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Path Planning Algorithm using a Mobile Anchor Node for Localization in Wireless Sensor Networks

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Abstract:

Determining location information of sensor node is an essential issue to capture the sensed data and to update the necessary information in many wireless sensor network applications, such as healthcare services, military applications, warning systems, environmental monitoring etc. Mobile Anchor Node is used to achieve Localization in a wireless sensor networks. Hence the main challenge is to design and develop a Path Planning Algorithm for a Mobile Anchor Node to broadcast three consecutive non-collinear messages for location estimation which in turn increases localization accuracy and coverage and also reduces time required to determine location information. In this paper, I propose a Path Planning Algorithm called Z-curve to perform trilateration calculation to estimate sensor nodes location. Proposed trajectory can successfully localize all deployed sensor nodes in a network region of interest with more accuracy and consumes less time for localization. Furthermore, to handle obstacles, Z-curve obstacle-handling trajectory is proposed.

Keywords— Wireless sensor networks, mobile anchor node, path planning, non-collinear, localization.

I. INTRODUCTION

A Wireless Sensor Network (WSN) consists of more number of sensor nodes which are able to sense the local information of interest and can forward the sensed information to a remote data collection device called sink over a wireless medium. Applications of WSNs are healthcare services, military applications, environmental monitoring etc., [1]. In these applications, knowing the position of sensor node is important to report events of interest. Determining the physical coordinates of a sensor node in a network region is known as localization [2]. Localization techniques for WSNs are mainly classified into two groups namely, range-based technique and range-free technique. Range-based techniques make use of node to node distances or inter node angle to estimate localization, such as methods proposed in [3]–[5]. Range-free techniques make use of connectivity information between sensors and location information messages, such as methods proposed in [6], [7], and [8].

Global Positioning System (GPS) is a commonly used method for localization of sensor nodes. But GPS method is not efficient since it is neither cost-effective nor energy-efficient [9], [10]. And also GPS equipped sensors have limited applicability since GPS works only in an open field [11] and increases size. Localization algorithms can handle the situation where they are able to estimate the physical location of sensors by using few sensors knowledge about absolute positions. Generally, these small proportions of sensor nodes with known location information (either equipped with GPS or installing at a fixed position) are termed as *anchors*. Sensor nodes which need to be localized are termed as *unknown nodes*.

WSNs are usually used for applications where human operation is impossible. So, installing sensor nodes in a predetermined location is often impossible. Even though all the sensor nodes in WSNs are able to determine their location, it will increase the cost of WSN and energy consumption [12], [13]. Hence, I am motivated to use a single mobile anchor node to localize an entire network. By comparatively, localization by using a mobile anchor node is more accurate and cost-effective than localization by using static anchor nodes [14]–[16]. The mobile anchor node travels around the region of interest in a network where unknown sensor nodes are deployed and transmits the location information [7].

Path planning algorithm must be designed to select a deterministic trajectory for a mobile anchor node to travel around region of interest so that it can guarantee that all the unknown sensor nodes can receive location information from mobile anchor node to estimate their positions. Here the key property is full coverage of network by three non-collinear location information messages (messages transmitted by the mobile anchor node where at least one of them is not on a straight line) and also through the shortest path length and it should pass closely to as many potential unknown sensors (to improve accuracy). Several paths for mobile anchor node movement to achieve localization have been surveyed in [7]. Here, I propose a path planning algorithm for localization named *Z-curve* which satisfies all features mentioned above.

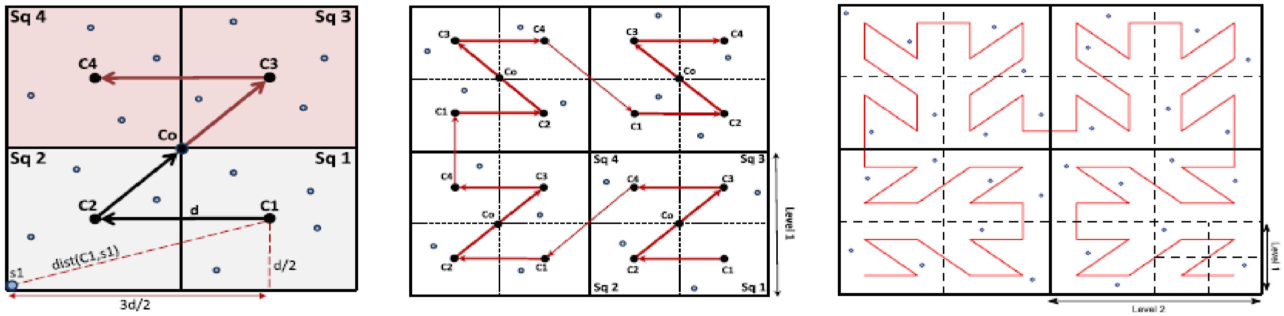
In summary, the contributions of this paper are as follows: I propose a path planning algorithm for mobile anchor node to achieve localization which can guarantee full coverage of sensor nodes in a network region with higher degree of precision for estimation of location by providing three consecutive non-collinear messages through the shortest possible path. The proposed trajectory can achieve more accuracy of location estimation and less time required to perform localization. And also, the obstacles are considered in the network field and the *Z-curve* obstacle handling trajectory is proposed to handle obstacle presence problem for a real environment.

II. RELATED WORK

Developing an optimum trajectory for mobile anchor node to achieve localization is mainly concerned with finding an optimal path for the mobile anchor node. Few of the fundamental properties of an optimum path for mobile anchor node have been introduced in [9] and [14]. Here, a brief review on the existing trajectories for mobile anchor node for localization is presented. Scan, Double Scan, and Hilbert are three well-known trajectories proposed in [9]. Their localization accuracy directly depends on the resolution of the trajectory which is the distance between two successive anchor positions. All the above mentioned trajectories can cover the network region, but SCAN method has collinearity as its disadvantage (anchor messages transmitted by the mobile anchor node while it is moving in a straight line). To overcome from the above mentioned problem, Double SCAN traverses the network region along both directions which leads to more expense as it is covering double distance. A Hilbert method is proposed to reduce the collinearity of SCAN without increasing the path length significantly, but sensor nodes present near the border of the deployment region are not able to estimate their locations. So, fully coverage is not achieved by this method and localization error has been increased. CIRCLES and S-CURVES methods were proposed in [17] to reduce the collinearity problem of path planning methods by eliminating straight lines. Even though these methods achieve the shortest path length when compared to previous methods, CIRCLES do not cover the four corners of network region and S-CURVES cannot guarantee that all sensor nodes can receive three location information messages to estimate their location. A path planning scheme for localization based on trilateration is introduced in [18]. Here the mobile anchor node will move according to an equilateral triangle to broadcast its current position. The path type can successfully handle the collinearity problem but it cannot achieve full coverage of network region of interest which in turn increases the localization error and path length also increases.

III. PROPOSED PATH PLANNING ALGORITHM AND LOCATION ESTIMATION

The proposed path planning algorithm for mobile anchor node presented in this section is termed as



(a) Level (1) (Basic Curve) (b) Level (2) (c) Level (3)

Fig. 1. *Z-curve* traversing path

Z-curve. The trajectory of the basic curve is shown in Fig 1(a) which is based on shape *Z*. The key motivation in the *Z-curve* designing is, a trajectory must have shorter jumps to avoid the collinearity problem and must create a path for mobile anchor node to transmit three consecutive non-collinear location information messages in order to reduce the localization time. If the mobile anchor node moves on the *Z-curve* path, unknown sensor nodes can be localized more accurately while the trajectory passes through whole network region and even considering the border of the deployment area. We use the level of the curve concept as follows. The basic curve is said to be of level (1) where l=1. To derive level (l), a 2-dimensional network region must be divided into 4^l sub-squares and the mobile anchor node moves in the *Z-curve* path by connecting the centres of the cells. Each vertex of the basic curve is termed as $C1, C2, C3, C4$ as shown in Figure 1(a) with level (l-1), which is appropriately reflected and/or rotated to fit into the new level curve. I illustrate level (2) and level (3) of *Z-Curve* in Fig 1(b) and 1(c), respectively.

Step 1: In the first step the relation between the communication range and localizability of unknown sensor nodes is analysed. Hence all unknown sensor nodes are localizable by *Z-curve* path, if:

$$\forall\, s_{i\,(i=1,\dots,n)} \exists \{b_{j\,(j=1,2,3)} \mid dist\,(b_j, s_i) \le R_c\} \quad (1)$$

where s_i denotes unknown sensor nodes and b_j denotes the anchor messages transmitted from three different anchor positions (e.g. $C1$). $dist\,(b_j, s_i)$ and R_c are distance between sensor node and anchor, and communication range, respectively.

Step 2: In the second step the communication range of the mobile anchor node traversed by the *Z curve* is adjusted as all sensor nodes must cover fully for localization. As mentioned in first step, the network region in level (1) is divided into four sub-square, namely sq_k, (k = 1, . . . , 4) and the centroid of each sub-square is named as C_k . C_o indicates the centre of the basic *Z-curve*. The side length of each sub-square is defined as the resolution of the proposed trajectory and it is denoted by *d*. To achieve the full coverage by the *Z-curve*, the main requirement is that the anchor message transmitted at C_k position would be received by sensor nodes located at the same *sq* and in addition with two more adjacent *sq*. So that, each unknown sensor node can receive three anchor messages. Let s_1 indicates the most distant sensor node located at the adjacent *sq* from $C1$. Hence, if s_1 can receive the anchor message from C_1, then we can guarantee that the message would be heard by all sensor nodes located inside sq_1, sq_2, sq_3.

From fig 1(a), by applying the Pythagoras theorem we obtain:

$$(dist\,(C_1, s_1))^2 = (d/2)^2 + (3d/2)^2$$

$$\Rightarrow dist\,(C_1, s_1) = \sqrt{(5/2)}d$$

where $(dist\,(C_1, s_1))$ indicates the distance between sensor node s_1 and anchor position C_1. And, from equation (1) we can obtain that $dist\ (b_j , s_i) \le R_c$. So, $R_c \ge \sqrt{(5/2)}d$. It is also valid for C_2, C_3 and C_4 anchor positions. Hence from this, all the unknown sensor nodes are able to receive three anchor messages and can cover fully for localization when the mobile anchor node traverses based on the *Z-curve* with $R_c \ge \sqrt{(5/2)}d$.

Step 3: In this step a shortest path for mobile anchor node is selected to traverse the network region and to broadcast three anchor messages to unknown sensor nodes in the region traversed by the *Z-curve* path planning algorithm. As shown in fig 1(a), *Z-curve* path is started by connecting the centers of two adjacent *sq*. The mobile anchor node at anchor position C_1 provides location information for s_i located in $sq_{1,2,3}$. Similarly, unknown sensor nodes located in $sq_{1,2,4}$ receive the message from C_2. The anchor message from C_o is collectable by s_i in $sq_{1,2,3,4}$. Hence, from this all the sensor nodes located in the below half region are localizable and the same process is repeated to achieve localizable for sensor nodes located in above half region. Hence mobile anchor node by moving on the *Z-curve* path provides the chance to achieve three anchor messages through the shortest path.

Step 4: In this step the received anchor messages are verified for non-collinearity. The *Z-curve* path provides three consecutive non-collinear anchor messages via the shortest path length. Let us consider, MSG represents a matrix which is formed by the coordinates of the three consecutive received anchor messages (x_{c1} , y_{c1}), (x_{c2} , y_{c2}), (x_{co} , y_{co}) in positions $C_{1,2,0}$.

$$MSG = \begin{pmatrix} x_{C2} - x_{C1} & y_{C2} - y_{C1} \\ x_{Co} - x_{C1} & y_{Co} - y_{C1} \end{pmatrix}$$

Hence, we can prove that the three received anchor messages are non-collinear, when

$$|MSG| = (x_{C2} - x_{C1})(y_{Co} - y_{C1}) - (y_{C2} - y_{C1})(x_{Co} - x_{C1}) \neq 0$$

where, $|MSG|$ indicates the determinant of MSG matrix. The last step demonstrates that the received three anchor messages via the shortest possible path dictated by the *Z-curve* are non-collinear. The total distance travelled by the mobile anchor node based on the *Z-curve* trajectory at level (l) and resolution *d* is given by:

$$length_{(Z-curve)} = [(5/8\times 4^l) - 1]\, d + [(3/8\times 4^l)]\sqrt{2}d$$

Fig 1(a) also implies that total length travelled in level (l) is equal to $2d + \sqrt{2}d$.

Step 5: In this step unknown sensor nodes estimate their positions by using trilateration calculation method as shown in fig 2. After receiving three consecutive non-collinear messages from mobile anchor node, it will estimate its position according to,

$$pos_{si}(x,y)=[(x_1+x_2+x_3)/3,(y_1+y_2+y_3)/3]$$

where, $pos_{si}(x,y)$ is position of unknown sensor node s_i, (x_1, y_1), (x_2, y_2), (x_3, y_3) are coordinates of mobile anchor node at 1, 2, 3 positions respectively.

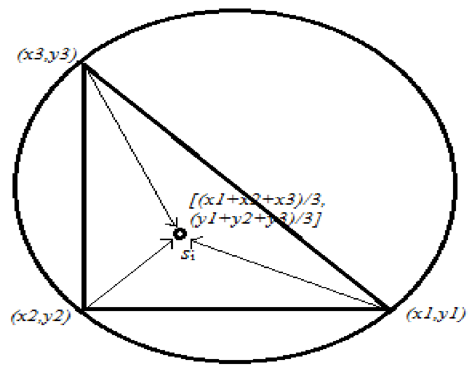


Fig. 2. Trilateration calculation for location estimation

IV. OBSTACLE-HANDLING TRAJECTORY

In a real environment, obstacles may occur in the network region and will block the path traversed by the mobile anchor node. Hence, *Z-curve* obstacle handling trajectory is proposed to handle obstacle presence problem. As the *Z-curve* is a deterministic path, the path movement and the anchor positions for location information transmission are known in advance, the mobile anchor node will cross the edge of the obstacle when an obstacle occurs and return back to the original path immediately.

V. CONCLUSIONS

In this paper, a path planning algorithm termed as *Z-curve* for mobile anchor node has been proposed to achieve localization using trilateration calculation technique. The proposed trajectory will guarantee that all unknown sensor nodes will receive three consecutive non-collinear messages through the shortest possible path. It is successfully able to assists unknown sensor nodes to achieve localization. And *Z-curve* obstacle- handling trajectory has also been presented to handle obstacles in the network region. In future work security can be provided for broadcasting message.

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