A combination of camera and scalar sensor in the wireless barrier network

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Abstract—**Barrier coverage is a heated issue in wireless sensor networks since it has various applications such as security-surveillance, intruder-detection. A lot of works have done on traditional sensor network, i.e., scalar sensor network. Recently, the study for camera sensor appeared because camera sensors could provide more abundant information than scalar sensors. However, it would cost a lot to form a barrier purely by camera sensors. Thus, we propose a design to combine the advantage of camera sensor and traditional scalar sensor. Also the camera sensor gets a new characteristic, rotation, which could help increase the probability of barrier coverage and reduce redundancy. Analysis and extension of our algorithm are also made in the end.**

Categories and Subject Descriptiors
C.2.1 [Computer-Communication Networks]: Network Architecture and Design C network topology

General Terms
Algorithms, Design, Theory, Performance

Keywords:
barrier coverage, camera sensors, scalar sensors, rotation

I. Introduction

Barrier coverage has become a powerful and useful tool in many sensor network applications, e.g., national border control, security surveillance and intruder detection, etc. In these applications, sensors are deployed in the region of interest to detect objects moving in the network. So the main goal of barrier coverage decides its different characteristics with area coverage and node coverage.

Previous studies in barrier coverage mainly concentrated on scalar sensor networks. Binary disk sensing model is always used, in which sensors could detect intruders if they are within the range of sensing radii [1, 2]. Also lots of algorithm considering the deployment or the design of scalar sensor network have generated [7, 8]and regarding theory proposed [6, 9, 10]. In order to guarantee the quality of barrier coverage, k-barrier coverage[1, 10], is introduced and developed.

Recently, the research in camera sensors has been more and more hot [3, 4, 5, 11]. Although traditional scalar sensors could fulfill the intruder-detection goals effectively, camera sensor provide much richer information and thereby could strengthen the characteristics of wireless barrier. Since it could present images and videos, we could observe the action of enemy clearly and detailedly. Furthermore, digital image process(DIP) technique has already enabled camera sensors with various powerful function. However, the cost of camera sensors is much higher than traditional sensors and it would always be hard achieve a good barrier coverage with cost-effective and stable method.

From the perspective of features, camera sensors are much more complicated than scalar sensors, since its working section is modeled as a sector instead of disk. Besides that, intruders may cross the sensing area without being identified because current face detection algorithm has a basic requirement of the angle between camera's orientation vector and face direction, i.e., moving direction. For example, if a camera views an object's back, then no face image would be identified. Therefore, to maintain a high level surveillance quality, a good camera barrier can always capture the frontal view image of enemy no matter from which direction and locatio it intrudes.

Therefore, we study the combination of traditional scalar sensor network and camera sensor network to fulfill a high camera barrier coverage performance with comparatively low cost and high reliability. A sleep-wakeup mechanism is also presented to prolong the network's life span. For camera barrier and full-view covered, we introduce the definition of previous work [11], i.e., full-view covered means an object's face would always be captured whatever it faces and a camera barrier is a connected zone across the region of interest with every point full-view covered.

Based on these definition, we study the method of determining whether a point or a place is full-view camera covered in the network with both scalar sensors and camera sensors. Then we propose our algorithm to construct camera barrier in both random and deterministic deployment. Random deployment would be meaningful when it comes to the circumstance that dispersing sensors from an aircraft or artillery ordinance in enemy country's terrain. Noting that sensors are deployed randomly, it would be probable that a strong would not come into force and we study that probability based on our simulation result. Also sensors could be located manually the controlled environment. As mentioned above, the main challenge here is find a feasible way to form an effective barrier while not demanding too many camera sensors. Additionally, the advantages of scalar sensors, such as full angle (2π), low cost should be added to the network performance.

The main contributions of this paper are as follows. First, we put forward an idea of how to combine camera sensor network and scalar sensor networks. Accurately, how to achieve a camera barrier performance by embellishing cameras into traditional sensor network. Second, we introduce rotation to camera sensors, which means each camera could change their orientation vector after initial deployment. We could find rotation could decrease the necessary number of camera sensors from sensitivity and simulation result. Third, we devise a pattern to achieve camera barrier coverage in both random distribution and deterministic deployment. Finally, we validate the result with simulation.

The rest of the paper is organized as follows. Section 2 reviews the related work about barrier coverage and full-view coverage of sensor networks. Section 3 describes the network model used in this study. Section 4 explores the fundamental limits of barrier coverage under sensor mobility. We present an efficient sensor mobility scheme that achieves the maximum barrier coverage and minimizes the maximum sensor moving distance. In Section 5, we present an algorithm to compute whether a network with mobile sensors is barrier coverable, and examine the impact of sensor mobility on barrier coverage. Finally, we conclude the paper in Section 6.

II. RELATED WORK

In the past few years, coverage has been an active research area in sensor networks. The goal of barrier coverage is to detect intruders that attempt to cross from one side of a region to the opposite side. Several different barrier coverage measures and the related works have been done.Many studies have focused on characterizing the barrier coverage and designing algorithms to achieve desired area coverage. In [12], the authors proposed algorithms to find paths which are most or least likely to be detected by sensors in a sensor network. The authors further studied the path exposure of a moving object in a sensor network [15], which is a quantitative measure of how well an object, moving on an arbitrary path, can be detected by the sensor network. Then some distributed algorithms have been proposed, in which sensor collaboration is exploited to detect the intruder [13, 14].

The concepts of weak and strong barrier coverage in wireless sensor networks are introduced in [1]. Weak barrier coverage is formed if the intruder would be detected when it takes the shortest path (i.e., an orthogonal line) to cross the region and strong barrier coverage guarantees the detection of the intruder no matter what kind of path it takes. In [9], the author study the characterization of detection under two circumstances that whether the sensors's location are known or not. In [6], Liu the critical conditions for strong barrier coverage,filling the gap in the understanding of the critical conditions for barrier coverage. And Xuan introduce the concept of quality of barrier coverage and propose a metric for measuring the quality of k-barrier coverage [10].

The full-view coverage model is first introduced by Cao in [15]. A full-view identification method is put forward and redundancy reduction and deployment strategy is given. Also, lots of regarding works [3, 4, 16]have been done previously.

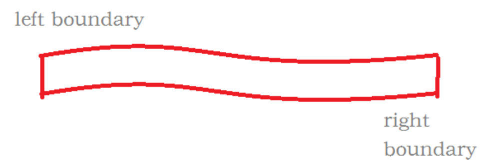

Fig. 1. Example belt region, boundary

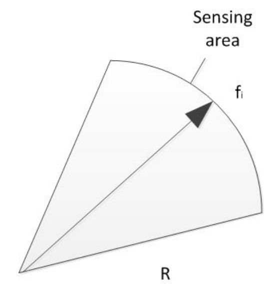

Fig. 2. Sensing area of camera sensor

III. DEFINITIONS AND NETWORK MODEL

This section describes the network model. Many definitions are adopted from [1, 6, 8, 10 ,11]. We assumed that the network is deployed in a long strip region. An example is shown in Figure 1. As proved in [17, Page 39] for a region of unit area, as the number of nodes becomes larger and larger, Poisson distribution of sensors approaches random uniform distribution of sensors, where each sensor has an equal likelihood of being at any location within the deployed region, independently of the other sensors.

Definition 3.1. **[Belt region]** *A belt (strip) region has four boundaries. Two of them are parallel, and the other two are orthogonal to the two parallel ones. For ease of presentation, one of the orthogonal boundaries is referred to as the left boundary and the other the right boundary .*

Definition 3.2. **[scalar barrier]** *A belt region with a sensor network deployed over it is said to be scalar barrier covered if and only if all crossing paths through the belt are covered by the sensor network.*

Definition 3.3. **[Binary disk model]** *Each scalar sensor is assumed to have a certain sensing range, r A sensor can only sense the environment and detect intruders within its sensing area.*

For camera sensors, each one has a sensing range R, a field-of-view (FoV) angle ϕ and an orientation vector $\overrightarrow{f_i}$. We use S_i to denote the i-th sensor, noting that camera sensors' sensor area is a sector(Figure 2). For any two points S,T, $\|ST\|$denotes the (Euclidean) distance between them. For any two vectors $\overrightarrow{v_1}$, $\overrightarrow{v_2}$, $\alpha(\overrightarrow{v_1},\overrightarrow{v_2})$ denotes the angle between them, ranging from 0 to π. Point P is covered by camera sensor S_i if $\|PS_i\| \leq R$ and $\alpha(\overrightarrow{f_i}, \overrightarrow{S_i, P}) \leq \phi/2$. We should notice that a point is covered is not equal to its image can be identified, since it also has connection objects face direction (moving direction).

Definition 3.4. **[Full-View Coverage]** *A point P is full-view* *covered if for any facing direction (i.e., any vector $\overrightarrow{d_i}$),there is a sensor S_i, such that P is covered by S_i and $\alpha(\overrightarrow{PS_i}, \overrightarrow{d_i}) \leq \theta$, where $(\in [0, \pi/2))$ is a predefined parameter called the effective angle. A region is full-view covered if every point in it is full-view covered.*

Definition 3.5. **[Weak Camera barrier]** *For a belt region L, assuming one side being the entrance and the opposite side being the destination, there's a zone B in inside L, a camera barrier is formed every path from one point on the entrance side to another point on the destination side intersects with B and would be face identified.*

Definition 3.6. **[Strong Camera barrier]** *For a belt region L, assuming one side being the entrance and the opposite side being the destination, a camera barrier B is a connected zone inside L such that B is full-view covered and every path from one point on the entrance side to another point on the destination side intersects with B.*

IV. STRATEGY FOR THE COMBINATION OF CAMERA SENSORS AND SCALAR SENSORS

In this section, we propose the basic guidelines of using both camera sensors and scalar sensors to achieve the performance of camera barrier coverage. Then, we introduce our method to verify full-view coverage.

A. Combination Strategy

As mentioned in the introduction, to form a camera barrier only by camera nodes would be rather expensive because its working area is only a sector (compared to the disk area of scalar sensor) and to identify intruders reliably, cameras have to be deployed in various direction to surround the object to make sure the object's facing direction close to sensors' orientation vector, i.e., $\alpha(\overrightarrow{PS_i}, \overrightarrow{d_i}) \leq \theta$. Therefore, to cover a specific area, much more sensors would be required and redundant sensors should be added as well to guarantee the reliability of network performance. Even if a subregion is full-view covered by camera sensors, it would be hard to guarantee that all these discrete areas could be joint to form an effective barrier. Also a camera sensor consumer more energy than scalar sensors that the network's life span would be lower. Thus, if theses sensors are deployed randomly in a belt region, the probability of network failure would be high or large number of camera sensors would be in demand to offset this high failure ratio, which makes camera sensor network inefficient and expensive.

However, traditional scalar sensor network could avoid the above short comings greatly since its sensing area would be larger and under the circumstance with same sensing radius and cost would be low since it does not have as many functions as camera sensor. Furthermore, scalar sensors could detect any intruders in sensing area without a strict restriction on facing direction. Based on these characters, scalar sensor network would form barrier coverage easier than camera sensor network although it could provide as abundant information as camera barrier.

Therefore, a combination strategy is put forward here based on their cons and pros.

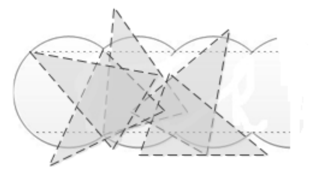

Fig. 3. combination of camera sensor and scalar sensor network

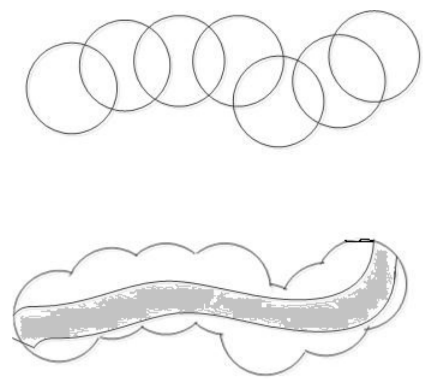

Fig. 4. Forming a camera barrier of belt region inside scalar barrier

1) Scalar sensor networks work as the backbone of barrier: From the above analysis, we could known intuitively that scalar sensors could form a barrier more easily than camera sensors. So we could construct the camera barrier on the basis of scalar sensor network.

2) Camera sensors work as function nodes to improve the performance of traditional barrier: By dotting camera sensors in the scalar sensor network, the previous barrier could be armed with new function such as image identification thereby becoming camera barrier.

Under this strategy, scalar sensors could work as pre-warning for the camera sensors and link up different parts of full-view covered areas. This method could help reduce the number of camera sensors because (1) it would increase the barrier formation probability (2) it could not need various camera sensors overlapping to make all the subregion link up, instead, camera sensors could only focus on full-view cover their specific area separately. The basic idea of this design is shown in Figure 3.

B. Full-view coverage verification algorithm

Note that the full-view coverage zone should be located in the barrier of scalar barrier. For the easiness of design and analyze, we concentrate on the belt region inside scalar barrier. Hence, if full-view coverage could be accomplished along this belt, a strong camera barrier would form. An illustration can be seen in Figure 4.

First, a method to determine weather one point is covered is referred from [11]. The circular list is illustrated in Fig 5.

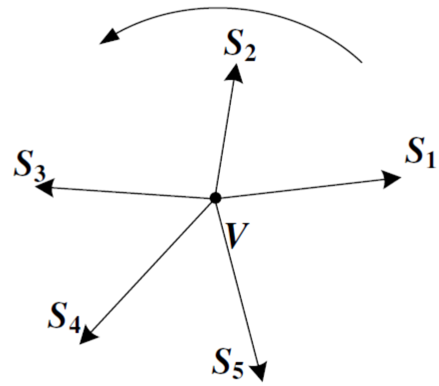

Fig. 5. The circular list of V

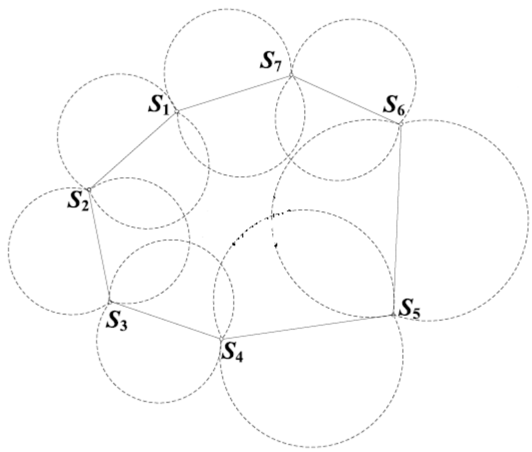

Fig. 6. An illustration of safe area

Lemma 1 A given point V is full-view covered if and only if for CL_V constructed as above, the rotation angle from $\overrightarrow{VS_i}to\overrightarrow{VS_{i+1}}$ is less than or equal to 2θ for any $1 \leq i \leq k$, where $V_{k+1} = V_1$.

Then, an effective way to guarantee the area or line being full-view covered is proposed. An effective algorithm is also adapted from Guohong Cao's work [11].

Lemma 3.2 Given S_i and S_j , there are two arcs $\widehat{S_iS_j}$ and $\widehat{S_iS_j}'$ which connect S_i and S_j and are symmetrical with respect to the lineS_iS_j , such that the unsafe region is the enclosed region bounded by the arcs and the safe region is the open region outside the unsafe region.

The proof of the two lemma is skipped.

From lema 3.2, we could find that a safe region is formed by several arc segments.(Fig. 6)

Thereby, a method to find a weather an area is full-view covered has been found.

C. Rotation

Noting that in the random distributed circumstances, cameras initial deployment would not be optimal and thus decrease the efficiency of first distribution. Here rotation is introduced to make up this shortcoming. After these cameras have been first fixed up in a certain area. They could rotate their face vector to search scalar sensors. If only one sensor is found, it would adjust its facing direction to the scalar sensor. Else if more than two sensors have been found, it would choose closest sensor (call it A) and the second closest sensro (B), then aiming at A with probability a and at B with probability b, a $\geq$ b. Simulation results show that this rotation mechanism greatly reduce the number of waste cameras thus increasing camera efficiency.

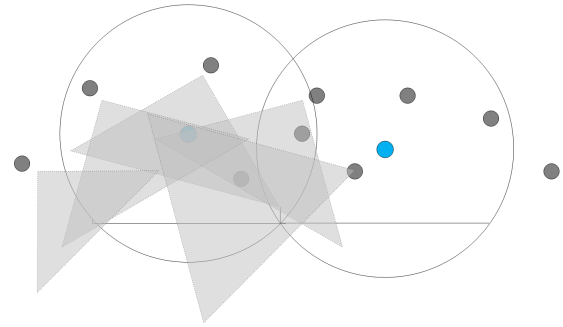

Fig. 7. An illustration of safe area

V. Deterministic deployment strategy

In the places suitable for predesign, such as people's estate, a country's border, a deterministic sensor deployment would be extremely useful. Here we still follow our guideline proposed in section V that scalar sensors form a road to link camera subregion. It can be seen in figure 7. We find a shortest line in the adjacent sensing circle then deploy camera sensors to guarantee that the point on this line can be full-view covered.

Since the angle between intruder's direction and border would be in 0 to π. The area behind the barrier cannot put any sensors. Therefore, large number of sensors can be saved.

VI. Simulation result

Due to the time reason, I have not finish this part. Sorry everyone.

VII. Conclusion

Barrier coverage has become a hot problem recently since it has a widespread application in security area. And camera barrier is no exception as well since it could provide more abundant and critical information than traditional barrier after using digital image process and wireless sensor network technology. However, due to its uncommon physical feature, camera barrier coverage problem is also difficult and deserves our attention.

Although camera barrier has large number of good performance, its cost is fairly high because many redundant cameras exist. Thereby, in this paper, a mechanism to introducing scalar sensors have been proposed to fulfill camera barrier while decreasing the number of cameras needed. Also we find that network could increase sensor efficiency by rotating their view vector. Due to the time limitation, I have not finish the simulation part.

ACKNOWLEDGMENT

Thanks for Professor Wang to provide us this opportunity to practice our writing and problem analyzing skill. At the first stage, it would be quite difficult for me to use Latex and understand how to write a paper. Under Dr. Wang's kind guidance and encouragement, I finally get some sense of research and improve my English-writing ability, which would be rather helpful in my future job career. Also thanks 973 lab for so many wonderful and enlightened lectures.

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