Coverage Overlaps Reduction with Delaunay Triangulation for Visual Sensor Networks

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Abstract

A visual sensor network (VSN) employs visual (camera) sensors instead of scalar sensors to establish the wireless network for wide area monitoring and target tracking. The visual sensing coverage of a VSN is quite related to the sensing direction and sensing angle of each camera sensors in the network. Many research issues of VSNs are similar but much different from the ones of ordinary scalar sensor networks, and the visual coverage issue is more specific. In the past years, a great number of research literatures have been proposed to address the coverage issues for ordinary scalar sensor networks. A part of the existing approaches use geometric structure concepts in the researches. However, utilizing geometric structures to solve visual sensing coverage has not drawn much attention of researches. This study, therefore, utilizes a geometric structure of Delaunay Triangulation with its characteristics to improve overall visual coverage of a sensing field for VSNs. The results of evaluation with simulations show the proposed approach performs very well and obtains a significant visual coverage improvement for VSNs. This could be a reference basis for further studies.

Keywords: Visual sensor network, Visual coverage, Delaunay triangulation, Geometry

1 Introduction

The ordinary scalar sensor-based wireless sensor networks have gained many attentions in the sensor network research field. The applications of such kind of sensor network also have been developed for various fields like monitoring and events detection. Coverage problems are essential and fundamental issues for sensor networks and the coverage performance is one of the important indices for sensor network QoS (Quality of Service) measurement [1]. Consequentially, a great deal of related coverage researches for the sensor networks have been proposed [2] in the past decade. Nowadays, a specific kind of sensor network which consists of camera sensors, so called visual sensor networks (VSN), draws attentions of researchers [3] and some related works for VSNs have been proposed. A VSN is one kind of the directional sensor networks (DSNs) [4-5] which are formed with directional sensors. The directional sensors could be ultrasonic sensors, infrared sensors, camera sensors, etc., thus each of the sensors in a VSN has a limited sensing angle and works for a designated direction. In other words, the visual sensing range of a camera sensor is quite different from the range of an omnidirectional scalar sensor. It is a sector-shaped area with limited radius and angle size. For ordinary scalar sensor networks, the overall field sensing coverage mainly depends on the positions of every deployed sensors. Nevertheless, the visual coverage for VSNs additionally depends on the AoV (Angle of View) and working direction of camera sensors in the networks. For ordinary scalar sensor networks, partial researches utilized Voronoi Diagram geometry [6-7] to deal with several coverage issues [8-9]. However, the utilization of geometric structures for the visual sensing coverage problems in VSNs has not gained much attention of studies. This study aimed at the utilization of the Delaunay Triangulation [10] geometry to deal the visual sensing coverage for VSNs. The Delaunay Triangulation is the dual graph of Voronoi Diagram, but their geometric structures and characteristics are quite different. The structure and characteristic of Delaunay Triangulation were used to improve the overall visual coverage ratio of a VSN sensing field. Rotatable camera sensors are assumed and utilized as a basis in this study and an algorithm for visual coverage improvement, so called VCI, was proposed for visual sensor networks.

2 Related Works

The researches of wireless sensor networks can be majorly categorized into four subjects [11]: (1) Sensing Coverage [12]; (2) Network Connectivity [13]; (3)

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Network Longevity [14]; and (4) Data Fidelity [15]. These issues still exist in the research field of visual sensor networks. The existing WSN methods or results are inapplicable to VSNs, especially in the coverage aspect, due to the additional characteristic of vision in VSNs. New problem research and solution are required. In VSNs, four primary causes will influence the coverage: (1) sensors density. Higher sensor density will cause a higher field coverage unless the saturated deployment; (2) sensors distribution. Too closed locations of adjacent sensors will cause serious coverage overlaps among these sensors unless their working directions are in mutual exclusions; (3) sensing distance. A longer sensing distance presents a larger field of view (FoV) of the sensor and it causes a possibility of overlapped coverages to other sensors; and (4) angle of view. A larger sensing angle wills presents a larger field of view and causes a higher possibility of overlapped coverages in sensing area.

With respect to the coverage problems of VSNs, the problems can be classified into two categories [16]. The first category is field coverage problems, which improves the overall coverage ratio for a certain sensing field. In such case, Huang et al. [17] focused on the multimedia image sensor networks and proposed a virtual potential field-based method with the considerations of sensor movement and direction rotation for the coverage enhancement. The second category is targets coverage, which decides a set of visual sensors to cover interested targets or specific points. In such case, the research [18] proposed approaches to deal maximum coverage with rotatable sensors (MCRS) that the number of targets can be covered is maximized while the angle rotations of sensors are minimized. Utilizations of geometric structures are another approach to solve ordinary WSN coverage problems [19-21]. However, it has not drawn much attention for VSN coverage solutions. Accordingly, this paper proposes an approach, which Delaunay Triangulation geometric structure is utilized, for the improvement of overall visual coverage ratio in a VSN. In other words, the proposed approach aim to decide and control the working direction of each stationary visual sensor for the reduction of coverage overlaps in a VSN. It is a distributed/localized approach, hence the global information of the deployed VSN is unnecessary.

3 Preliminaries

Given a set of points (visual sensors) in a sensing field, the Delaunay Triangulation is formed by triangles and it can be constructed from the Voronoi Diagram. The method is to connect the points of adjacent Voronoi cells. In other words, each line in the Delaunay Triangulation is the bisector line of the Voronoi edge of two adjacent Voronoi cells. That is to say, Voronoi Diagram and Delaunay Triangulation are the dual graphs to each other. The Delaunay Triangulation satisfies the characteristics: (1) any two edges do not intersect across each other; (2) skinny triangles will be reduced since the minimum angle of all triangles is maximized; and (3) any triangle can be circumscribed by a circle without any other vertices included. Figure 1 shows the example of Delaunay Triangulation for a given set of visual sensors.

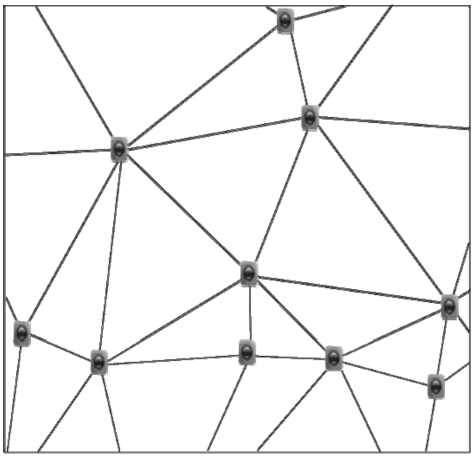

Figure 1. An example of delaunay triangulation

Figure 2 shows the visual sensor model used in this study. The central node means a visual sensor, which coordinates are (a, b). The angle θ indicates the working direction of the visual sensor. The value φ is the angle of view (AoV) of the sensor. The notation d indicates the effective distance to shoot a picture, thus sensing range of the visual sensor.

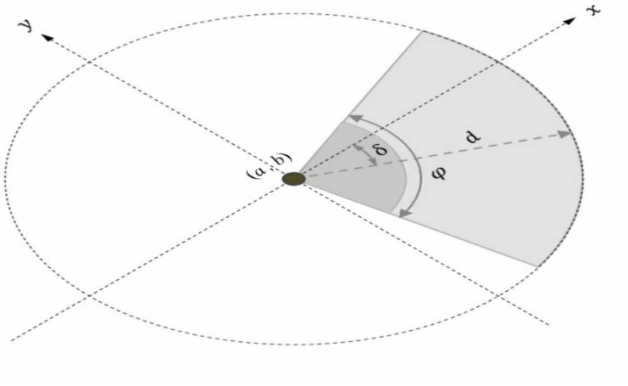

Figure 2. Visual sensor model

The valid vision field of a visual sensor is a fan-shaped field (FoV). For any point p located at (p_1, p_2), it will be covered by the visual sensor if and only if it satisfies:

$$\begin{gathered}\sqrt{(p_1-a)^2+(p_1-b)^2} \le b \\ (p_1-a)\cos\theta+(p_1-b)\sin \ge\end{gathered} \tag{1}$$

$$\cos(\frac{\varphi}{2})\cdot\sqrt{(p_1-a)^2+(p_1-b)^2} \tag{2}$$

In addition, there are four basic assumptions used for this study:(1) the visual sensors are rotatable to decide their working direction; (2) the visual sensors are randomly deployed in the sensing area; (3) the sensor devices know their coordinates, which localization system can be equipped; and (4) there is no concern of the network communication distance between two adjacent visual sensors.

4 Visual Coverage Improvement with Delaunay Triangulation

4.1 Approach with DT triangle angles (DTTA)

Figure 3 is the case that two visual sensors locate respectively at the vertices of the same DT triangle. The working directions of these two sensors face to the interior of the same triangle. In this case, the coverage overlap usually will be large. Accordingly, making the two sensors to change the working direction will reduce the overlap area. Therefore, the first approach proposed in this paper utilizes the included angles of Delaunay Triangulation triangles to decide new working directions. As shown in Figure 4, making the directions of the two adjacent sensors to change toward the interiors of the different triangles and to be the bisector lines of the different included angles respectively.

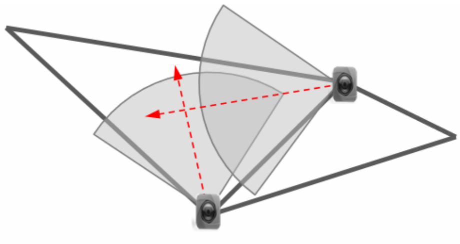

Figure 3. Coverage overlap due to working direction

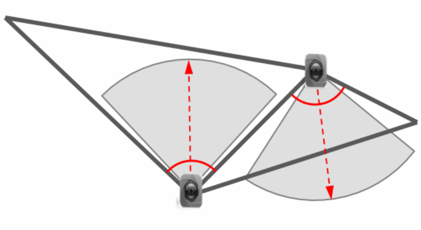

Figure 4. Overlap reduction by changing working direction with DT triangle angle

Figure 5 shows an example that there are n (*n*=6) visual sensors connected to visual sensor *v*. These sensors form a partial Delaunay Triangulation. The location of the sensor *v* has *n*=6 included angles which belong to different DT triangles respectively. Let β_{ij} denote the included angle formed by visual sensors v_i, v, and v_j which sensors coordinates are (x_i, y_i), (a, b), and (x_j, y_j) respectively. v_i and v_j are the vectors from v to v_i and v_j respectively. The size of the included angle β_{ij} will be

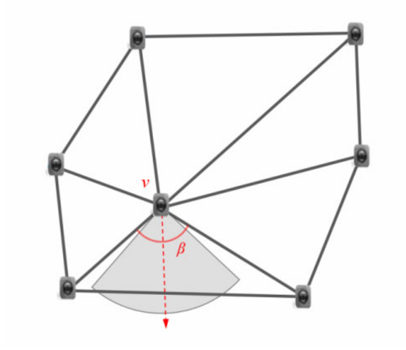

Figure 5. Decision of workingdirection with DT triangle included angle

$$\begin{aligned}\beta_{ij} &= \cos^{-1}\left(\frac{\vec{\upsilon}_l \cdot \vec{\upsilon}_j}{(|\vec{\upsilon}_l||\vec{\upsilon}_j|)}\right) \\ &= \cos^{-1}\frac{(x_i-a)(x_j-a)+(y_i-b)(y_j-b)}{\sqrt{(x_i-a)^2+(y_i-b)^2}\sqrt{(x_j-a)^2+(y_j-b)^2}}\end{aligned} \tag{3}$$

After the calculation of the sizes of n included angles, a maximum angle will be found. Let the largest included angle is β_{mn}. This included angle will be used to decide as the new working direction of the visual sensor v. The new direction (δ) will be the bisector of the maximum included angle. Let $\alpha(\vec{\upsilon}_l)$ be the angle degree of the vector $\vec{\upsilon}_l$ relative to the positive x-axis.

$$\alpha(\overline{v_l}) = \begin{cases} \sin^{-1}\dfrac{y_i-b}{\sqrt{(x_i-a)^2+(y_i-b)^2}}, \\ -\sin^{-1}\dfrac{y_i-b}{\sqrt{(x_i-a)^2+(y_i-b)^2}}+\operatorname{sgn}(y_i-b)\cdot\pi, x_i<a \end{cases} \tag{4}$$

$$\delta = \begin{cases} \dfrac{a(\overrightarrow{v_m})+a(\overrightarrow{v_n})}{n}, |a(\overrightarrow{v_m})-a(\overrightarrow{v_n})|<\pi \\ \dfrac{a(\overrightarrow{v_m})+a(\overrightarrow{v_n})}{n}-\pi, |a(\overrightarrow{v_m})-a(\overrightarrow{v_n})|\ge\pi \end{cases} \tag{5}$$

Because the larger included angle means the other two angles of the same triangle will be smaller. This also means that the sensors located on the other two vertices have lower probability of using the other two included angles of the same triangle to decide their new working directions. Accordingly, it could avoid that the three sensors change their directions toward the interior of the same triangle. Consequently, larger coverage overlap will be avoided. Moreover, once the sensor *v* has decided its new direction, clockwise or anticlockwise direction rotation should be determined. A smaller rotation distance will consume less energy, which is important to a sensor device.

Figure 6 shows an example that it applies the proposed approach described in this subsection. The coverage overlap of the result is significantly reduced in this example.

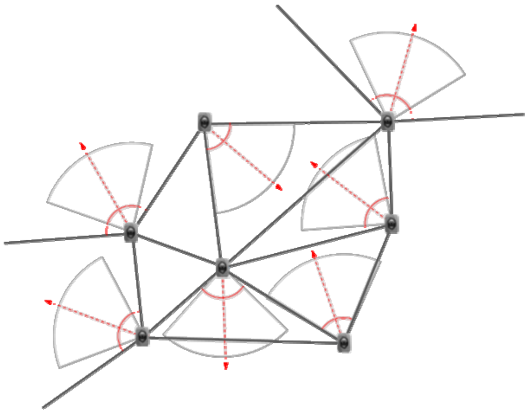

Figure 6. Example of changing working directions with DT triangle included angles

Algorithm 1. The algorithm of DTTA approach

Dtta algorithm

```
virtually divide the VSN field into DT triangles based on visual sensor locations
let $V = \{ v_i \mid 1 \leq i \leq n \}$, $n$ is the number of visual sensors
let $\beta_{ij}$ denote the included angle $\angle v_i v v_j$
for each $v \in V$
    for each DT triangle $\Delta v_i v v_j$ associated with $v$
        $\overrightarrow{v_i} =$ the vector from $v$ to $v_i$
        $\overrightarrow{v_j} =$ the vector from $v$ to $v_j$
        $\beta_{ij} = \cos^{-1}\left((\overrightarrow{v_i} \cdot \overrightarrow{v_j})/(|\overrightarrow{v_i}||\overrightarrow{v_j}|)\right)$
    end for
    $m = \underset{i}{\operatorname{argmax}}\ \beta_{ij}$
    $n = \underset{j}{\operatorname{argmax}}\ \beta_{ij}$
    $\alpha(\overrightarrow{v_m}) =$ angle degree of $\overrightarrow{v_m}$ relative to positive $x$ axis
    $\alpha(\overrightarrow{v_n}) =$ angle degree of $\overrightarrow{v_n}$ relative to positive $x$ axis
    if $(|\alpha(\overrightarrow{v_m}) - \alpha(\overrightarrow{v_n})| < \pi)$
        $\delta = (\alpha(\overrightarrow{v_m}) + \alpha(\overrightarrow{v_n}))/2$
    else
        $\delta = -\pi + (\alpha(\overrightarrow{v_m}) + \alpha(\overrightarrow{v_n}))/2$
    end if
    change the working direction of sensor $v$ to new direction $\delta$
end for
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4.2 Approach with DT Triangle Edges (DTTE)

The case shown in Figure 7 is that two visual sensors have face-to-face working directions. In the cases like this, the coverage overlaps usually are larger because the directions of the two sensors are almost on the same common edge of two DT triangles. Accordingly, the overlap can be reduced if the two directions of adjacent sensors can be made to keep away from the common edge. In other words, making the directions of adjacent sensors to face to different edges will reduce the coverage overlap. As shown in Figure 8, the triangle edges in a DelaunayTriangulation can be utilized to make decisions for the working directions of visual sensors. Once different edges are selected, the center point of the respective edge will be determined as the new direction for its associated sensor.

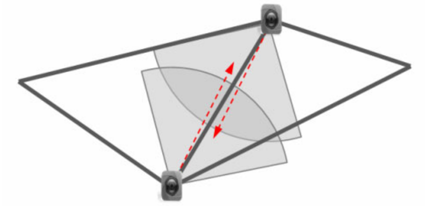

Figure 7. Coverage overlap due to face-to-face working direction

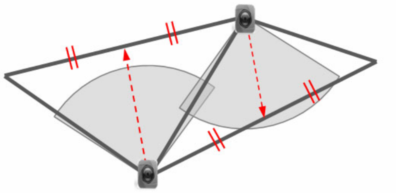

Figure 8. Overlap reduction by changing working direction with DT triangle edge

The case shown in Figure 7 is that two visual sensors have face-to-face working directions. In the cases like this, the coverage overlaps usually are larger because the directions of the two sensors are almost on the same common edge of two DT triangles. Accordingly, the overlap can be reduced if the two directions of adjacent sensors can be made to keep away from the common edge. In other words, making the directions of adjacent sensors to face to different edges will reduce the coverage overlap. As shown in Figure 8, the triangle edges in a DelaunayTriangulation can be utilized to make decisions for the working directions of visual sensors. Once different edges are selected, the center point of the respective edge will be determined as the new direction for its associated sensor

Figure 9 shows an example that there are n (n=7) visual sensors connected to sensor v and these sensors form a partial Delaunay Triangulation. Therefore, there are n=7 DT triangles in the example. Let λ_{ij} denote the edge connected from visual sensors v_i and v_j which sensors coordinates are (x_i, y_i) and (x_j, y_j) respectively. The length of the DT triangle edge λ_{ij} will be $\lambda_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$. In the design of our proposed approach, the edge of the largest length among these n=7 edges which are around the sensor $v$will be selected for new direction decision forthe sensor v. Let λ_{mn} is the selected one, the center point which coordinates (x_u, y_u)= $((x_m+x_n)/2, (y_m+y_n)/2)$ will become the target point of new direction of v. The new direction can be determined as:

$$\delta = \begin{cases} \sin^{-1} \dfrac{y_u - b}{\sqrt{(x_u - a)^2 + (y_u - a)^2}}, x_u \geq a \\ -\sin^{-1} \dfrac{y_u - b}{\sqrt{(x_u - a)^2 + (y_u - b)^2}} + \operatorname{sgn}(y_u - b) \cdot \pi, x_u < a \end{cases} \qquad \textbf{(6)}$$

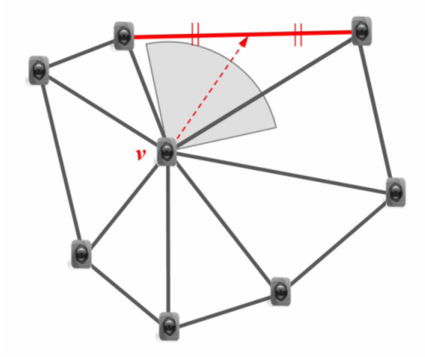

Figure 9. Decision of workingdirection with DT triangleslargest edge

Figure 10 is an example that shows the result of applying the proposed approach. The approach could reduce the coverage overlap significantly in the example.

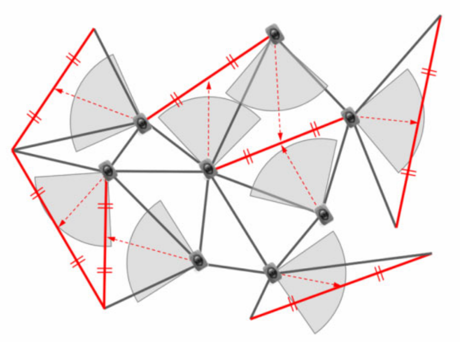

Figure 10. Example of changing working directions with DT triangleslargest edge

Algorithm 2. The algorithm of DTTE approach

Dtta algorithm

```
virtually divide the VSN field into DT triangles based on visual sensor locations
let $V = \{ v_i \mid 1 \leq i \leq n \}$, $n$ is the number of visual sensors
let $(x_i, y_i)$ denote the coordinates of $v_i$
let $\lambda_{ij}$ denote the edge $\overline{v_i v_j}$ of DT triangle $\Delta v_i v v_j$
for each $v \in V$
    $(a, b)$ = coordinates of $v$
    for each DT triangle $\Delta v_i v v_j$ associated with $v$
        $|\lambda_{ij}| = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$
    end for
    $m = \underset{i}{\operatorname{argmax}} |\lambda_{ij}|$
    $n = \underset{j}{\operatorname{argmax}} |\lambda_{ij}|$
    $x_u = (x_m + x_n)/2$
    $y_u = (y_m + y_n)/2$
    if $(x_u \geq a)$
        $\delta = \sin^{-1}((y_u - b)/\sqrt{(x_u - a)^2 + (y_u - b)^2})$
    else
        $\delta = \operatorname{sgn}(y_u - b) \cdot \pi - \sin^{-1}((y_u - b)/\sqrt{(x_u - a)^2 + (y_u - b)^2})$
    end if
    change the working direction of sensor $v$ to new direction $\delta$
end for
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5 Performance Evaluations

The proposed two approaches are based on DT triangle angles (DTTA) and DT triangle edges (DTTE) respectively. To evaluate the performance of these two approaches, simulations were held for this study. Initially, the visual sensors were deployed randomly. The parametersused in the simulations is shown in Table 1. The parameters are thesize of VSN field (*F*), number of visual sensors (*n*), the effective sensing distance of the sensors (*d*), and the angle of view (AoV) of the sensors (φ). The simulation results were summarized with average of 100 runs for each case.

Table 1. Simulation settings

Symbol	Description	Constant	Variable
F	VSN field size	500m×500m	N/A
n	number of visual sensors	100	80 to 120
d	effective visual sensing distance	70m	50m to 90m
φ	AoV of visual sensors	135°	115° to 155°

5.1 Performance with Variablenumber of Visual Sensors

To acquire the variationin visual coverage performance with different numbers of visual sensors, the simulation made the values of parameters d and φ to be constant (d=70m and φ=135°). The value of parameter n is set from 80 to 120 with an interval of 10. Figure 11 shows that both DTTA and DTTE can significantly reduce the initial visual coverage overlap and improve the coverage ratio; meanwhile, the performance of DTTA is better than the one of DTTE. Figure 12 shows the increased ratio while respectively comparing DTTA and DTTE with the initial coverage. DTTA obtained 6.3 to 4.9 percent of visual coverage increment while n=80 to n=120. DTTE obtained 6 to 3.4 percent.

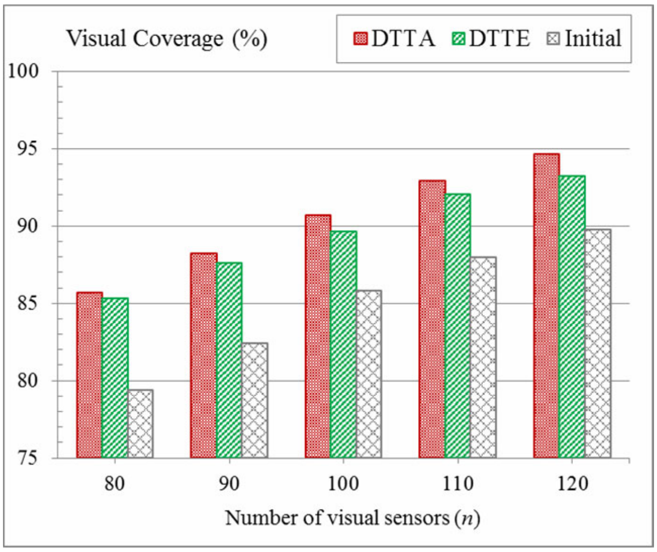

Figure 11. Ratio of visual coverage (d=70m, φ=135°)

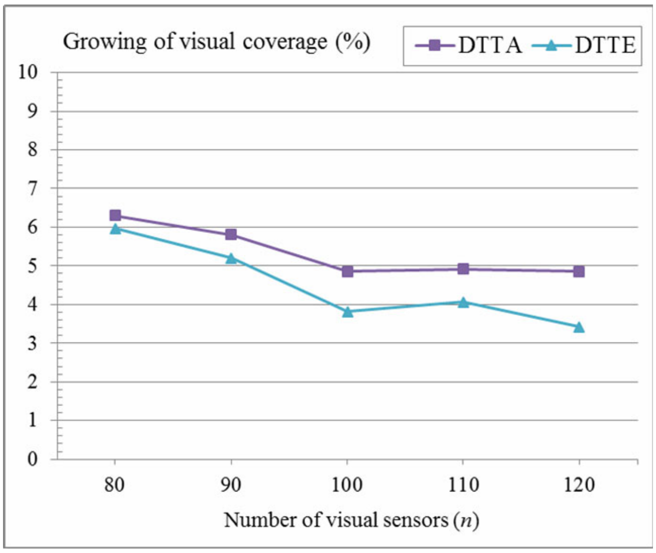

Figure 12. Growing ratio of visual coverage (d=70m, φ=135°)

5.2 Performance with Variable AoV

To observe the influence of the different AoVs of visual sensors on visual coverage performance, the simulation made the parameters n and d to be a fixed value respectively (n=100 and d=70m). The value of AoV parameter φ is set from 115° to 155° with an interval of 10°. Figure 13 still shows that both DTTA and DTTE can efficiently improve the coverage ratio; meanwhile, the performance of DTTA is also better than the one of DTTE. Figure 14 shows the ratio of improvement while respectively comparing DTTA and DTTE with the initial coverage. DTTA obtained 6 to 4.7 percent of visual coverage increment while φ=115° to φ=155°. DTTE obtained 3 to 4.6 percent. The results indicate that the two proposed approaches perform well for the reduction of initial visual coverage overlap in VSNs.

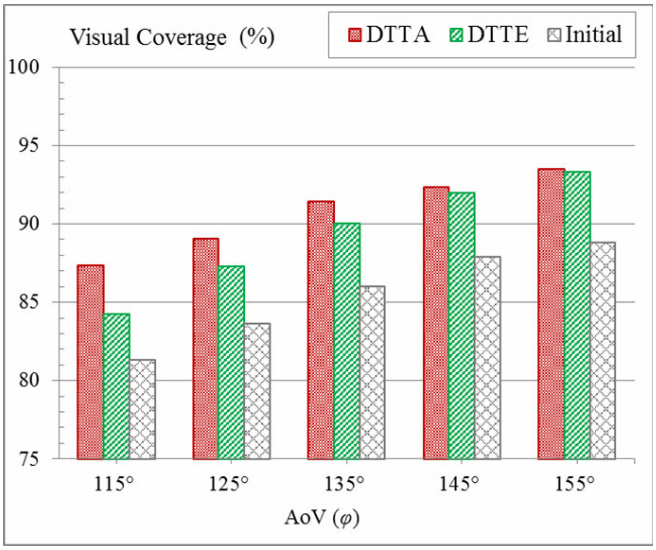

Figure 13. Ratio of visual coverage (n =100, d=70m)

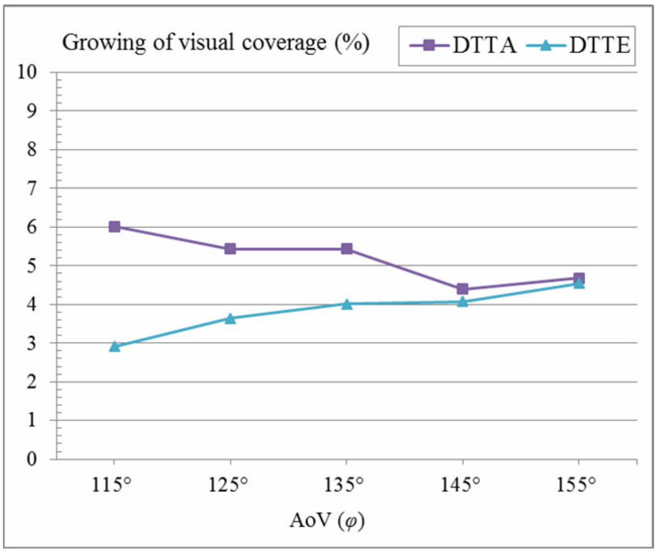

Figure 14. Growing ratio of visual coverage (n =100, d=70m)

5.3 Performance with Variable Effective Sensing Distance

The simulation in this subsection is to explore the difference ofvisual coverage performance while using variant effective vision distances of sensors. The simulation used a constant value for the parameters n and φ respectively (n=100 and φ=135°). The value of the parameter n is set from 50m to 90m with an interval of 10m. Figure 15 also shows that both DTTA and DTTE improve the coverage ratio very well. Although the DTTA performed better than DTTE in most these cases, its performance of the case d=50m is less than the one of DTTE and in the case d=60m it performed almost the same with DTTE. Figure 16 shows the increased visual coverage ratio while respectively comparing DTTA and DTTE with the initial coverage. DTTA obtained 5.4 to 3.3 percent of visual coverage increment while d=50m to d=90m. DTTE obtained 7.1 to 2 percent. The results still indicate that the two proposed approaches perform well for the reduction of initial visual coverage overlap in VSNs.

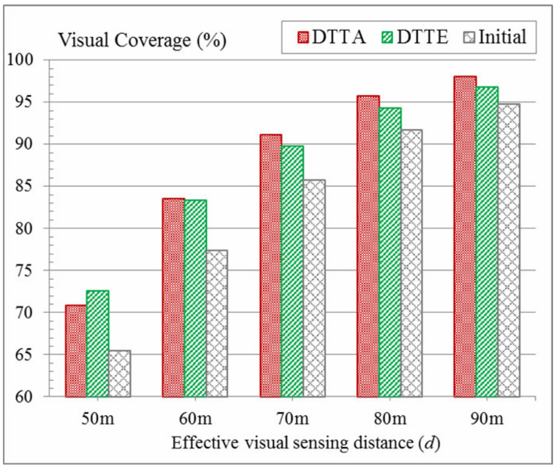

Figure 15. Ratio of visual coverage (n =100, φ=135°)

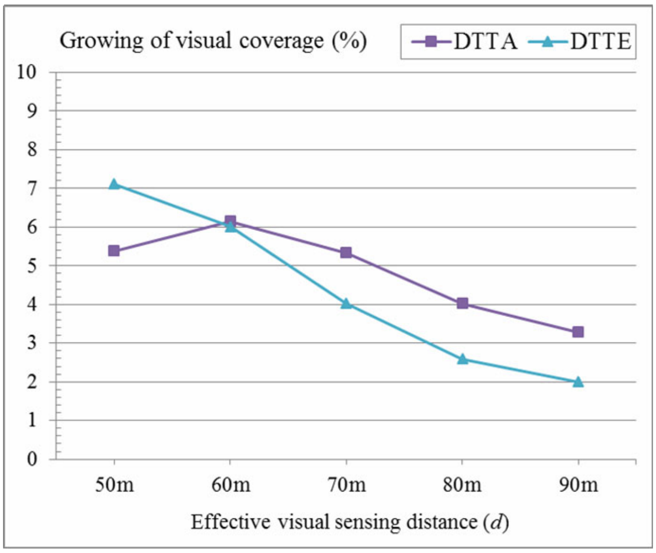

Figure 16. Growing ratio of visual coverage (n =100, φ=135°)

6 Conclusion

This study utilized one of the geometric structure, Delaunay Triangulation, to deal with the visual coverage problem in visual sensor networks. A Delaunay Triangulation consists of many featured triangles and each triangle comprised by angles and edges. This paper utilizes DT triangle angles and edges and proposes two approaches (DTTA and DTTE) to improve the visual coverage ratio in a VSN field. The simulation results of performance evaluation show that both of the proposed approaches can significantly improve the visual coverage no matter the values of the three key parameters (number of visual sensors, AoV of sensors, effective visual sensing distance) are changed. The approaches can achieve the reduction of coverage overlaps occur in initial deployment of visual sensors. Moreover, it was found that DTTA performed better than DTTE in most of the simulation cases. In future works, the DTTA approach could be a reference and be utilized in the design of advanced algorithms for visual coverage issues in visual sensor networks.

Acknowledgments

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References

[1] C. Zhu, C. Zheng, L. Shu, G. Han, A Survey on Coverage and Connectivity Issues in Wireless Sensor Networks, *Journal of Network and Computer Applications*, Vol. 35, No. 2, pp.619-632, March, 2012.

[2] D. G. Costa, L. A. Guedes, The Coverage Problem in Video-based Wireless Sensor Networks: A Survey, *Sensors*, Vol. 10, No. 9, pp. 8215-8247, September, 2010.

[3] Y. Charfi, N. Wakamiya, M. Murata, Challenging Issues in Visual Sensor Networks, *IEEE Wireless Communications*, Vol. 16, No. 2, pp. 44-49, May, 2009.

[4] D. Tao, T. Y. Wu, A Survey on Barrier Coverage Problem in Directional Sensor Networks, *IEEE Sensors Journal*, Vol. 15, No. 2, pp. 876-885, February, 2015.

[5] T. W. Sung, C. S. Yang, Voronoi-based Coverage Improvement Approach for Wireless Directional Sensor Networks, *Journal of Network and Computer Applications*, Vol. 39, pp. 202-213, March, 2014.

[6] M. D. Berg, M. V. Kreveld, M. Overmars, O. Cheong, V. Diagrams, *Computational Geometry: Algorithms and Applications*, Springer-Verlag, 2000.

[7] T. C. Biedl, C. Grimm, L. Palios, J. R. Shewchuk, S. Verdonschot, Realizing Farthest-point Voronoi Diagrams, *Proceedings of the 28th Canadian Conference on Computational Geometry*, Vancouver, British Columbia, 2016, pp. 48-56.

[8] R. Mulligan, H. M. Ammari, Coverage in Wireless Sensor Networks: A Survey, *Network Protocols and Algorithms*, Vol. 2, No. 2, pp. 27-53, June, 2010.

[9] G. Wang, G. Cao, P. Berman, T. L. Porta, Bidding Protocols for Deploying Mobile Sensors, *IEEE Transactions on Mobile Computing*, Vol. 6, No. 5, pp. 563-576, May, 2007.

[10] F. Aurenhammer, R. Klein, D. T. Lee, *Voronoi Diagrams and Delaunay Triangulations*, World Scientific, 2013.

[11] M. Younis, K. Akkaya, Strategies and techniques for Node Placement in Wireless Sensor Networks: A Survey, *Ad Hoc Networks*, Vol. 6, No. 4, pp. 621-655, June, 2008.

[12] C. Liu, G. Cao, Spatial-Temporal Coverage Optimization in Wireless Sensor Networks, *IEEE Transactions on Mobile Computing*, Vol. 10, No. 4, pp. 465-478, April, 2011.

[13] T. W. Sung, C. S. Yang, An Adaptive Joining Mechanism for Improving the Connection Ratio of ZigBee Wireless Sensor Networks, *International Journal of Communication Systems*, Vol. 23, No. 2, pp. 231-251, February, 2010.

[14] R. Kosar, I. Bojaxhiu, E. Onur, C. Ersoy, Lifetime Extension for Surveillance Wireless Sensor Networks with Intelligent Redeployment, *Journal of Network and Computer Applications*, Vol. 34, No. 6, pp. 1784-1793, November, 2011.

[15] H. Luo, H. Tao, H. Ma, S. K. Das, Data Fusion with Desired Reliability in Wireless Sensor Networks, *IEEE Transactions on Parallel and Distributed Systems*, Vol. 22, No. 3, pp. 501-513, March, 2011.

[16] C. Pham, A. Makhoul, R. Saadi, Risk-based Adaptive Scheduling in Randomly Deployed Video Sensor Networks for Critical Surveillance Applications, *Journal of Network and Computer Applications*, Vol. 34, No. 2, pp. 783-795, March, 2011.

[17] H. Huang, L. Sun, R. Wang, J. Li, A Novel Coverage Enhancement Algorithm for Image Sensor Networks, *International Journal of Distributed Sensor Networks*, Vol. 8,

No.5, pp.184-195, May, 2012.

[18] Y. C. Hsu, Y. T. Chen, C. K. Liang, Distributed Coverage-Enhancing Algorithms in Directional Sensor Networks with Rotatable Sensors*, International Conference on Distributed Computing and Networking*, Hong Kong, China, 2012, pp. 201-213.

[19] Channakrishnaraju, M. Siddappa, A Study on Efficient Methods Used to Enhance Coverage in Wireless Sensor Networks, *International Journal of Advanced Information Science and Technology*, Vol. 2, No. 5, pp. 109-115, May, 2013.

[20] H. Chizari, M. Hosseini, T. Poston, S. A. Razak, A. H. Abdullah, Delaunay Triangulation as a New Coverage Measurement Method in Wireless Sensor Network, *Sensors*, Vol. 11, No. 3, pp. 3163-3176, March, 2011.

[21] T. W. Sung, C. S. Yang, A Cell-based Sensor Deployment Strategy with Improved Coverage for Mobility-assisted Hybrid Wireless Sensor Networks, *International Journal of Ad Hoc and Ubiquitous Computing*, Vol. 5, No. 3, pp. 189-198, March, 2010.

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