field-of-view. In order to provide better coverage of the field-of-view and hence better estimation of the correlation characteristics, key points in the observed scene are projected at the virtual cameras; in addition to the *physical* camera. This is shown to significantly improve the estimation of the spatial correlation characteristics to be almost identical to that extracted by well-known image processing techniques. An analytical closed-form solution of the proposed model is derived and validated and its performance is evaluated and compared against the state-of-the-art models; in terms of correlation characteristics estimating accuracy, visual information gain, and distortion ratio. The experimental and simulation results demonstrate that, compared to similar existing models, the proposed model achieves very accurate estimation of the correlation characteristics and significant improvement on the overall network resource utilization for a negligible increase in the camera node's computational cost.

1. Introduction

Wireless Multimedia Sensor Networks (WMSNs) consist of a large number of self-organized sensor nodes that equipped with different types of sensors such as cameras that have the ability to capture visual data from the environment being monitored. Each of these integrated cameras has a directional sensing capability that is usually referred to as the camera's Field of View (FoV). The FoV defines the direction of viewing for a visible region emanating from the camera node. WMSNs have been widely used in many applications including environmental monitoring, surveillance, industrial automation, and health care monitoring [1,2].

Camera sensor nodes have limited storage, energy, processing, and transmission resources. Yet, the visual information requires complicated processing techniques and high transmission bandwidth [1]. Therefore, the challenge is how to process and deliver such resource-intensive data as visual information with such limited resources.

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Collaborative in-network processing has been suggested as an effective method to decrease the volume of multimedia data to be transferred in WMSNs [1]. According to the application requirements, the nodes can collaborate with each other to merge data originated from multiple views, or filter out uninteresting scenes. In WMSNs, the camera nodes can provide multiple views and resolutions of the area being observed [3]. Moreover, if the nodes are deployed randomly, a correlation among the visual information observed by cameras with overlapping fields of view is likely to occur [4]. The correlation characteristics can be determined to develop efficient collaborative in-network processing algorithms, such as multi-view video coding [5], packet scheduling for multi-camera streaming [6], resource allocation [7], correlation-based QoS routing [8], and image gathering [9].

On the other hand, heterogeneity, in terms of camera sensing capability, has been considered as one of the characteristics of applied WMSNs, where the camera nodes have different sensing radii and angles of view. Cameras with different levels of resolution, coverage, and power consumption have been widely deployed in heterogeneous sensor networks in order to enhance the network performance and lifetime [10,11]. For example, in surveillance applications, high-end and low-end camera nodes with different sensing capabilities are usually deployed. The low-end camera nodes are composed of low-resolution imaging sensors that can be responsible of performing motion detection, while the high-end camera nodes are composed of high-end pan-tilt-zoom cameras that can be used on-demand for achieving object recognition and tracking.

The state-of-the-art approaches to exploit the correlation characteristics of the overlapping FoVs are based on either processing-intense image processing techniques or spatial correlation techniques that are limited to homogeneous camera nodes. In this paper, we introduce a new geometrical model to extract the spatial correlation characteristics of heterogeneous camera nodes in WMSNs. The model considers the different sensing radii and the angles of view of the camera nodes. In order to derive a closed-form analytical correlation function of the model, a novel technique was devised. This technique assumes that two virtual camera nodes are located at the far ends of the actual camera node's FoV in order to provide full coverage of the FoV. A preliminary version of this work appeared in [12], where the idea of using the virtual cameras was first introduced. This version includes detailed and extensive analysis of the model and comprehensive evaluation of its performance with homogeneous as well as heterogeneous cameras.

This paper is organized as follows. In Section 2, the related research work is reviewed. In Section 3, the proposed spatial correlation model and its analysis are introduced. In Section 4, the performance of the proposed model is evaluated and the results are discussed. Section 5 concludes the paper.

2. Related work

Several research works addressed the problem of exploiting the correlation of visual information detected by multiple camera nodes with overlapping FoVs. These works can be categorized into two classes: image-processing based and special-correlation based.

Image processing methods have been used to exploit the correlation of information observed by multiple camera nodes. For example, in [13], an image shape matching method was applied to find the overlap among spatially correlated images from neighboring camera nodes. A background subtraction method is employed to exploit the temporal correlation of a given image sequence. Using the temporal and spatial correlation, data from correlated nodes are transferred to the sink node.

In [14], correlated images are itemized using correspondence analysis, and then each of the correlated sensor nodes transmits the overlapped area in low resolution to the sink, which reconstructs a high-resolution version. Nevertheless, image processing algorithms are complex and computationally intensive. Moreover, the performance of image processing techniques is application-dependent so that different kinds of images require different processing techniques [15]. Therefore, geometrical correlation methods have been used to exploit the correlation of visual information observed by multiple camera nodes.

In [16], a method for cooperative processing based on correlation was considered. It was assumed that the sensing areas compose of a set of discrete points and that the sensing area of a camera node is divided into two parts: the triangle area and the segment area. Therefore, two heavy calculation loops are used to examine every point in one node's sensing area if it falls in others' sensing areas. Then, the correlation level of a pair of sensor nodes can be estimated as the ratio of the overlapping discrete points to the total number of points in one sensor node's sensing area. Based on the obtained correlation characteristics, the highly correlated nodes can be teamed together and the sensing areas can be divided among them. To reduce the workload on the camera nodes, two of them cooperate with each other, and each one transmits part of its assigned area to the sink node, which combines the partial images together. However, this scheme works only with two camera nodes that are highly correlated.

In [17], it is assumed that the camera's FoV can be represented by trapezium in the ground plane. Two approaches were proposed to calculate the correlation coefficients of two camera nodes: grid-based and relative position-based, which were inspired by [18,19], respectively. In the grid-based approach, the entire area of interest is divided into grids, in which the central point of every grid has to be examined for every camera if it falls in its FoV. Then, the regions could be constructed by grouping the girds that belong to the same nodes. Then, the correlation coefficient of two camera nodes is defined as the ratio of the overlapped grids to the total number of grids in one camera's FoV. On the other hand, the relative position-based approach creates a polygon through the intersection points of the nodes trapezium sides. Then, the correlation coefficient of two camera nodes is defined as the ratio of the polygon area to the camera's FoV area. The grid-based approach is very complex in that it requires a lot of time and energy. The relative position-based approach is lighter than the grid-based, but it does not consider the camera's sensing direction accurately as it produces high correlation for nodes with opposite directions.