Cubic-based 3-D Localization for Wireless Sensor Networks

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***Abstract* – Localization using sensor network has attracted much attention for its comparable low-cost and potential use with monitoring and targeting purposes in real and hostile application scenarios. Currently, there are many available approaches to locate persons/things based of GPS and RFID technologies. However, in some application scenario, e.g., disaster rescue application, such localization devices may be damaged and may not provide the location information of the survivors. The main goal of this paper is to design and develop a robust localization technique for human existence detection in case of disasters such as earthquake or fire. In this paper, we propose a 3-D localization technique based on the hop-count data collected from sensor anchors to estimate the location of the activated sensor mote in 3-D coordination. Our algorithm incorporates two salient features, grid-based output and event-triggering mechanism, to guarantee both improve accuracy and power efficiency. Simulation results indicate that the proposed algorithm can improve the localization precision of the human existence and work well in real environment.**

Keywords– Wireless Sensor Network, Localization Technique, 3 Dimensions.

I. INTRODUCTION

Wireless sensor network (WSN) is an emerging technology and now widely used in many application areas; including civil monitoring, environmental monitoring and so on [1]. In WSNs, localization is necessary to allow end-users to know the locations of sensors which have been triggered by events or readings. While global positioning systems (GPS) can be incorporated within each mote in the WSN, it is often costly to implement this function if the WSN consists of large number of motes, which typically amount up to thousands [2]. To overcome this problem, the locations of some of the motes are made known beforehand and these motes are known as anchor motes [3]. These motes are often used in localization techniques to identify the location of the trigger motes or target motes [4].

Additionally, localization is key issue in WSN since it is very important to provide the accurate location information in timely manner. For example, after a disaster such as fire or earthquake, WSN is very useful to detect the survivor existence in order to perform the rescue operation. Quickly searching and rescuing survivors are key issues in many disasters since it can save lots of people life. Most of the current localization techniques based on WSN technologies provide the location information in 2-D coordination. That means we can only know the location of the objects with x- and y-coordinates. In some situation, the height such as z-coordinate may be useful and important to us. For example, if we like to measure any crack or damage of the bridge, it may be useful to know the position with all x-, y-, and z-coordinates to identify the exact location of the damage in the bridge. In addition, it is complementary for disaster management tasks such as finding escape route and rescuing survivors as well. For example, in case of fire in a high building, we can simply find out the escape route in a certain floor with the use of 3-D location information.

According to the features that sensor networks have no space constraints, flexible distribution, mobile convenience and quick reaction, in this paper, we proposed a 3-D localization scheme that uses wireless sensor network to detect the human/object existence which is applicable in all types of rescue applications. Our proposed technique will provide the location of the object in a 3-D format. With the proposed algorithm, we can monitor the building based on sensor network, quickly find out the survivors after any disaster and perform the rescue operation in the most effective way.

The rest of the paper is organized as follows. We first briefly describe some related works in Section 2. Section 3 describes the key idea of our proposed method to obtain 3-D localization precision of the nodes. Simulation results are presented in Section 4. Finally, we conclude the paper in Section 5.

II. RELATED WORKS

Currently, the localization techniques in WSN can be generally classified into three categories, *range-based* localization technique, *range-free* localization technique and *mobile-beacon-based* technique. All these techniques are considered 2-D location techniques because the output location information will be in terms of x- and y-coordinates.

Range-based techniques are based on distance estimation between motes. In other words, range-based technique conducts complex measurements on distance or angle of arrival signals in order to estimate the target location by using sophisticated devices. Due to the expensive hardware cost, range-base technique is rarely used in WSN applications which require huge number of sensor nodes. In *range-free* techniques, on the other hand, the estimation of the target node position is solely based on the connectivity between non-anchor nodes and anchors [5]. In *mobile-beacon-based* technique, the position of the beacon mote is dynamically changing and the location of unknown mote is estimated by computing the range between the unknown mote and the mobile beacon. Our proposed localization technique belongs to the range-free technique and thus, in this section, we will briefly discuss about other range-free techniques which make use of similar assumptions.

A. DV-Hop Technique

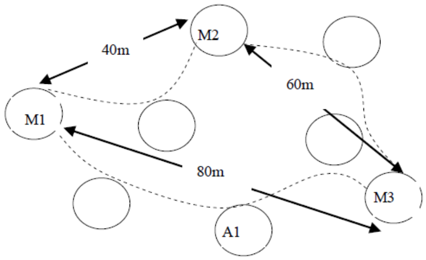

Figure 1: Example of DV-hop technique.

In [8] [9], D. Niculescu and N. Badri proposed a range-free localization method called DV-Hop. This is the most basic range-free technique which employs a classical distance vector exchange so that all nodes in the network get the distances to different anchors in hop-count numbers. The basic idea is to transform the distance to all anchor nodes from hops to meters by using computed average size of a hop. Accordingly, in DV-Hop, a mote will establish information of the locations and number of hops from this mote to other motes in the WSN. The mote will then make an approximation of the single-hop distance where the information is flooded throughout the WSN. Lastly, based on the location of anchor motes and the approximate single-hop distance, the mote will then be able to make an approximation of its own location. The advantages of the DV-Hop scheme are its simplicity and the fact that it does not depend on measurement error. However, despite its simplicity, DV-Hop propagation method is only applicable to isotropic networks in which the properties of the graph are the same in all directions.

B. Monte-Carlo Localization Technique

In MCL algorithm [10], time is divided into discrete time unit so that a moving node can be re-localized to the new position in each new time unit. The algorithm consists of two phases. During the initialization phase (time $t = 0$), a sensor node has no knowledge about its position. Therefore, a random N sample is selected within the deployment area, which form the first sample set L_0. The following phase will then repeat itself at each time unit. At each following time step, the new set L_t is obtained based on both possible node movement and new observations on node's connectivity to the anchors. This process can be further divided into two steps: *prediction* and *filtering*.

In *prediction* step, a node makes use of its previous location in L_{t-1} together with the mobility model to obtain its new set of positions L_t. In *filtering* step, the impossible calculated locations from the prediction process based on new observations between the mote and the anchors in the vicinity will be eliminated. Iteration of these two processes will maintain a set of samples and, in the end, the node location estimation is done by taking the average of all N sample values in set L_t by the equation:

Estimated node location = (1)

C. Monte-Carlo Localization Boxed Technique

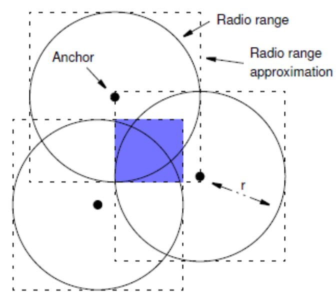

Figure 2: Anchor box established in MCB.

The Monte-Carlo Localization Boxed (MCB) technique [11] was developed based on the MCL technique. The major differences are the way of using anchor information and the method for drawing new samples. While MCL algorithm uses the two-hop anchor information in the filtering step, MCB algorithm uses both one-hop and two-hop anchor information in both prediction and filtering steps.

An initial anchor box B_0 is set up, from which the initial random sample set L_0 is drawn. If the node is not connected to any anchor, the coordinates of the anchor box is $B_0 = \{(0, x_r); (0, y_r)\}$ where x_r and y_r is the maximum x and y coordinate of the deployment area. Otherwise, the anchor box is built that covers the area where the anchors' radio ranges will overlap. The coordinates of is given as follows:

(2)

Letdenotes the coordinate of anchor *j*. Hence, the coordinates of the four corners of is also given by:

(3)

Figure 2 shows an example of how anchor box is created.

III. Proposed 3-D Localization Technique

The basic idea of proposed technique is to break down the monitored 3-D space into an $n \times n \times n$ grid structure and generates an output cube which is the 3-D space where the target node is located. In this localization technique, the coordinates and ranges of all anchor nodes are known in advance. The localization is carried out by calculating the hop-count distances from the target node to each anchor and then determining the vertex coordinates and volume of output localizing cuboid.

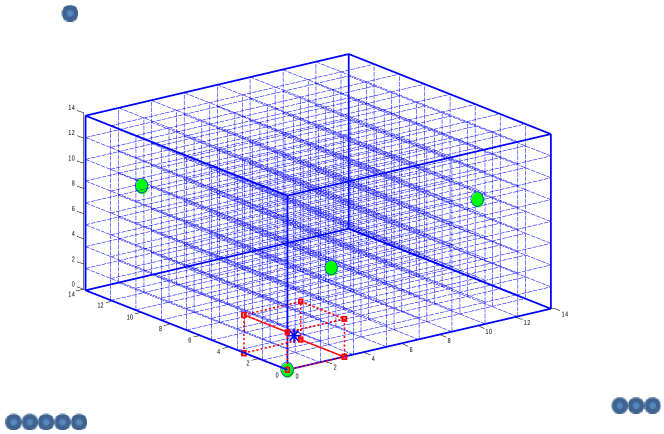

Figure 3: A 3-D monitored space with eight anchors.

For this algorithm, the monitored 3-D space is enclosed within (0, 0, 0) and (X_s, Y_s, Z_s). The algorithm first divides the monitored space into an $n\times n\times n$ grid structure and places eight fixed anchor nodes at eight corners. Figure 3 shows a 14x14x14 3-D monitored space with eight anchors at each corner and with several number of relay nodes. For this algorithm, the smallest volume unit is known as a *cube* with 1x1x1 grid structure. The dimension of each cube is $r\times r\times r$ cubic unit and the diagonal length of a cube, as BoxDiagonal, is same as the transmission range, R, of the wireless sensor. Thus, we can find the length of one side of a cube, as GridLength, using the formula:

. (4)

Figure 4 shows both *BoxDiagonal* and *GridLength*.

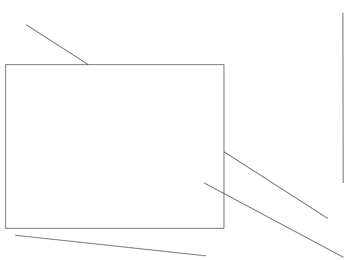

Figure 4: GridLength and BoxDiagonal.

A. Assumption

Our proposed localization algorithm adopts similar assumptions as the MCL and MCB algorithm, which are:

1. Anchor motes which are equipped with GPS or fixedly-placed at pre-known locations, are allowed to know their location all the time;
2. The transmission range of all anchor motes is identical and equal to R;

B. Finding Distance between Anchors and Target Node

Figure 5: Finding distance between anchor mote and target node.

In the first stage of this cubic-based 3D-localization technique, the distance between each anchor and the target node will be established in terms of X, Y and Z coordinates as in Figure 4. The shortest distance between two points, d, can be found by using the equation:

$$d^2 = (X_2 - X_1)^2 + (Y_2 - Y_1)^2 + (Z_2 - Z_1)^2 \quad (5)$$

After obtaining the shortest distance between the target node and each anchor, we will be able to find the number of hops from the target node to the respective anchor mote. The number of hops, H, from the target node to each anchor can be found by the following relationship:

H=Ceiling ( ).

Based on the results collected from the WSN, we will have a set of hop-count data where h_j is the number of hops from the target node to anchor mote j, and N is the number of anchor motes. The output of the algorithm is a 3-D cube, B, which contains possible locations of the target node expressed in terms of x-,y-,z- coordinates (x_{min}, y_{min}, z_{min}) and (x_{max}, y_{max}, z_{max}) of the cubic space.

For the algorithm, the distance for 1 hop-count is set as being equivalent to the range of a mote. Hence, if , the target node must be inside the h_1-hop coverage cubic space of anchor mote 1. In this way, the range of a mote will in fact form a cube with the mote right in the one corner of the cube.

The algorithm will determine the region B_j which is the -hop count covered cube of anchor j with . The X, Y and Z coordinates of lower and upper corners of the cube, B_j, is given by:

(6)

where . Figure 6 shows the output cube which contains the target node with lower and upper corner points as Point A and Point B, respectively.

Figure 6: Output cube containing the target node.

C. Finding the Location of the Target Node

When we have more than one anchor node within the grid structure, we will receive a set of hop-count data . With each value of , we will be able to find a corresponding 3-D space for each anchor. By finding the overlapping volume of all the , we will be able to determine the 3-D space B. Hence,

= (7)

The 3-D space B is the estimated cube which includes the location of the target node. The upper bound and lower bound of X , Y and Z coordinates for this cube is given by:

(8)

Based on this, we will be able to obtain the corresponding number of cubes for each anchor we have. Assuming the case where we only have two anchors, we will obtain two cubes as shown in Figure 7 where the possible location of the target node is enclosed with the red box. We will then find the common volume intersected by these two cubes and this will help us narrow down the possible cube volume which contains the target node. Point C is one corner of this volume which is the minimum point in terms of X, Y and Z coordinate and Point D is the corner directly opposite Point C which is the maximum point in terms of X, Y and Z coordinate. We will then proceed to find a possible 3-D space bounded with the red dotted box as shown in Figure 8 which shows the estimated cube contains the target node.

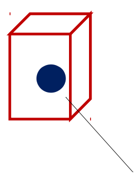

Figure 7: Obtaining red box containing possible location of target node.

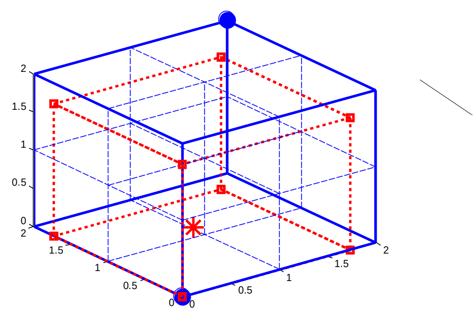

Figure 8: Estimated 3-D output cube to detect the target node.

IV. Simulation and Experimental Results

A. Simulation Setup

In this sub-section, we evaluate the performance of our proposed 3-D cubic-based localization algorithm based on MatLab simulation. For MatLab simulation, we set up the WSN as the parameters shown in Table 1.

TABLE

WSN Setup Parameters

Parameter	Values
Anchor Range R	1.732051
Grid Structure	8×8×8
Number of Anchors	8
Anchor Coordinates	(0,0,0); (0,0,8); (0,8,0); (0,8,8); (8,0,0); (8,0,8); (8,8,0); (8,8,8)
Target Coordinates	Randomly generated by program
Sample Size (Iteration Times)	100

B. Simulation Results

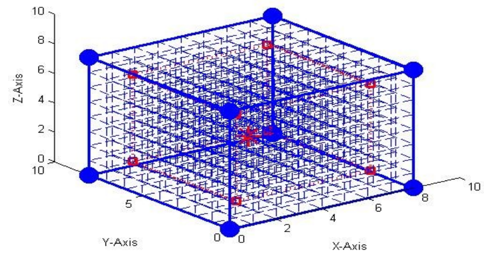

Figure 9: MATLAB simulation result for hop-count set (4,4,4,5,4,5,5,5).

Different combinations of hop-count values and the corresponding output effective volumes are summarized in Table 2. The hop-count values shown in each row do not correspond to actual anchor number. It can be seen that, for 8×8×8 grid structure, only the hop-count values of 1 or 2 can give a smaller output cube volume which can contribute to higher localization accuracy. From Table 2, there are two possible output cube volumes for the hop-count set (4,4,4,4,5,5,5,5), 200.8602 and 237.6202. This is because there are different distributions of the four anchors with $h_i = 4$. The two actual anchor numbers, (h_1,h_2,h_3,h_4,h_5,h_6,h_7,h_8), are (4,4,4,5,4,5,5,5) and (4,4,5,5,4,4,5,5). The simulation results are shown in Figure 9. In the figure, the blue nodes indicate the anchors and the red asterisk indicates the location of the target node and the red dotted box indicates the output cubic space based on our proposed 3-D localization algorithm. Even though the hop-count set is the same for both cases, different spatial distribution of the anchor number has affected the output cube volume.

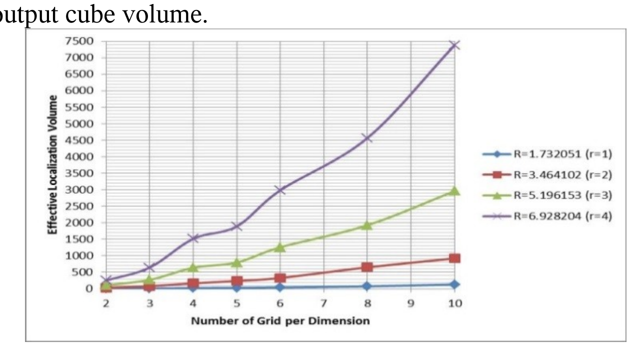

Figure 10: Average effective output localization volume for different *n*.

Figure 11: Average percentage of effective output localization volume to the monitoring region volume for different *n*.

Next, we analyse the effective output localization volume obtained from different combination of node's transmission range, R, and grid structure, nxnxn as shown in Figure 10 and 11. In both figures, the x-axis refers n and the length of the grid increases with R. Figure 11 shows the average effective output localization volume for different n and R. For a fixed grid structure, nxnxn, as R increases, the output volume increases. This is because the grid size increases with R correspondingly. The growth of average effective output volume follows a cubic relationship to the R, which implies a rapid drop in localization accuracy as well. The relationship can be expressed as:

$$\rightarrow \qquad (9)$$

For a fixed R, the average effective output localization volume increases with n. That means the localization accuracy decreases with n. This is a reasonable observation because a larger n give more possibilities for a target node to be positioned.

Figure 11 shows the average percentages of the effective output localization volume to the total monitoring volume. The percentage of the average effective output localization volume to the total monitoring volume decreases with total monitoring volume. For example, for n=10, the average percentage of the effective output localization volume to the total monitoring volume is about 10.

V. Conclusions

In recent times, search and rescue with modern localization techniques bring interest to the scientific and industrial sides. This paper presents a robust cubic-based 3D-localization technique particularly tailored for disaster rescue applications. By adopting cubic-based output and event-triggering mechanism, the proposed algorithm can reduce computational complexity, improve output accuracy and reduce power consumption.

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References

[1] F. Akyildiz et al., "Wireless Sensor Networks: a survey," Computer Networks, vol.38, 2002, pp. 393-422.

[2] C K Seow and S Y Tan, "Non Line of Sight Localization in Multipath Environment," IEEE Trans. on Mobile Computing, Vol. 7, No. 5, pp. 647-660, May 2008

[3] L. Hu and D. Evans, "Localization for mobile sensor networks," in *Proc. of ACM MobiCom'04*, vol. 1, Philadelphia, PA, 26 September - 1 October, 2004, pp. 45-57.

[4] A. Baggio and K. Langendoen, "Monte-Carlo localization for mobile wireless sensor networks," *Ad Hoc Networks*, vol. 6, January, 2008, pp. 718-733.

[5] G. Mao, B. Fidan, and B. D. O. Anderson, "Wireless sensor network localization techniques," *Computer Networks*, vol. 51, , 11 July, 2007, pp. 2529-2553.

[6] P. Bahl and V. N. Padmanabhan, "RADAR: an in-building RF-based user location and tracking system," in *Proc. of IEEE/ACM INFOCOM'00*, vol. 2, Tel Aviv, Israel, 26-30 March, 2000, pp. 775-784.

[7] A. Ward, A. Jones, and A. Hopper, "A new location technique for the active office," *IEEE Personal Communications,* vol. 4, October, 1997, pp. 42-47.

[8] D. Niculescu and N. Badri, "Ad-hoc positioning system (APS) using AOA," in *Proc. of IEEE/ACM INFOCOM'03*, vol. 3, San Francisco, CA, 30 March-3 April, 2003, pp. 1734-1743.

[9] D. Niculescu, N. Badri, "DV Based Positioning in Ad hoc Networks," in *Journal of Telecommunication Systems*, 2003, 22(1-4): pp. 267-280.

[10] D. Fox, W. Burgard, F. Dellaert, and S. Thrun, "Monte-Carlo Localization: Efficient Position Estimation for Mobile Robots," In *Proceedings **of** the National Gonfemnce on Artifical ntelligence.* AAAI, May 1999.

[11] Baggio A. , Langendoen K., " Monte Carlo Localization for Mobile Wireless Sensor Networks", in *ELSEVIER Ad Hoc Networks*, Volume 6, Issue 5, July 2008.

[12] N. B. Priyantha, A. Chakraborty, and H. Balakrishnan, "The cricket location-support system," in *Proc. of ACM MobiCom'00*, vol. 1, Boston, MA, 2000, pp. 32-43.

[13] Yang Liu, Jianping Xing, and Ran Wang, "3D-OSSDL: Three Dimensional Optimum Space Step Distance Localization Scheme in Stereo Wireless Sensor Networks," in *Advances in Intelligent and Soft Computing,* vol. 112, pp 17-25, 2012.