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Object Tracking in Rotational-based and Regular Deployment Visual Sensor Networks

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Abstract: Visual sensor networks offer surveillance applications, particularly object tracking. This study uses a rotational-based and regular deployment visual sensor network to track an object. The proposed method is applied to detect the object tracking in security monitoring. This study provides two types of network architecture to deploy the sensor nodes and utilizes the lines of sight between cameras to form a defense face to surround the mobile object. Each sensor node has rotational camera lens and is deployed to form regular network architecture. The proposed tracking method assigns the sensor nodes to surround by an object and to provide continuous monitoring for the object. The proposed update method can ensure that the object is tracking by an update defense face, even if the object is moving out of the original defense face. The major advantage of this algorithm that is can solve the lost object location problem of object tracking. Finally, this study utilizes simulations to analyse and estimate the efficacy and the performance of object tracking in the proposed network architecture.

Key words: Camera, network architecture, object tracking, sensor network

INTRODUCTION

Visual Sensor Networks (VSNs) are a type of wireless sensor network, comprising tiny visual sensor nodes referred to as camera nodes. A camera node integrating an image sensor, embedded processor and wireless transceiver is responsible for capturing images of a target (Wang and Cao, 2011). Since, the development of micro-electromechanical systems and image processing, visual sensor networks offer surveillance applications, particularly object tracking.

Vision sensor nodes distributed throughout the area. By the cooperation of multiple of visual sensor nodes, the visual information can be transmitted to the control center. The VSNs also provide users with high-level services enabling the distillation of large quantities of data into information of interest by using specific queries (Ma *et al*., 2012).

The VSNs can be applied for environmental monitoring, in areas such as import and export control, or monitoring a specific area for activity. The camera node can be divided into two types. The first one involves fixing the field-of-view and angle of the camera. The camera cannot be rotated and maintains a constant line of sight, thereby limiting the video information to a given region. The drawback of this type is that the event must occur in the given region and the area outside the sensing region is called a blind spot. In the second type, the camera rotates periodically; thereby increasing the range of the visual sensor but it still does not overcome the blind spot of the previous model. According to the angle of the camera, the blind spot appears in different positions. Therefore, how to design an appropriate VSN architecture to track moving objects is an important issue. The barrier coverage is a very important concept in VSNs. The mobile object must be detected by a camera when it is moving through the barrier monitoring area. Shih *et al.* (2010) proposed cone-based barrier coverage algorithm (CoBRA) in wireless camera sensor networks. A sensor can build the possible barrier line relationship according to the distance between itself and its neighbors. The barrier line can be built with the minimum number of camera sensors.

Monari and Kroschel (2009) proposed a computational geometry algorithm to determine the minimum number of sensors that are needed to locate an object. By non-overlapping sensor coverage, the algorithm still can locate the object, even if the object is temporarily out of sight. However, this approach is applied in static camera networks and indoor environment.

Wang *et al.* (2011) exploited the concept of full-view coverage and proposed a systematic way to build up a camera barrier in both random and deterministic deployment. The full-view camera barrier coverage guarantees that the intruder will be detected by a camera. If the viewing direction of camera is close enough to the intruder's facing direction, the face image of intruder can be identified effectively.

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The boundary line can detect whether an object through the defense line but they cannot know the location of object. This study discusses how to use the defense lines to track the object continuously.

NETWORK ARCHITECTURE

To take advantage of the defense lines to track objects, this study proposes a regular network structure to deploy the rotation sensor nodes. Using the rotation sensor nodes, the object can be surrounded by a set of nodes. When the object moves, the sensor nodes can continue to surround it and to locate its position.

Here, two types of network architecture to deploy the sensor nodes that are pre-placement in a W(width)×H(height) region. The conditions of all nodes are the same, i.e., sensing range, communication range and Field of View (FoV). Every camera node knows its physical location and can rotate 360° to track object. Each node has communication devices that can communicate and coordinate with each other. This study assumes that the target object move randomly in an open area. The proposed algorithm is suitable for an object and multiple objects.

Next, this study discusses how to deploy the sensor nodes. Since, the sensing range of camera is limited, some blind spot appears in irregular network architecture. Therefore, the sensor nodes are deployed in an open area to compose the regular network architecture. In this regular network architecture, a set of camera nodes are selected to form a face, to surround the object and to detect the location of object. This study utilities the sensing range of camera to form a defense line. This study defines that $\overline{X_1X_2}$ is the defense line between two nodes X_1 and X_2. A face is composed of three or more defense lines. In a variety of geometric shapes, this study chooses the two geometric shapes that are square and hexagon, to form regular shaped face. The proposed two kinds of regular network architecture are shown in Fig. 1. A camera node is deployed at the intersection of X and Y axis. When a camera node detects an object, this node requires its neighbor nodes to assist surrounded the object. These face architecture can achieve full barrier coverage without gaps.

OBJECT TRACKING ALGORITHM

After deploying the network, the sensors need an object tracking algorithm to automatically track objects. This section discusses how to track object in the VSNs. First, this study defines the defense face. Next, this study discusses how to update the defense face.

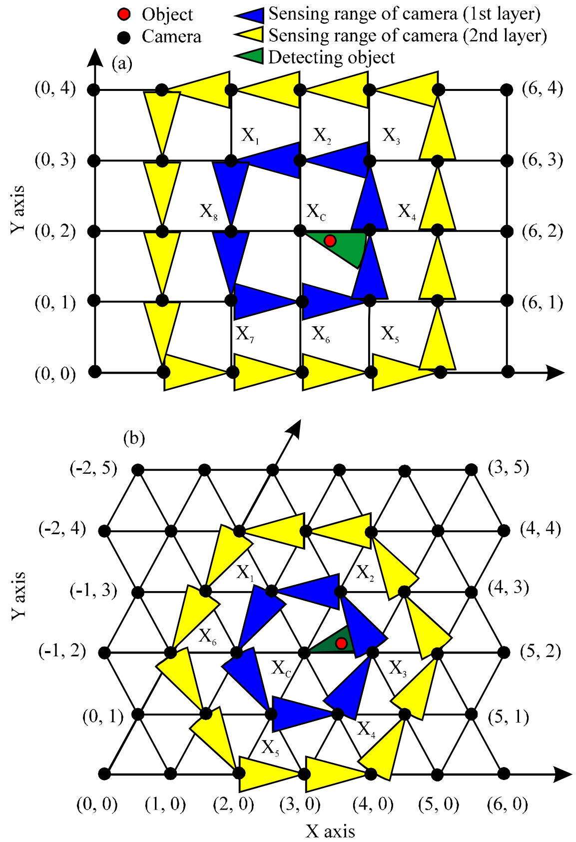

Fig. 1(a-b): (a) Square regular network architecture and (b) Hexagon regular network architecture

Defense face: This subsection presents the object tracking method. This study assumes every node knows it neighbor nodes and their location by the information exchange. Before the object is detected, each camera is rotated clockwise and its viewing direction is arbitrary. The camera nodes do not form a specific face. This study defines that the node detecting the object is X_c (as called the center node). When X_c detects the object, it informs its neighbors X_1~X_8 in the square architecture or X_1~X_6 in the hexagon architecture as shown in Fig. 1a-b, respectively. The viewing direction of node X_1 is rotated to X_2 and the defense line is $\overline{X_1X_2}$. Other nodes also rotate toward their specific node. These defense lines composed a square or hexagon defense face and surrounded the object in the face as shown in Fig. 1a-b (the blue sensing range). The node X_c monitors the object continuously and the face can prevent losing the object tracking due to the object's fast moving.

To avoid losing the position of the object, this study proposed the idea of N-layer defense faces. The second layer face is built to surround by the first layer face when the mobile object is fast. If too many layers are built, it needs to add more cameras to track object, to raise the cost and to make architecture more complex. Therefore, this study only considers 2-layer face architecture as shown in the Fig. 1a-b (the yellow sensing range).

Defense face updating: This subsection discusses how to update the defense face when the object is close to the boundary of defense face. In order to detect mobile object, the defense face must be updated to prevent losing track of the object. When a defense line $\overline{X_iX_j}$ (i.e., $\overline{X_3X_4}$) detects the object, the sensor node X_i (i.e., X_3) becomes new center node as shown in Fig. 2a. This node informs and adds its some neighbors to form new defense face and removes some nodes from the original defense face.

In the square network architecture, eight update cases are divided into two update styles as shown in Fig. 2b-c. If the new center node and original center node is not at the same x- or y-coordinate in the square network architecture, the update style is similar to Fig. 2b. The new center node has to remove 9 cameras, add 9 cameras and rotate 7 cameras to form the new defense face. Otherwise, the second update style is similar to Fig. 2c. The new center node has to remove 5 cameras, add 5 cameras and rotate 7 cameras to form the new defense face.

In the hexagon network architecture, six update cases are the similar. Figure 2d shows one situation of six update cases. The new center node has to remove 5 cameras, add 5 cameras and rotate 7 cameras to form the new defense face.

SIMULATION RESULTS AND ANALYSIS

This study utilities the simulation results to analyze the performance of proposed network architecture. Because previous studies did not use face structure

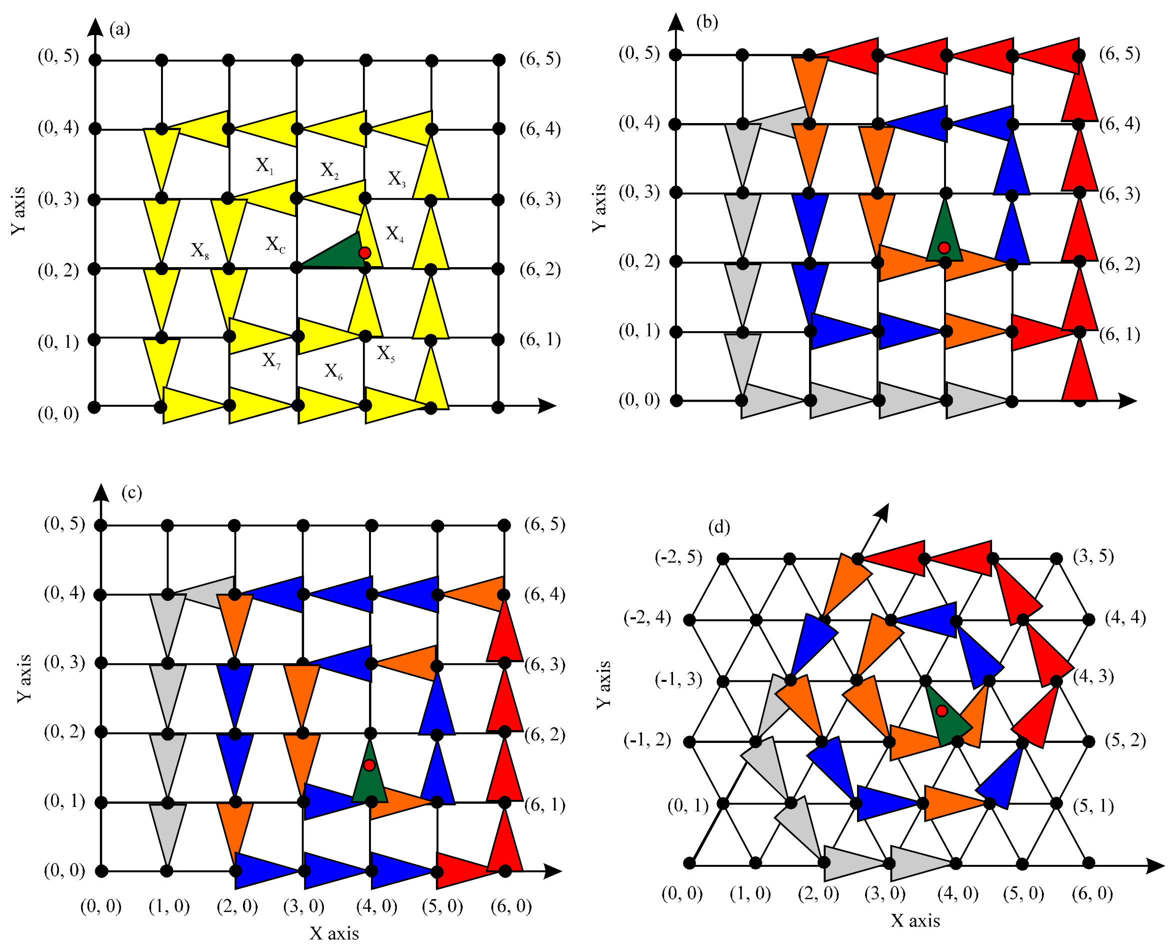

Fig. 2(a-d): (a) Situation of an object traveled through a defense line, (b) First update style of square network architecture, (c) Second update style of square network architecture and (d) Update styles of hexagon network architecture surrounded by objects, this section presents the simulation results that compare the performance with two kinds of network architecture. This study uses Microsoft Visual C# to develop the simulator. The sensor nodes are deployed in a 700×700 m region. This study adopts the random waypoint to simulate the moving path of the mobile object. The simulation assumptions are listed below. The angle of view of the camera is 30°. The sensing range of camera is 70 m. The simulation time is 300 sec. The velocity of object is varied from 1-10 m sec^{-1}. The rotation velocity of camera is varied from 10-40° sec^{-1}.

This study uses tracking ratio and face update cost to analysis the tracking performance of two kinds of different face architecture. Tracking ratio indicates whether the object can be surrounded by defense faces. The face update cost indicates the number of camera nodes that need to add or rotate to form new defense face. This study presents the performance of Face-Lv1 and Face-Lv1. In Face-Lv1, the network only uses 1-layer face to track object. In Face-Lv2, the network uses 1-layer face and 2-layer face to track object:

$$\text{Tracking ratio} = \frac{\text{Surrounded time of object by defence faces}}{\text{Simulation time-the time of first detecting object}}$$

Figure 3 presents the tracking ratio in different rotation velocity and network architecture. Hex and Squ means the hexagon and square network architecture, respectively. The rotation velocity includes 10, 20 and 40° sec^{-1}. The simulation results of tracking ratio with Face-Lv1 are presented in Fig. 3a. From the simulation results in Fig. 3a, the tracking ratio is raised when the rotation velocity is increased. This is because the rotation velocity affects the speed of establishing a defense face. When the defense face is built or updated faster, the proposed method are able to increase the time surrounded by objects. The simulator must wait to establish complete defense face and then it begin to calculate the time that the face surrounds the object in the simulator. The performance of tracking ratio in the square network architecture (the solid line in the figure) is better than that in the hexagon network architecture (the dotted line in the figure). However, the blind spots exist in the square network architecture but no in the hexagon network. This is because the hexagon face has smaller coverage area than the square face. Therefore, the object tracking in the hexagon network architecture has more number of updates than that in the square network architecture. The tracking ratio is decreased when the velocity of object is increased. To update the defense face, the sensor nodes have to rotate the angle of camera. Before the formation of

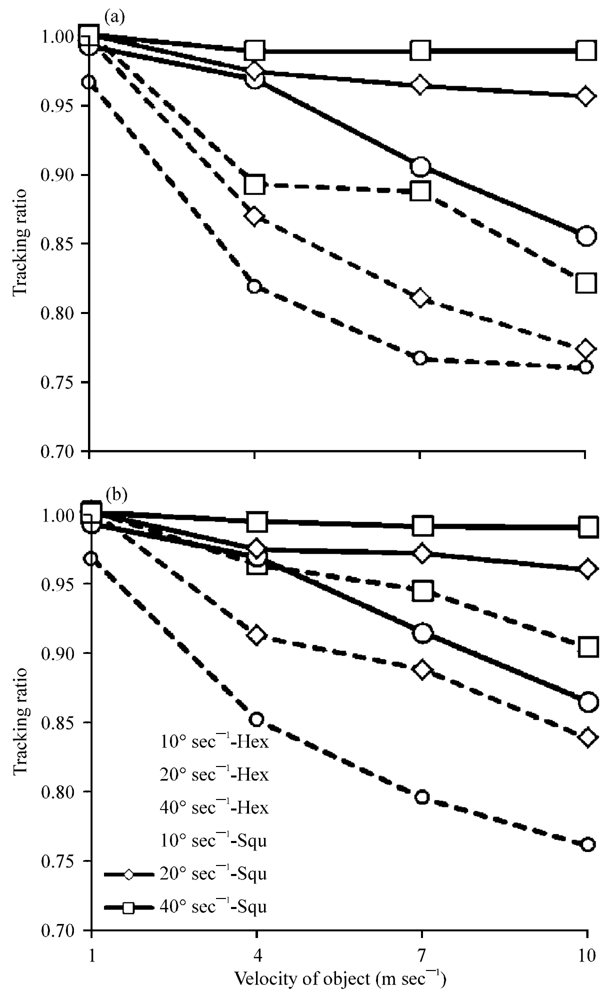

Fig. 3(a-b): (a) Performance of tracking ratio with Face-Lv1 and (b) Performance of tracking ratio with Face-Lv2

new defense face, the object is not surrounded by defense faces. This will decrease the tracking ratio. To increase the rotation velocity, it can raise the tracking ratio in Fig. 3a. The simulation results of tracking ratio with Face-Lv2 in Fig. 3b are similar as Face-Lv1 in Fig. 3a. To compare Fig. 3a-b, the tracking ratio is increased when 2-layer face is established to track object. The 2-layer face can improve the tracking ratio, especially when the velocity of object is increased. In hexagon network architecture, the 2-layer face also can raise the tracking ratio.

The update cost of Face-Lv1 is presented in Fig. 4a. The object tracking in hexagon network architecture has more update cost than that in the square network architecture. This is because the object tracking in the hexagon network architecture has more number of

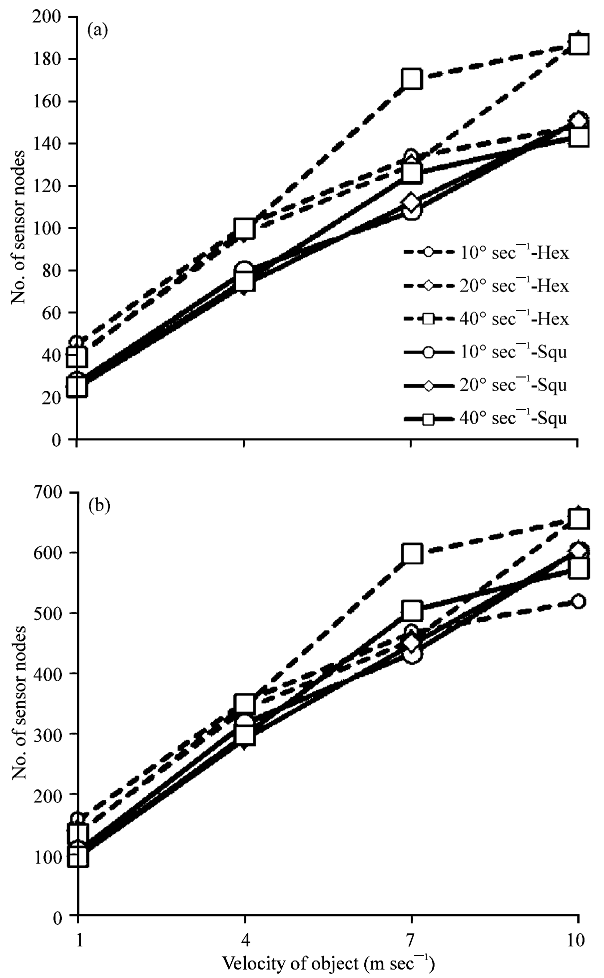

Fig. 4(a-b): (a) Performance of update cost with Face-Lv1 and (b) Performance of update cost with Face-Lv1

updates than that in the square network architecture. The update cost is raised when the velocity of object is increased in Fig. 4a. To avoid losing the location of the object, the proposed object tracking method has to update the defense face frequently. The update cost of Face-Lv2 is presented in Fig. 4b. When the scheme of 2-layer face is used to track object, the network needs more sensor nodes to form defense face. This phenomenon can be clearly observed and compared in Fig. 4a-b.

CONCLUSION

This study proposed two types of network architecture to track object in the VSNs. The sensor nodes are regularly deployed in the sensing area. Every sensor equipped with rotating camera that can track target continuously. The camera that detects the target requires its neighbors to surround by the object. The sensing ranges of its neighbors form a defense face to locate the position of object. The major advantage of this algorithm that is can solve the lost object location problem of object tracking. From the simulation results, the performance of tracking ratio in the square network architecture is better than that in the hexagon network architecture.

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