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Optimal visual sensor placement for coverage based on target location profile

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ABSTRACT

The proper placement of visual sensors across a sensor field for covering targets with arbitrary location and orientation is a mission-critical decision in surveillance applications. The specifics of sensor deployment in these applications not only determine the maximum achievable coverage, but it also affects the quality of the target's appearance in cameras for subsequent use in vision tasks. However, the inaccuracies inherent in localization techniques and the lack of knowledge regarding the target orientation render existing proposals insufficient for real-life scenarios. In this paper, we address both challenges. First, we extend the conventional point representation of targets with a circular model to account for full-angle coverage of targets with known location yet with unknown orientation from all directions. We then assume, in the absence of precise location information, a trajectory profile of targets could instead be generated through the importance sampling of the environment, indicating spots where the target is most likely located. This profile-based abstraction enables us to capture the uncertainty in target's location by encircling every agglomeration of proximal samples within one cluster. Each cluster can then be viewed as a virtual macroscopic circular target for which we formulate the coverage problem in terms of a Binary Integer Programming (BIP) model. We have also taken into account the presence of obstruction in between multiple targets by calculating the angles of view of the sensors in an occlusion-dependant manner, effectively determining optimal placement for maximal instead of full-angle coverage. Evaluation results derived from our simulation experiments reveal that the proposed mechanism can effectively achieve high coverage accuracy with minimum number of deployed sensors.

1. Introduction

Coverage and detection of objects with arbitrary location and orientation are the two critical tasks in visual sensor networks. The underlying requirement in the coverage problem is the proper placement of sensors in the field such that the targets are covered from different views. Target coverage specifically can be proven difficult since the localization techniques are not accurate and the orientation of objects is not fixed due to their possible movement in the environment, essentially resulting in the frequent re-planning of the network for adaptation against the new changes. In this paper, we generalize the coverage problem so as to account for scenarios where the targets' location and orientation are not known a priori.

We introduce the notion of location profile-based coverage which assumes that the spots where the target is most likely located are monitored and a trajectory profile is accordingly generated using an importance sampling procedure. This profile-based abstraction would be able to capture the uncertainty typical of the localization techniques. Monitoring the people's behavior in a shop and observing the location of employees in an office are amongst the many example scenarios. To achieve the full

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coverage of the given profile would simply mean that the target is covered in all possible locations. The lack of knowledge regarding the target orientation is the other challenging factor to affect the correct operation of many surveillance applications especially in cases where the coverage of the frontal side of the objects is mandatory. Existing solutions mainly rely on precise a priori information, and thus relaxing this assumption calls for the full-angle coverage of profile samples from all directions.

In the majority of previous works, targets are modeled by a point representation with a known location, and the associated coverage problem is dealt with mathematical programming or heuristic approaches. The point model, however, is oblivious to the orientation and the size of the targets; hence, despite its relative simplicity in terms of the calculation of an optimal cover set, it is not applicable to scenarios requiring the coverage of the frontal side of the objects or when the location of targets cannot be determined with confidence. To the best of our knowledge, the visual sensor placement problem has not yet been viewed through the prism of the generalized notion of location profile-based coverage. Probably, the most relevant line of research to our proposed model is that of the minimum cost area coverage problem. However, in most of the envisaged scenarios, it is commonplace that a large area be covered by a single deployed sensor and the selected sensors are not normally expected to cover the area from all directions.

In many surveillance applications, ranging from face detection to human tracking and 3D model generation, a single sensor is not capable of providing sufficient coverage for the targets and it is quite typical to come up with a placement plan featuring a balanced arrangement of sensors. In this paper, we will extend the conventional point representation of targets with a circular model, and will propose a new scheme for full-angle coverage to guarantee that the targets would be covered from all directions. As with the profile-based abstraction discussed above, we will introduce a simple clustering mechanism which encircles every agglomeration of proximal samples within one cluster. Each cluster is then viewed as a virtual macroscopic circular target to effectively reduce the location profile-based coverage into a circular target coverage problem. The resultant problem will then be solved using a Binary Integer Programming (BIP) formulation. The adoption of a circular representation for clusters pays off in several ways: First, we would be able to make use of the angle information provided by the circular target model to calculate the correlation between sensors. Second, achieving the full-angle coverage of clusters ensures that each target with an arbitrary orientation will be fully covered with high probability as long as it is located in the sensor field. Third, the problem complexity will be significantly reduced as it can be easily argued that solving the full-target coverage problem in its original form would not be feasible in reasonable time.

Object occlusion, which occurs when a visual sensor loses sight of a target due to obstruction by other targets, is one of the major issues in visual sensor networks [1]. A sensor arrangement which aims at covering a given target from multiple views reduces the chances of losing the target due to occlusions. However, the full-angle coverage of targets may be impossible once occlusion is taken into account even using all the available sensors. In this paper, we propose a maximal occlusion-based coverage algorithm which calculates the unblocked angles of view for the sensors and selects the most promising set of sensors which its cardinality is less than a given threshold.

The rest of this paper is organized as follows: In Section 2, we give a brief overview of the state-of-the-art in visual sensor placement. In Section 3, we present a new scheme for the full-angle coverage of targets with known location on the basis of an innovative circular model. The maximal occlusion-based coverage is studied in Section 4. In Section 5, the problem of location profile-based coverage will first be presented. We then demonstrate how an area coverage problem based on the targets' location profile can be mapped onto a virtual macroscopic circular target coverage problem using clustering techniques. The resultant problem will then be formulated in terms of a BIP model in Section 6. In Section 7, we report on our performance measurement results derived from the simulation experiments. The paper ends with a concluding epilogue along with a hint on future works conceivable in this area.

2. Related work

The problem of optimal sensor placement has been widely studied in the literature. Of early relevant scenarios is the *Art Gallery Problem* [2] in which some guards should be optimally placed in a gallery such that the whole gallery is theft-proof. Although it has been shown that by triangulation, number of needed guards with 360° and 180° angle-of-view for a 2D polygon is $\lfloor \frac{n}{3} \rfloor$ where n is number of triangles in the polygon [3,4], but [5] proves that finding optimal solution in a 3D plane is an NP-complete problem. Also, since in this problem the location of targets are assumed to be fixed and single-view coverage is sufficient for each one, it could not be applied to the problems where full coverage of the targets is required.

The problem of directional sensor placement is also similar to the problem of optimal camera placement in camera networks in which the main objective is to find optimal locations of cameras for field surveillance. Horster and Lienhart [6] proposes an ILP formulation for this problem through discretization of camera locations in a grid layout by random sampling that includes various constraints and an application-specific cost function. Although we have adopted a similar perspective regarding space discretization, our target model is far more realistic in that it is synthesized from a clustering algorithm and can be used for directional coverage of the targets whose precise locations are unknown. Inspired by the aforementioned study, Zhao et al. [7] presents an LP formulation for calculating the optimal camera placement based on the probabilistic observations that assuming occlusion in the environment, finds the optimal placement locations for coverage of a tag. However, optimal camera placement solutions in camera networks are not generally applicable in visual sensor networks because unlike the cameras, placement sites for sensors are not limited to the ceiling or the walls in the area of interest and they can be deployed almost everywhere in the field. In addition, while energy consumption