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Distributed collaborative camera actuation for redundant data elimination in wireless multimedia sensor networks ☆

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ABSTRACT

Given the high cost of processing and communicating the multimedia data in wireless multimedia sensor networks (WMSNs), it is important to reduce possible data redundancy. Therefore, camera sensors should only be actuated when an event is detected within their vicinity. In the meantime, the coverage of the event should not be compromised. In this paper, we propose a low-cost distributed actuation scheme which strives to turn on the least number of cameras to avoid possible redundancy in the multimedia data while still providing the necessary event coverage. The basic idea of this scheme is the collaboration of camera sensors that have heard from scalar sensors about an occurring event to minimize the possible coverage overlaps. This is done by either counting the number of scalar sensors or determining the event boundaries with scalar sensors. Through simulation, we show how the distributed scheme performs in terms of coverage under several centralized and random deployment schemes. We also compare the performance with the case when all the cameras in the vicinity are actuated and when blockages in the region exist.

1. Introduction

Wireless multimedia sensor networks (WMSNs) have started to receive a lot of attention very recently due to their potential to be deployed flexibly in various applications with lower costs [1]. Such networks deploy a certain number of image and video sensors [2–5] in conjunction with a large number of scalar sensors (i.e., temperature, motion, light, etc.) to collect and process multimedia data. Typical applications of WMSNs include multimedia surveillance, habitat monitoring, intrusion detection and health care delivery [1].

In such applications, battery operated multimedia sensors are employed to acquire different viewpoints of the occurring events for fine-grained monitoring. However, as opposed to scalar sensors which can be sensing all the time, multimedia sensors cannot be collecting and transmitting multimedia data all the time as this will quickly drain their battery power. This is because, WMSNs can produce a high volume of multimedia data whose handling requires higher bandwidth and excessive CPU processing. Therefore, it will be wiser to turn them on whenever an event is detected within the vicinity by means of the scalar sensors. For instance, in a habitat monitoring application, motion sensors can be deployed in sheer numbers and sense information continuously to detect possible events related to the living organisms. Once an event is detected with motion sensors, the multimedia sensors in the vicinity can be actuated (i.e., turned on) to capture an image or video of the event until the event ends. Such video data can then be used by the researchers for scientific observations. Similar use is possible in surveillance applications where frequency of incidents is very low (e.g., surveillance of critical infrastructures, border control, etc.). In this case, the captured videos or images can later be used by criminal justice people to do quality and fast investigations.

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One of the questions in actuating the camera sensors on need basis is how many and which camera sensors to be actuated. Obviously, to get an adequate coverage of the event, it is better to actuate all the camera sensors within the vicinity of the event. However, this may introduce a lot of coverage overlaps among the camera sensors' field-of-view (FoV) which eventually causes some of the camera sensors to produce and transmit redundant multimedia data. Obviously, processing and transmitting such redundant data over possibly multiple hops to the base-station will unnecessarily increase the energy consumption of the whole network. While performing multimedia data aggregation in some cases may be possible, this process by itself is very costly in terms of CPU processing power and thus may consume as much energy as communication of the same data as opposed to traditional aggregation in wireless sensor networks (WSNs) [6]. Therefore, a mechanism is needed to determine which camera sensors to actuate in order to minimize the amount of redundant multimedia data while still providing the necessary coverage for the events. While event coverage can be guaranteed with initial centralized camera placement, we target applications where redundant cameras are deployed arbitrarily for providing fault-tolerance and multi-perspective event coverage. These applications include habitat monitoring, underwater monitoring and border control where camera failures can be expected. Finally, such an actuation mechanism should be run on-site in order to speed up the decision process and not to miss the events since performing off-line decision making (i.e., at the base-station) and informing the appropriate nodes to be actuated will take much longer time.

In this paper, we propose a distributed solution to camera actuation problem in WMSNs with almost negligible message overhead on camera sensors. The idea is for each camera sensor to utilize the number of scalar sensors which detected an event within its FoV and exchange this information with the neighboring camera sensors to determine the possible coverage overlaps. We show that counting the number of scalar sensors is a reasonable way to determine the size of the event areas when a randomly uniformly deployed network is considered. Based on such information, the camera sensors which hear from a higher number of scalar sensors will be given priority in actuation. The nodes with lower priority will need to wait to hear from other camera sensors about the scalar sensors (i.e., spots) they already covered. If a certain number of scalar sensors under their FoV is already covered or the number of such scalar sensors is not significant, the node will not be actuated. We later provide an alternative approach to determine the event areas based on the sensors that sit on event boundaries [7]. In this way, more accurate event areas can be obtained which helps to provide better decisions for the cameras.

In simulations, in addition to random deployment, we used two centralized camera placement approaches which can achieve maximized event coverage. In this way, we demonstrated that even such centralized placements can benefit from our actuation approaches. In addition, we made a theoretical analysis where we compute the coverage when all the camera sensors within the network are actuated. In this way, we compared the performance of manually and randomly deployed WMSNs to that of theoretical achievable upper bound. Simulation results clearly indicated the trade-off between coverage and amount of overlaps among FoVs. However, by tuning the parameters with the distributed approach, one can achieve significant redundant data elimination while still providing a coverage which is close to the case when all the cameras are actuated. Finally, we considered occlusions in the event area and assessed the effect of having such occlusions to coverage.

This paper is organized as follows. In the next section, we summarize the related work. Section 3 states our considered network model, assumptions and problem definition. In Section 4, we provide the achievable theoretical upper bounds for coverage. Section 5 details our distributed solution based on counting sensors along with the pseudo-code. In Section 6, we provide a different event detection approach based on event boundary detection and update the algorithm accordingly. Section 7 includes the simulations to assess the performance of the distributed approach under a variety of conditions. Finally, Section 8 concludes the paper.

2. Related work

An overwhelming majority of the studies in WMSNs are related to processing, compression or distributed coding of multimedia data for increased network lifetime [1,8,9] and quality of service (QoS) provisioning which is required for transmission of multimedia data [10,11].

Coverage problems in WMSNs on the other hand have not received much attention given the fact that they can be modeled through the well-known art gallery problem [12]. Once the FoV of the camera sensors are known, art gallery problem can be used to determine the least number of nodes and their locations in order to provide 100% coverage of a monitored region. It has been shown in [12] that the problem can be solved in polynomial time in two dimensional (2D) environments. However, the solution for art gallery problem cannot be used for our problem if WMSN is arbitrarily deployed. For art gallery solution, a prior manual deployment of camera sensors should be done assuming that the topology for the scalar sensors within the WMSN and the deployment region are known in advance. Then, the locations of camera sensors should be made available to scalar sensors so that they can know which camera sensor to actuate when an event occurs. Our proposed solution does not require any up-front information at the sensor nodes and can adjust itself based on the current topology of the WMSN. Finally, even in a manually deployed WMSN, due to fixed orientation of cameras and nature of the optimal camera placement solutions based on Integer Programming, there will still be room for coverage redundancy which can be exploited by our proposed actuation algorithm. These will be discussed in details in Section 7.3.1.

Due to FoV, in some works coverage was considered as a special case of circular coverage used in WSNs and such networks are referred as directional FoV sensor networks. For instance, the work in [13] proposes a node placement strategy for providing full coverage and connectivity among nodes in such networks. We do not consider