An Optimal Sensor Placement for Full Coverage in Road Monitoring Systems with Proper Shape of Sensing Range

Ikram Syed, Irfanud Din and Hoon Kim*
Department of Electronics Engineering, Incheon National University, Incheon, Korea
ikram@incheon.ac.kr , irfan@incheon.ac.kr , hoon@incheon.ac.kr

Abstract: The use of large-scale wireless sensor networks in road monitoring systems has been the subject of much recent research, particularly with regard to the issue of how sensors can be efficiently placed in order to reduce network costs while maintaining the required performance. In this paper, we propose an optimal sensor deployment scheme enabling complete road surface coverage with a minimum number of properly shaped sensors. Based on a trapezoidal sensing range geometry derived from sensor characteristic parameters, an optimal sensor separation distance is proposed for a given sensing range in order to minimize the number of sensors while providing complete coverage. Results of sensor deployment assessment show that the proposed scheme can be effectively applied to cover various road areas.

[Ikram Syed, Irfanud Din and Hoon Kim. **An Optimal Sensor Placement for Full Coverage in Road Monitoring Systems with Proper Shape of Sensing Range.** *Life Sci J* 2013; 10(2): 2524-2527]. (ISSN: 1097-8135). http://www.lifesciencesite.com 350

Keywords: Wireless sensor network, road monitoring system, coverage, sensor deployment, sensing range

1. INTRODUCTION

Wireless sensor networks (WSNs) consist of spatially distributed sensors that monitor environmental conditions or events of concern and cooperatively pass the resulting data through a network to a main location. These sensors are low cost, low power, small in size and able to communicate over short distances [1], which make the sensors deployment easy to monitor the environmental conditions, such as temperature, sound, motion and other parameters at different location [2].

One of the fundamental issues in WSN is the coverage problem. Coverage is consider to be an important performance index of WSN [3], it represents how well a given area can be monitored by sensor nodes [3]; i.e., a sensing area can be considered to be covered if every point within it is monitored by at least one sensor node. Recently, a large amount of research activity has been dedicated to determining the optimal placement of sensor nodes for obtaining complete coverage over a given region.

One of the WSN applications is road monitoring system, which are used to monitor events such as accidents, illegal car parking, and traffic signal violations; for such applications, efficient deployment of monitoring sensors is vital not only to the effective coverage of the monitored area but also in reducing network costs [4]. Most existing monitoring sensor deployment problems assume sensors with an omni-directional, disk-type sensing range [5][6]. However, in real-world applications, environmental impairments or equipment constraints may dictate the use of sensors with sector-like directional sensing range geometries [7]; correspondingly, some research has gone into determining optimal sensor deployments for various sensing range geometries.

Wang et al. [8] and Han et al. [9] proposed optimal sensor separation distances for meeting coverage requirements with a minimum number of sensors having disk-type sensing range geometry, while Horster and Leinhart [10] and Tezcan and Wang [11] proposed optimal deployments for sensors with triangular sensing range geometries. Gonzales-Barbosa [12] developed a sensor deployment algorithm for use with mixed sensing range geometries [12], and Boukerche and Fei [13] proposed a coverage preserving scheme for irregular sensing range geometries [13]. As almost all previous work has been based on disk- or triangle-type sensing range geometries, further study is needed for the deployment of other practical and suitable road monitoring geometries. In this paper, we propose an optimal sensor deployment scheme that uses an appropriate sensing range geometry and has a minimum number of sensors needed to meet the coverage requirements.

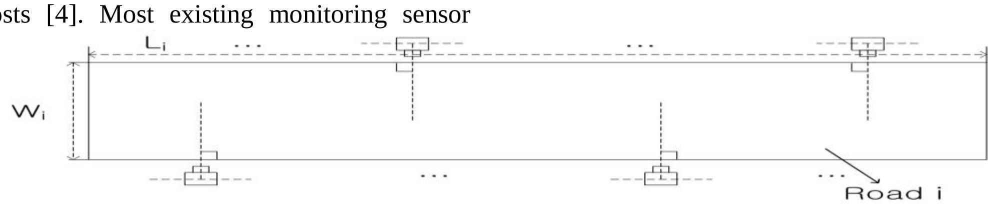


Figure1. Road Monitoring Model

2. SYSTEM MODEL

In this paper, a road monitoring system in which sensors are placed vertically on both sides of a road in order to minimize overlapping between neighboring sensors while providing full coverage of the road with a minimum number of sensors is proposed. Figure 1 shown a schematic of a monitoring system for a road (i) of width Wi and length Li.

For each sensor, the sensing range geometry is characterized by the following characteristic parameters: vertical view angle (θ); horizontal view angle (ϕ); position angle (ξ); and height (h). The on-the-ground sensing range geometry is assumed to be a two-dimensional trapezoidal shape, as shown in Figure 2(a). If x, y, and z are the lengths of the upper and lower parallel sides and the height of the sensing range of the trapezoid, respectively, they can be defined as follows:

$$x = 2h\sec(\xi)\tan\left(\frac{\varnothing}{2}\right) \quad (1)$$

$$y = 2h\sec\left(\xi+\theta\right)\tan\left(\frac{\varnothing}{2}\right) \quad (2)$$

$$z = h\tan\left(\theta+\xi\right) - h\tan\left(\xi\right) \quad (3)$$

and the sensing range of the trapezoid can be represented as a function of the sensor characteristic parameters, as shown in Figure 2(b).

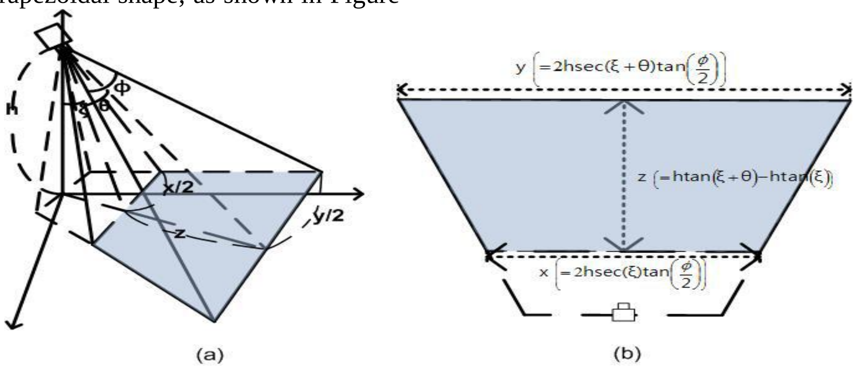


Figure 2.2-D sensing range representation for road monitoring sensor
(a) 2-D sensing range induction (b) Sensing range as a function of sensor characteristic parameters

3. PROPOSED SENSOR DEPLOYMENT

The objective of this study is to find the optimal positioning of sensors subject to coverage constraints while minimizing the number of sensors. Note that, for each road, sensor positions can be identified using the separation distance between sensors on the roadside. To cover the entire target area with a minimum number of sensors, the individual separation needs to be as wide as possible while satisfying the coverage requirements. We propose sensor deployments to satisfy this condition for the three different cases shown in Figure 3. In Case I, where z is equal to Wi, and Case II, where z is larger than Wi, it is possible to cover the entire width of the road with sensors, as shown in Figs. 3(a) and (b), respectively. In these cases, the sensors are placed in an orthogonal pattern and the sensing ranges do not overlap. In Case I, the separation distance between sensors, Di, can be calculated as the sum of x and y; as this case is simple and straightforward, only Case II and Case III are examined further. In Case II, Di is given by the sum $y + 2 \times di$, where di is half the length of the segment defined by the intersection of the road edge and the sensing trapezoid (see Figure 3(b)) and can be calculated from a proportional expression based on the properties of similar triangles of deviant crease line:

$$\left(d_i - x/2\right):\left(y/2 - d_i\right) = \left(z - W_i\right):W_i \quad (4)$$

Figure3(c) shows Case III; as z is smaller than W_i, it is impossible for one sensor to cover the full width of the road, and therefore additional sensors must be placed directly on the opposite side of the road in such a way that the remaining area is covered and unavoidable overlaps between adjacent sensors on same side are minimized. In this case, D_i can again be calculated from di, derived here from a proportional expression similar to Eq. (4):

$$\left(d_i - x/2\right):\left(y/2 - d_i\right) = \left(z - W_i\right)/2 : W_i \quad (5)$$

A comprehensive representation of D_i for Cases II and III is given by

$$D_i \begin{cases} y + \dfrac{zy + W_i(x-y)}{z} & if\ W_i \le z \quad (Case\ II \\ y + \dfrac{zy + W_i(x-y)}{2z} & elsewhere \quad (Case\ III \end{cases} \quad (6)$$

The optimal number of sensors, n, for all three cases can then be calculated as

$$n = \left(\frac{2L_i}{D_i}\right) + 1 \quad (7)$$

Where Li is the length of the road, and Di is the distance between adjacent sensors.

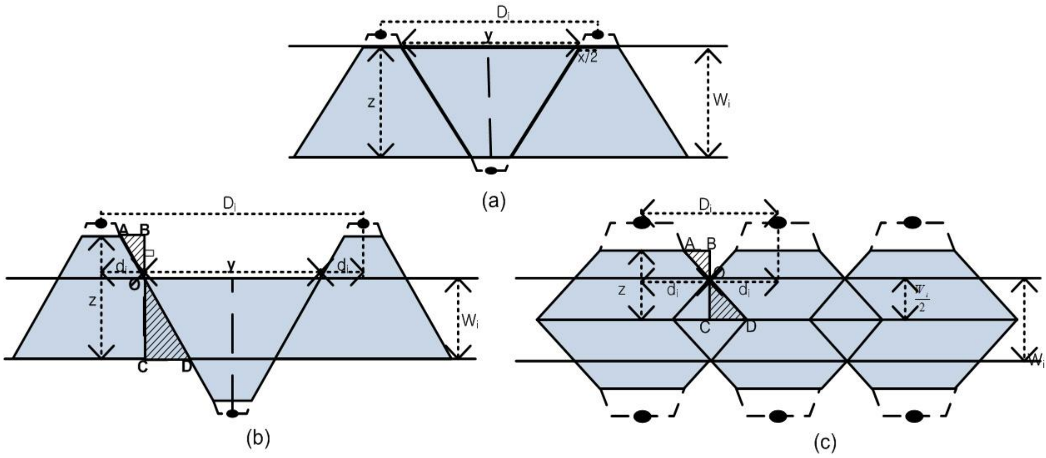


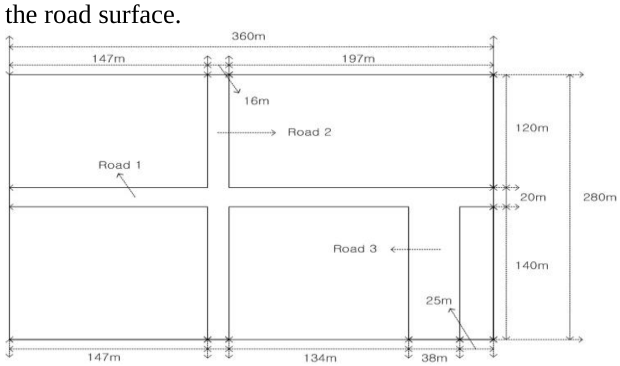
Figure 3. Proposed scheme model. (a) Case I. (b) Case II. (c) Case III

4. SENSOR DEPLOYMENT RESULTS

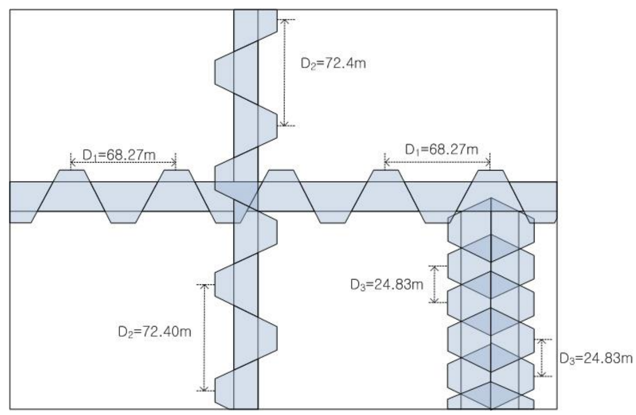
Figure 4(a) shows a road model, and Figure 4(b) shows the results of the proposed sensor deployment on the model. The widths of roads 1, 2, and 3 are 20, 16, and 38 m, respectively, and their lengths are 360, 280, and 140 m, respectively. The sensors have parameters θ = 30°, ϕ = 60°, ξ = 45°, and h = 10 m, resulting in sensing ranges x = 16.31 m, y = 44.48 m, and z = 27.23 m. The separation distances for Roads 1, 2, and 3 are 68.27, 72.40, and 24.83 m, respectively. In Figure 4 (b) Roads 1 and 2 correspond to Case II, while Road 3 corresponds to Case III; the separation distance for Road 2 is longer than that for Road 1 because it is narrower than Road 1.

5. CONCLUSION

In this paper, we proposed an optimal sensor deployment for a road monitoring system in which the sensors are placed vertically with respect to the road surface along both sides of the road. The proper sensing range of a trapezoidal geometry was derived, and based on this, a sensor deployment that provided total coverage with a minimal number of sensors was developed. Further work in this area will include the development of deployment schemes for situations in which sensors can be positioned with more flexibility and orientated in a variety of directions with respect to the road surface.



(a)



(b)

Figure 4. Road model and optimal sensor deployment result. (a) Road model. (b) Optimal sensor deployment

***Corresponding Author:**
Hoon Kim,
Dept. of Electronics Engineering,
University of Incheon, Korea.
Email: hoon@incheon.ac.kr .

REFERENCES

[1] I.F. Akyildiz, W. Su, Y. Sankarasubramaniam, E. Cayirci, "Wireless sensor networks: a survey", Computer Networks, Vol. 38 (2002), pp.393-422.

[2] Z. Ruan, E.C.H. Ngai and J. Liu, "Wireless Sensor Network Deployment in Mobile Phones Assisted Environment", IEEE International Workshop on Quality of Service, (China, 2010), pp. 1-9.

[3] J. Adriaens, S. Megerian, M. Potkonjak, "Optimal Worst Case Coverage of Directional Field-of-View Sensor Networks", Sensor and Ad Hoc Communications and Networks, (2006), pp. 336-345.

[4] S. Coleri, S. Cheung, and P. Varaiya, "Sensor networks for monitoring traffic," In Proc. 42nd

Ann. Allerton Conf on Comm. control and computing, (Illinois US, Sept. 2004).
[5] X. F. Cheng, P. Liu, Z. G. Chen, H. B. Wu, X. H. Fan "The Optimal Sensing Coverage for Road Surveillance", Wireless Sensor Network, Vol.2 (2010) No.4, pp.318-327.
[6] R. Iyengar, K. Kar, and S. Banerjee, "Low-coordination Topologies for Redundancy in Sensor Networks", In ACM MobiHoc, (New York, USA, 2005), pp. 332-342.
[7] K. Kar and S. Banerjee, "Node Placement for Connected Coverage in Sensor Networks", In Proc. of WiOpt 2003: Modeling and Optimization in Mobile, Ad Hoc and Wireless Networks, (France, March 2003).
[8] Y .C. Wang, C.C. Hu, and Y.C. Tseng, "Efficient Deployment Algorithms for Ensuring Coverage and Connectivity of Wireless Sensor Networks", Proc. WICON 05: First IEEE Int'l Conf. Wireless Internet, (2005), pp. 114-121.
[9] X. Han, X. Cao, E. L. Lloyd, and C.C. Shen, "Deploying Directional Sensor Networks with Guaranteed Connectivity and Coverage", In Proc. of Sensor, Mesh and Ad Hoc Communications and Networks, (San Francisco, USA, June 2008), pp.153-160.
[10] E. Horster, R. Lienhart, "Approximating optimal visual sensor placement", In Proc. ICME, (June 2008), pp.1257-1260.
[11] N. Tezcan and W. Wang, "Self-Orienting Wireless Multimedia Sensor Networks for Maximizing Multimedia Coverage," In IEEE International Conference on Communications (ICC), (May 2008), pp. 2206-2210.
[12] J.J. Gonzalez-Barbosa, T. Garcia-Ramirez, J. Salas, J. Hurtado-Ramos, J.J. Rico-Jimenez, "Optimal Camera Placement for Total Coverage", In Proc. ICRA '09, (2009), pp. 844-848.
[13] A. Boukerche, X. Fei, "A coverage-preserving scheme for wireless sensor network with irregular sensing range", Ad Hoc Networks, 2007, Vol. 5, pp. 1303-1316.

6/18/2013