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Self-orienting the cameras for maximizing the view-coverage ratio in camera sensor networks

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ABSTRACT

In recent years, camera sensor networks are widely studied due to the strength of the camera sensors in retrieving more types of information in terms of videos or images. Different from traditional scalar sensor networks, camera sensors from distinct positions can get distinct images with the same object. The object is more likely to be recognized if its image is captured around the frontier view of the camera. To this end, a new coverage model *full-view coverage* Wang and Cao (2011) is proposed for the camera sensors, to judge whether an object is recognized no matter which direction it faces to. However, the full-view coverage model fails to evaluate the coverage quality when the object is not full-view covered. In this paper, we introduce a novel *view-coverage* model which measures the coverage quality with a finer granularity for the purpose of face recognition. Based on this model, we propose a distributed multi-round view-coverage enhancing (VCE) algorithm by the self-orientation of the camera sensors. In this algorithm, sensors are continuously rotated to reduce the overlapping view-coverage with their neighbors until reaching the stable state. Furthermore, we address two important issues in the VCE algorithm, and propose the corresponding refinement procedures. The first one is about the sensors near the boundary of the target region whose view-coverage may include the outside of the target region, which is meaningless for our problem. The second one is about the rotating angle which should be set appropriately to achieve a global optimal solution. Simulation results show that our algorithm brings a significant improvement on the view-coverage ratio compared with random deployment. Also, the refinement procedures make a remarkable improvement over the basic VCE algorithm. Moreover, we evaluate the performance of our algorithm with real deployed camera sensors.

1. Introduction

Recent years have witnessed a booming development of camera sensor networks (CSNs) fostered by the advances in the technologies of camera sensors and embedded processors. Compared with traditional scalar sensors, camera sensor networks enrich the information acquired from the physical environment in the form of videos or images. Such network enables a wide range of applications such as traffic monitoring, health care, battlefield surveillance and so on [1].

Coverage is a fundamental problem in wireless sensor networks. In traditional scalar sensor network, a target (or an area) is considered to be covered if it is within the sensing area of some sensors, which can be roughly a disk

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(in omni-directional coverage model) or a sector (in directional coverage model). In CSNs, however, an effective surveillance system should not only ensure the detection of the object, but also the recognition of it. As studied in [2], an object is more likely to be recognized if its image is captured around the frontier view of the camera. i.e., the object is facing straight or nearly straight to the camera. Motivated by this requirement, Wang et al. in [3] propose a novel coverage model in CSNs, which is called full-view coverage. An object is considered to be full-view covered if no matter which direction the object faces to, it is recognized by at least one camera sensor. The full-view coverage model gives the yes or no answers of whether an object (or a region) is full-view covered. However, it fails to evaluate the coverage quality when the object (or a region) is not full-view covered. In fact, full-view coverage can hardly be achieved in a large-scale random deployment scenario unless with very high density [3]. Therefore, in this paper we propose a view-coverage model to characterize the coverage quality for the purpose of face recognition with finer granularity. A facing direction of an object is said to be view-covered if there is at least one sensor whose sensing range includes the object and the angle between the sensor's viewing direction and the object's facing direction is below a given threshold. Accordingly, we define the metric of view-coverage ratio of an object, which is the percent of its facing directions that are view-covered. In fact, full-view coverage is a special case of view-coverage, where an object is full-view covered if the view-coverage ratio of this object is 100%. As an extension, we define the metric of the view-coverage ratio of a target region, and derive the view-coverage ratio of a target region under random uniform deployment. The random deployment is easy and less expensive for large sensor networks, and sometimes inevitable, e.g., in the hostile environments. However, it does not ensure optimal coverage, and some improvement is needed by moving or rotating the sensors. Although there are considerable research works on enhancing the coverage in WSNs, most of them focus on the disk (or sector) sensing model, and no result can be directly applied to the view-coverage model, which is intrinsically much more complex and challenging.

We propose a distributed multi-round view-coverage enhancing algorithm (VCE algorithm) by the self-orientation of the camera sensors after they are randomly deployed in a sensor field. At each round of the algorithm, each sensor collects the current orientation information of its sensing neighbors and makes a decision of rotating clockwise or anti-clockwise with a predefined rotating angle which results in less overlapping view-coverage with its sensing neighbors. In this way, the view-coverage ratio of the target region is gradually increased until reaching the stable state that each sensor oscillates around some direction.

Furthermore, we propose some refinement procedures on the basis of the algorithm. First, for the sensors that are near the boundary of the target region, the view-coverage on the outside should also be avoided since it contributes none to the view-coverage of the target region, and we deal with this problem by our effort of *Boundary Effect Mitigation*. Second, if sensors rotate with a fixed small angle at each round of the algorithm, it is more likely to be trapped into local minima, and cannot achieve global optimal solution. To this end, we propose the *Dynamic Rotating Angle* scheme, where sensors first rotate with a large angle to make a coarse adjustment and then rotate with a small angle to make a finer adjustment. Then we combine the two refinement procedures into the VCE algorithm, and propose the improved view-coverage enhancing algorithm (IVCE algorithm).

The main contribution of this paper lies in the following aspects:

1. we introduce the view-coverage model which measures the coverage quality for the purpose of facing recognition. Compared with the full-view coverage model, it enables a finer-granularity measurement of the coverage quality in capturing the objects' face;
2. we propose a distributed algorithm to improve the view-coverage ratio under random deployment by self-orientation of the camera sensors. Also, we address some refinement issues to improve the performance of the basic algorithm. One is to alleviate the boundary effect, and the other one is to adopt dynamic rotating angle to achieve global optimization solution. Both issues are rarely studied in similar works;
3. we evaluate the performance of our algorithm with real deployed camera sensors. By using our algorithm, the recognition ratio (i.e., how much of the photos are correctly recognized) is greatly improved. To the best of our knowledge, this work is the first to evaluate the coverage performance by real deployed camera sensors in conjunction with face recognition system.

The rest of the paper is organized as follows. In Section 2, we present the related work. Section 3 proposes the view coverage model and formulates the maximal view-coverage problem. In Section 4, we propose a basic distributed view-coverage enhancing algorithm. Section 5 improves the basic view-coverage enhancing algorithm by mitigating the boundary effect and adopting dynamic rotating angle. The evaluation by simulation and experiment are discussed in Section 6 and Section 7 respectively. Finally, Section 8 concludes the paper.

2. Related works

Camera sensors are a kind of directional sensors which may adjust their working directions on the requirement of applications. The optimal coverage problems in directional sensor networks have been widely studied in recent years. The survey can be found in [4]. Based on the subject to be covered, the coverage problem can be categorized into three types: point (target) coverage, area coverage and barrier coverage, and we survey the related work from these three types. The issues on point coverage in directional sensor networks are discussed in [5–8]. In [5], the authors propose the MCMS problem which achieves the maximum point coverage with minimum sensors and present a centralized as well as distributed