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Self-orienting wireless multimedia sensor networks for occlusion-free viewpoints

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ABSTRACT

Wireless multimedia sensor networks (WMSN) are formations of a large number of compact form-factor computing devices that can capture multimedia content, such as video and audio, and communicate them over wireless channels. The efficiency of a WMSN heavily depends on the correct orientation (i.e., view) of its individual sensory units in the field. In this paper, we study the problem of self-orientation in WMSN, that is finding the most beneficial orientation for all multimedia sensors to maximize multimedia coverage. We propose a new algorithm to determine a node's multimedia coverage and find the sensor orientation that minimizes the negative effect of occlusions and overlapping regions in the sensing field. Our approach enables multimedia sensor nodes to compute their directional coverage leading to an efficient and self-configurable sensor orientation calculation. By using simulations, we show that the occlusion-free viewpoint approach increases the multimedia coverage significantly. The self-orientation methodology is designed in the form of a distributed algorithm, making it a suitable candidate for deployment in practical systems.

1. Introduction

As we manufacture more sophisticated sensing electronics cheaper every day, the nature of the information to be hauled by wireless sensor networks (WSNs) change. We are now able to capture audio-visual information from the environment using low-cost, low-resolution cameras embedded in sensor nodes. The need for using such multimedia sensors is usually driven by the necessity of providing comprehensive information pertaining to a specific region of interest. To be able to support the demand for monitoring, we focus on wireless multimedia sensor nodes with directional sensing views. Performance of directional sensing is very much dependent on the obstacles present in the environment. Therefore, finding the most favorable orientation for the multimedia sensors is an important and challenging problem. For example, deploying a large number of low-resolution image sensors is recently shown to be a good alternative to having a single high-resolution camera [1]. Distributed methods for camera sensor networks also show gains from using a large number of low-power image sensors [1,2]. In such WMSNs, inherent disadvantages due to physical obstacles in an environment (e.g., trees, buildings, etc.) can be turned into a multimodality advantage, with the flexibility to adjust orientations of the multimedia sensors attached to the wireless nodes.

There have been several works on vision planning which take the object geometry information as an input from a database, as well as modifications of the camera and the lens to determine camera poses and settings [3]. Therefore, orientation of multimedia sensors can be performed on site once the multimedia sensors have been deployed. However, such methods need an accurate field information database before deployment and are mostly applied to a small number of multimedia devices. Due to external effects or application-specific queries in WMSNs, multimedia nodes may need to change/re-orient their pose (direction of sensory unit) over time. In WMSNs, nodes

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may fail due to battery outage or external effects which should be handled by a dynamic update of the poses which can be performed via local information exchange among sensors.

In this paper, we present a new distributed method to find the most beneficial orientations for the sensors used in a WMSN. We specifically consider (i) minimizing the effects of occlusion in the environment and (ii) improving the cumulative quality of the information sensed from the region of interest. Let us consider a WMSN with a large number of scattered nodes, each having neighbors with which it can communicate directly. Using a *distributed* method outlined in this paper, each node can discover its neighbors and examine possible overlapping sensing regions as well as the obstacles in the environment. In our scheme, each sensor node determines the most beneficial orientation for its multimedia sensor so that the entire image of a field can be constructed using low-resolution snapshots from multiple sensors. Our approach enables multimedia sensor nodes to monitor their coverage performance, provisioning self-configurable sensor orientations in an efficient way.

The proposed algorithm also decreases the obstacles' detrimental effect on the quality of the sensed information while maximizing total covered area. As discussed in [4,5], WMSNs have stringent constraints of limited communication bandwidth, processing capability, and power supply to deliver multimedia context. It is crucial to capture the most recent occlusion-free multimedia context from the environment. This helps newly designed WMSN protocols [5] delivering efficient multimedia context with the limited bandwidth resource.

In this context, we summarized the contributions of this paper as follows: (i) the proposed algorithm is fully distributed using local information: thus communication overhead is incurred only between neighboring nodes; (ii) with the flexibility to adjust orientations of the multimedia sensors, multimedia sensor nodes update the orientation of multimedia sensors on the fly to increase the multimedia coverage significantly, (iii) overlapped and occluded regions in the sensing field can be decreased by collecting the current pose of neighboring nodes and (iv) coverage is increased even for sparse networks by using self-orientation instead of random orientations, for arbitrary obstacles in the sensor field.

The remainder of the paper is organized as follows. In Section 2, we review the existing work on sensing coverage and multimedia coverage in WMSNs. We summarize the challenges on multimedia converge and define the multimedia coverage problem in Section 3, and propose a new distributed algorithm for multimedia coverage calculation in Section 4. Performance evaluation is discussed in Sections 5 and 6 concludes the paper.

2. Related work

Maintaining and maximizing the coverage of an area have been studied in great depth in the fields of multimedia, robotics and wireless sensor networking. From the perspective of sensor networking, considerable work is present for the omnidirectional coverage problem [6–9] that aims to cover a plane by arranging circles on the plane. However, the proposed solutions for omnidirectional coverage cannot be used for the coverage of bidirectional and field-of-view sensors such as low-resolution video cameras. A common limitation of these existing protocols [6,10,11] is that the collected information on phenomena (e.g., temperature, concentration of a substance, light intensity, pressure, humidity, etc.) are assumed to come from an omnidirectional sensing. However, multimedia sensors, (i.e., low-resolution cameras, microphones, etc.) have the unique feature of capturing direction-sensitive multimedia content. Especially, video sensors can only capture useful images when there is line of sight between the event and the sensor [12]. Hence, coverage models developed for traditional wireless sensor networks are not sufficient for deployment planning of a multimedia sensor network.

In [13], a preliminary investigation of the coverage problem for video sensor networks is addressed. The concept of sensing range is replaced with the camera's *field of view*, which is the maximum volume visible from the camera when sensors are placed on the floor. All camera nodes are assumed to be situated on a plane (at the ceiling of the monitored room), and they shoot the images of the scene from a parallel plane. Such a ceiling placement, however, may only fit specific indoor applications. Then, authors proposed a routing scheme for the video sensors based on cameras' field of view metrics. Video sensors are directed to the floor, and coverage is determined by disk shaped scenes on the floor, without considering effects of any occlusions. On the other hand, a wide range of multimedia applications require outdoor placement of multimedia sensors. Several projects on habitat monitoring use acoustic and video feeds from the multimedia sensors scattered in the environment. Similarly, a large number of video sensors are already used by oceanographers to observe sandbars via image processing techniques.

In addition, triangular view regions are used for computing multimedia coverage of sensor networks in [14]. The major goal of this work is to find the minimum observed distance to any multimedia sensor that any target traveling through the field must have, even if the target optimally tries to avoid the sensors. Sensors are assumed to have a isosceles triangular coverage (field of view) placed on a square field. Using mathematical modeling, worst-case breach coverage is calculated using a polynomial time algorithm. One limitation of this work is the lack of occlusions which is the most common problem of multimedia sensors. Any obstacle in the Field of View (FoV) region result in occlusion which should be considered while calculating the worst-case breach coverage. Second, the proposed algorithm determines the closest observable distance to a sensor that any target must have for a given a deployment. Differing from this study, our goal is to determine and then increase the multimedia coverage of each individual sensor and in total by designing a local algorithm to self-orient the pose of the sensors.

In terms of occlusion effect, [1] has several investigations for wireless camera networks. The paper shows that deploying a large number of low-resolution image sensors