

Poster Abstract: Connected Wireless Camera Network Deployment with Visibility Coverage

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ABSTRACT

First responder applications often require safety surveillance using wireless camera networks [1]. To ensure visual sensing coverage, it is crucial to place optical sensor nodes at proper locations. Under the scenario of energy constrained wireless camera deployment, the issue of communication cost should also be considered. Previous camera deployment research (e.g Art Gallery Problem) mainly concerned sensing coverage. One well-known solution for the art gallery problem is to triangulate the objective polygon and then select vertices to ensure full coverage. However, deploying cameras only in the vertices of polygon may induce inefficiency both in number of necessary cameras and overall communication cost. To reduce the cost, we propose two deployment algorithms: 1) connected visibility region planning algorithm for static deployment given the floor plan is known, and 2) connected visibility region tracking algorithm for the dynamic deployment during the run time. In extensive simulations with real floor plans, our algorithms outperform previous solutions significantly.

Categories and Subject Descriptors

C.2.2 [Computer-Communication Networks]: Network Protocols

Keywords:

Sensor Networks; Sensing Coverage; Camera networks; Connectivity

1. INTRODUCTION

We model each camera as a node whose sensing range is only restricted by line of sight. That is, each point with a direct line of sight path to a camera is within its range. This is a generalization of the “cone” model [3] of a camera. As can be seen later, we would like to focus on the non-trivial problem caused by using visibility as the sensing range. The cameras are equipped with wireless radio transceivers for easy deployment. We will model the indoor domain as a polygon P and we consider the problem of deploying cameras

to ensure (1) full coverage of P by their sensing ranges, defined by visibility; (2) the cameras form a connected network through their radio links. Formally, Our research problem can be stated as the **Minimum Connected Guarding Network Problem**: Given a polygon P with n vertices of possibly k holes, place a minimum number of cameras with communication range of r such that (i) the cameras form a connected network through wireless links; (ii) every point of P has direct line of sight to at least one camera.

The solution of the minimum connected guarding network problem clearly depends on the scale of the communication link connecting these nodes. Take one extreme, say the communication range of the sensor nodes is so big such that any two nodes inside the domain P can directly communicate with each other. The minimum connected guarding network problem boils down to the classical art gallery problem – finding a minimum number of point guards such that any point of P is within direct line of sight of at least one guard. The art gallery problem is a well known NP-hard problem and it has been extensively studied for approximation solutions [2]. Take the other extreme, say that the communication range r is very small compared to the scale of the domain P . When r goes to zero, we basically need to place the sensors along a path to keep them connected. Thus the problem converges to one of finding a connected geometric network such that any point is visible to at least one point of the network. It is not hard to show that such a network of minimum length must be a tree. The problem of finding a minimum guarding tree for a polygon has not been studied before. A problem similar to our problem is the watchman tour problem [4], i.e., finding a tour of minimum length that guard the entire polygon P . It is known that the watchman tour problem is NP-hard for the general polygon with holes. But nothing is known about the problem if we replace the tour by a tree.

Researchers have proposed many camera deployment algorithms to maximize the visual coverage of the camera network, but little attention is given to provide a connected network while minimizing the wireless communication cost. To fill this missing gap, our design goal is to achieve full visibility coverage with the minimal number of necessary cameras and also optimize the overall communication costs. Two algorithms have been proposed in this work: Connected Visibility region Planning algorithm (CVP) and Connected Visibility region Tracking algorithm (CVT). Given the floor plan abstraction in terms of a polygon, CVP identifies a set of visibility regions for concave angles of a polygon, and then

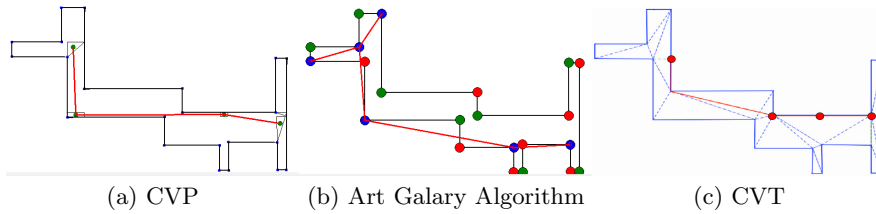


Figure 1. Simulation with a Real Floor Plan

compute the a minimal connected set of regions with the wireless communication range constraint. CVT is designed for the run-time deployment on a tour inside the building. A related problem is the shortest watchman path. Instead of finding a minimum single path, we search the shortest route for the minimum connected guarding network problem.

2. ALGORITHM DESIGN

Connected Visibility Region Planning Algorithm. Let $P = \{p_1, p_2, \dots, p_n\}$ denote the input polygon. We can define the Visibility Region of a reflex point p_i . The Visibility Region of reflex point p_i has the following property: for each point in this region, it is visible to the two adjacent points of p_i in the polygon P . For a given list of reflex points of the polygon, we generate the Visibility Region for each of them. For each reflex angle $\angle p^r$, we compute its opposite angle $\angle p_o^r$. Then we compute the two intersection points between $\angle p_o^r$ and P , denoted by p_1^{angle} and p_2^{angle} . After this, all vertexes of polygon P that lies within the angle $\angle p_o^r$ can be found, denoted by $\{p^{in}\}$. Combining $p^r, p_1^{angle}, p_2^{angle}$ and $\{p^{in}\}$ and sort them, we get the polygon $R = \{p^r, p_1^{angle}, p_1^{in}, \dots, p_k^{in}, p_2^{angle}\}$. To ensure the property of the region to be visible to both adjacent points of p^r , we compute if lines $p_1^{angle} p_1^{in}$ and $p_k^{in} p_2^{angle}$ divide R into two parts, respectively. If so, we remove the part that does not contain p^r .

After obtaining the Visibility Regions $\{R_i\}$ for all the reflex points, we further reduce the redundancy by selecting only the intersections between visibility regions. After obtaining the intersections between Visibility Regions, we select a subset from these regions to ensure full coverage. The regions are selected according to their sizes of overlapped visibility areas. We denote these regions by $\{R_i^f\}$. For each region in $\{R_i^f\}$, we deploy a camera in its centroid. Then we generate an Euclidean minimum spanning tree to interconnect all these cameras. After getting the minimum spanning tree among the cameras, we examine if there are any connections within the spanning tree that have geometric distance that are larger than the maximum communication range of wireless cameras. If so, we would deploy wireless relays between those pairs of cameras for connectivity.

Connected Visibility Region Tracking Algorithm. Tan proposed an $O(n^5)$ algorithm to find a simple watchman route for simple polygon in [4]. For input polygon P , suppose x is a reflex vertex in P and its adjacent vertex is v . Let a ray from v to x , hitting the polygon at y , then $C = \overline{xy}$ is a cut of P and separated P into two parts. We call the part of P that not containing v the cut, denoted as $P(C)$, and the watchman should pass this cut to see through the other part. A cut C_j is dominated by the other cut C_i if $P(C_j)$ contains $P(C_i)$, and a cut is essential if it is not dominated by any other cuts.

With the essential cut, the origin problem is reduced to find the shortest route that touch every essential cut. To solve this problem, we triangulate the given polygon and

“unrolled” the polygon using the essential cut as mirrors, and pick the route on that unrolled polygon. We first list the essential cuts in clockwise order. Starting from point s , we want to find a path to visit this cut list. Once the path touch the other essential cut, it mirrors the essential cut’s belonging triangle next to the cut, hence the path go through the cut as reflected by the cut. The path finding process will stop until it reach the mirroring s , we can get the watchman route by mapping this path back to the original polygon. We can prove that given a polygon, let the shortest watchman route be R , the minimum connected guarding path be P , then $|R| \leq 2 \cdot |P|$.

3. EVALUATION

We have implemented a completed camera deployment algorithm simulation framework, which can plug in deployment algorithms such as CVP and CVT. We use one of the well-known solution to art gallery problem, the 3-coloring algorithm as a baseline. In our experiments, we take the floor plan of a realistic building as inputs. From these experiment results, we can see our algorithms can achieve significant improvement against the classic 3-coloring algorithm, both in reducing the number of necessary cameras and in reducing the communication costs.

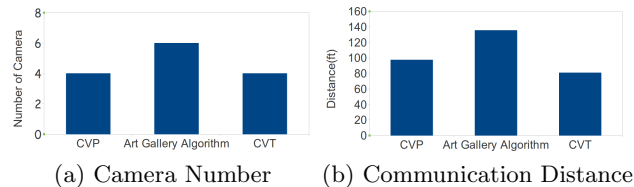


Figure 2. Deployment Cost

A case study with three algorithms is shown in Figure 1. The red lines represent communication links that connect wireless camera nodes. In Figure 1 (c), the dotted lines represent essential cuts. The deployment cost is shown in Figure 2. From Figure 2 (a), we can see that CVP requires only 4 cameras, the same number as CVT. The 3-coloring art gallery algorithm requires 6 cameras to ensure full coverage. In Figure 2 (b), the total communication distances for CVP, art gallery algorithm, and CVT are 97.44 feet, 135.56 feet, and 80.85 feet respectively.

4. REFERENCES

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