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FRAMEWORK AND FEATURE EQUIVALENCE STUDY OF LOCALIZATION TECHNIQUES FOR WSN

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***Abstract*—Two-dimensional localization process of sensor entities is gaining immense research interest, due to its applications not only in the field of Wireless Sensor Network (WSN) or Internet of Things (IoT), but also in disciplines that are radically different than mainstream areas such as healthcare, food processing, construction, etc. Having knowledge of information about location of origin of data is crucial from point of view of adding relative relevance to that data. However, the embedded system, which is the major base of development for WSN and IoT as well as the taxonomy of node structures, imposes constraints on selection and development of localization scheme. Through this research effort, we will try to model basic localization schemes and evaluate their tradeoffs between achieved accuracy and expense, energy cost. In the end, few new dimensions to the existing localization problem are also discussed.**

Keywords—Wireless sensor network; localization; quadrant approach; relative positioning; hybrid positioning

I. INTRODUCTION

The Wireless Sensor Network (WSN) is a network of small, low power nodes, capable of sensing the physical parameters and reporting this data to the main controller for further processing. The Internet of Things (IoT) can be considered as an extension of WSN, where each "Thing" is a node capable of sensing the changes and taking the action as coordinated by the main controller. For many applications, in order to analyze and develop appropriate control action, knowing the location of the node is crucial [1]. Because of the development constraints in WSN, the conventional means of localization proves inefficient. This is because localization in WSN demands precise calculation without spending more on memory, cost, power or overall performance. The conventional era of localization schemes is characterized by the precision of evaluating the location. However, there are much-diversified applications of WSN present that require different scales of accuracy and power efficiency from localization schemes [2]. Hence, this has evolved as an emerging research dimension. The research approach usually comprises of mixing multiple principle methods of node localization. However, because of this, developing a fixed taxonomy of localization schemes is difficult. In this paper, we will create a framework for the taxonomy of the WSN localization algorithms, and compare these algorithms on the basis of preliminary constraints in embedded development. At last, we introduce the prospects of research in the future.

II. TAXONOMY OF LOCALIZATION TECHNIQUES

The trivial classification of localization techniques [3] is based on physical principles and assumptions about distance, time and angle amongst the nodes. However, exact classification has become too diversified because of research emphasizing on the use of hybridizing fundamental techniques. And hence, there is a need to put the taxonomy in terms of more fulfilled framework as shown in Fig. 1.

A. *Absolute Positioning*

This type summarizes the techniques that are related to acquiring and processing location data in terms of fixed coordinate system. Here, each node is capable of absolutely identifying the own location by means of specialized hardware on each node. The techniques can process the location information in terms of fixed coordinate system that is either global or built on local fixed coordinate system [4]. The location information processing is done at a central location. Conventionally this technique is called anchor based positioning.

The GPS approach [5] provides more accuracy and wider application but suffers because of more costs and powers which will restrain the performance. While installing the sensor in the known location is easy and cheap to implement. At the same time, it can save extra energy cost for communication with GPS. But it has very strict demands that the nodes could not move in the process of localization which limited its area of application.

B. *Relative Positioning*

Relative positioning techniques are based on extracting relative location information of node from its neighbor nodes as a function of fundamental distance calculation techniques. These fundamental techniques rely on relative measurements of time, speed and distance data obtained during transmission and reception of actual information. This approach gives more cost effective solution to localization problem but suffers from multiple limitations. For example, whether to use centralized or decentralized calculation approach is major tradeoff [6]

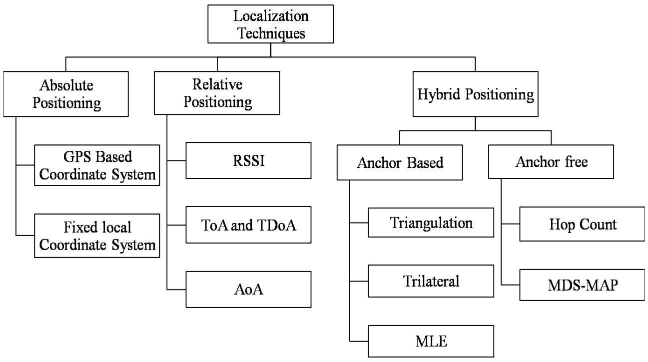

Fig. 1. Taxonomy of Localization Techniques

between investing resources for local processing versus expected energy consumption in transmitting localization information to a centralized location for processing.

C. Hybrid Positioning

As the name suggests, the hybrid approach combines the absolute and relative positioning techniques to develop new localization algorithms. The focus is usually on obtaining better accuracy at the lesser expense of hardware or energy requirements of the node.

The hybrid positioning approach has become a major research effort to evaluate the most appropriate combination of absolute and relative positioning techniques. However, the type of application still remains a major player in the selection of algorithm. Thus, with a hybrid approach, it can be ensured to have developed and employed better localization scheme. That being said, this approach demands extensive research effort to finalize the appropriate scheme.

III. Fundamental Relative Positioning Methodologies

The hybrid localization algorithm in WSN mainly concerns with a selection of relative distance measurements. The anchor nodes are the absolute nodes, and the neighbor nodes here refer to those nodes in the communication range and can communicate. The neighbor nodes use the fundamental positioning methodologies to obtain relative localization parameters with respect to anchor nodes.

A. Received Signal Strength Indicator

During radio propagation, an important characteristic is that the radio signal attenuates as the distance between the transmitter and receiver increases. The power of the received radio signal falls off exponentially with distance increasing, and the receiver can measure this attenuation based on Received Signal Strength Indication (RSSI) in order to estimate the distance to the sender. RSSI measures the power of the signal at the receiver. Based on the transmit power, the propagation loss is calculated and the loss can be translated into distance estimate.

RSSI information is measured by the receiving node. Suppose η is the coefficient depending on the environmental conditions (which may change between 1.6 and 6), d is the distance between the receiving anchor node and the sending node and A is the absolute value of RSSI for the distance of 1 m. Then, the RSSI value can be calculated using (1).

$$RSSI = -(10.\eta.\log(d) + A) \qquad (1)$$

RSSI is the most popular technique for the indoor and outdoor environment with acceptable accuracy. It is also most suitable for WSN due to low cost, low power consumption, simple hardware, etc. For shorter distance, RSSI offers a high level of accuracy. Furthermore, the RSSI information can be enhanced by means employing iterative improvements to η [7]. That being said, the RSSI information as a standalone tool for localization introduces many ambiguities. For example, the RSSI information does not account for the presence of an obstruction, type of antenna, etc.

B. Time of Arrival

The Time of Arrival (ToA) mainly measures the distance between anchor node and the target node and which is proportional to the propagation time of the signal. It requires high precision timing and synchronization [8]. The calculations can be performed using different signals, such as RF, acoustic, infrared and ultrasound.

The ToA technique can be further extended using the time measurement from transmitter to receiver by means of the Time Difference of arrival (TDoA) of different communication media [9] at different speeds. TDoA offers a high level of accuracy, but also requires relatively fast processing capabilities in sensor nodes to resolve many timing differences for fine-grained measurements. At the same time, it also involves additional hardware overhead per node.

C. Angle of Arrival

The angle of Arrival (AoA) means the angle at which signals are received by the receiver from the transmitter. An Angle of Arrival system is able to estimate the angle at which signals are received [10] and to use simple geometric relationships to estimate the relative locations of transmitter and receiver. The implementation of the AoA system [11] relies on the smart antenna with antenna arrays to measure the angle at which the signal arrives.

There are two major disadvantages of the AoA techniques which make it inappropriate to use in WSN. First, the cost of the complex antenna array is high. Second, the AoA techniques do not scale well for a large number of nodes.

IV. Hybrid Positioning Implementation

The fundamental positioning methods are basically relative distance measurement techniques. However, in order to transform the localization information in terms of an actual coordinate system for positioning, a proper framework method is required. This section summarizes the practical implementation methodologies for position estimation.

A. Triangulation Method

The triangulation method is one of the popularly used direction-based measurement technique. It combines several parameters from possible localization entities such as RSSI

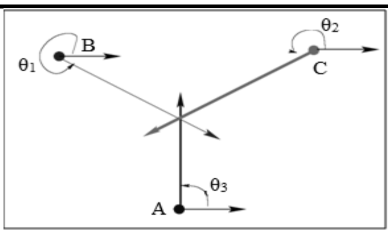

Fig. 2. The Triangulation Process

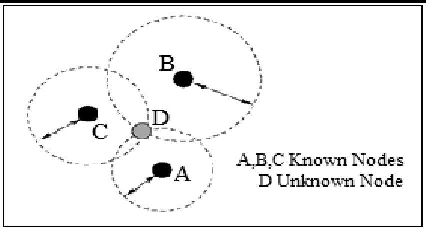

Fig. 3. The Trilateral Process

or time of arrival of information from three or more neighbor nodes. For achieving better precision, the Arrival of Angle (AoA) measurement [12] is also popular.

As shown in Fig. 2, suppose that the anchor nodes B, C are located in the position (x_1, y_1), (x_2, y_2) and the unknown node A is located in (x_0, y_0). The angles of signal arrived from B and C are (θ_1, θ_2), as shown in Fig. 1. Then we can get the following equation.

$$\tan\theta_i = \frac{(x_0 - x_i)}{(y_0 - y_i)} \quad (i = 1,2) \tag{2}$$

The solution (x0, y0) of the two equations is the location of the unknown node A. The triangulation method yields an acceptable level of precision and is popularly used not only in WSN but also in telecommunication based applications.

B. *Trilateral Measurement*

In the wireless sensor networks, the coordinate is usually 2-dimention, so if we know the distances of the unknown node to three anchor nodes respectively, we can compute the location of the unknown node [13]. The trilateral Measurement is also considered as the most fundamental measurement in the distance-based approaches.

The principle of the Trilateral Measurement is to compute the cross point of three circles with known radius. Suppose as shown in Fig. 3, the locations of the three anchor nodes A, B, C are known, and the distances from the unknown node D to A, B, C are d_a, d_b, and dc. Then we obtain the equation set (3).

$$\begin{aligned} \sqrt{(x - x_a)^2 + (y - y_a)^2} &= d_a \\ \sqrt{(x - x_b)^2 + (y - y_b)^2} &= d_b \\ \sqrt{(x - x_c)^2 + (y - y_c)^2} &= d_c \end{aligned} \tag{3}$$

The coordinate of the new unknown node is found out in terms of coordinates (x, y) as formulated in (4).

$$\begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} 2(x_a - x_c) & 2(y_a - y_c) \\ 2(x_b - x_c) & 2(y_b - y_c) \end{bmatrix}^{-1} \begin{bmatrix} x_a^2 - x_c^2 + y_a^2 - y_c^2 + d_c^2 - d_a^2 \\ x_b^2 - x_c^2 + y_b^2 - y_c^2 + d_c^2 - d_b^2 \end{bmatrix} \tag{4}$$

Practically, because of the bias limitations, it is difficult that trilateral process yields a single point of node position. The method can be enhanced using the multilateral technique for position estimation using multiple anchors. The trilateral method is also practically implementable with better precision in WSN systems. That being said, it still demands a larger number of anchor nodes for achieving an acceptable level of precision in the localization process.

C. *Maximum Likelihood Estimation*

The method uses mathematical likelihood function initially obtained using a relative positioning approach and attempts to maximize the function to support the obtained values of coordinates.Suppose n anchor nodes coordinate are (x_1, y_1),…, (x_n, y_n), the distances of the unknown node D to the anchor nodes are d_1, d_2,… , d_n and the coordinate of D are (x, y).

$$\begin{aligned} &(x_1 - x)^2 + (y_1 - y)^2 = d_1 \\ &\quad\ldots \\ &(x_n - x)^2 + (y_n - y)^2 = d_n \end{aligned} \tag{5}$$

From the equation set in (5), each one minus the final equation, we can get (6).

$$\begin{aligned} &x_1^2 - x_n^2 - 2(x_1 - x_n)x + y_1^2 - y_n^2 - 2(y_1 - y_n)y = d_1^2 - d_n^2 \\ &\quad\ldots \\ &x_{n-1}^2 - x_n^2 - 2(x_{n-1} - x_n)x + y_{n-1}^2 - y_n^2 - 2(y_{n-1} - y_n)y = d_{n-1}^2 - d_n^2 \end{aligned} \tag{6}$$

The linear equations are then expressed as signified in (7).

$$\begin{aligned} &AX = b \text{ Where, } X = \begin{bmatrix} x \\ y \end{bmatrix} \\ &A = \begin{bmatrix} 2(x_1 - x_n) & 2(y_1 - y_n) \\ \ldots & \\ 2(x_{n-1} - x_n) & 2(y_{n-1} - y_n) \end{bmatrix} \\ &b = \begin{bmatrix} x_1^2 - x_n^2 + y_1^2 - y_n^2 + d_n^2 - d_1^2 \\ \ldots \\ x_{n-1}^2 - x_n^2 + y_{n-1}^2 - y_n^2 + d_n^2 - d_{n-1}^2 \end{bmatrix} \end{aligned} \tag{7}$$

Now the least squares equation method can be used to estimate the unknown nodes coordinate. For example, the coordinate x can be obtained using (8).

$$X_a = (A^T A)^{-1} A^T b \tag{8}$$

As per [13, 14], the MLE algorithm is robust to the much noise compared to the direct triangulation algorithm. The MLE method has attracted a wide research effort. However, since it involves extensive processing, the MLE approach is best suited when incorporated in centralized calculation technique.

V. PROSPECTS AND FUTURE WORK

A. *Movable Node Localization*

Many of the localization algorithms are used in the fixed unknown node whose location can't change. But the localization of mobile nodes seems to have a better prospect because mobile nodes make it possible for target tracking, especially in indoor areas where the GPS could not work very well due to the limit of the electromagnet. For example, the firefighters enter a burning building for the first time. It is impossible for them to find the target immediately. But it will become much easier for them if the target tracking system is installed in the building. Some work has been done and more will be done in the future. The traditional localization algorithms may not sufficient to meet the demands of real-time communication. We should try new ways for estimation of the location. The prediction of the new position may be a promising idea. The node containing the previous few locations could predict its next location by this information. In this way, the artificial intelligence (AI) and machine learning can be employed in the location algorithm to improve the accuracy.

B. *Quadrant Fixation Approach*

Note that there has been a wide variety of applications in WSN and especially in IoT domain, that demand position based estimation without additional computation overhead. These applications do not intend to acquire the precise location of the individual nodes; rather the knowledge of nodes in the particular geographical area is sufficient. Conventionally, such applications have been using relative positioning algorithms. Though these methods yield results at the lesser expense of processing and transmission power, using them as standalone location evaluation tool puts serious concerns on the reliability of node discovery. Thus, it is possible to implement hybrid localization approach to acquiring and process only the positional information in terms of the vicinity of anchor nodes.

For example, in irrigation system using WSN like described in [15], in order to activate a certain number of nodes for water regulation, the knowledge about which nodes are precisely located within a part of the total geographical area is sufficient. For such applications, the quadrant fixation approach in localization is useful. The approach is to use anchors and a robust relative positioning structure like multilateral positioning to estimate the location of nodes. This would also be useful for nodes that act upon same requests.

Like done in quadrant fixation approach, the hybrid approach of combining multiple positioning methodologies is also useful to design and develop application specific algorithms for localization. Another viewpoint can also be to get initial localization data using simple relative positioning and performing iterative improvements on the initial data. This successive approach performed at variable rate can be useful in pseudo-real time localization.

VI. Conclusion

This article has provided a review of the wireless sensor network localization techniques and introduced the simple framework for the taxonomy of fundamental positioning methods such as absolute, relative and hybrid positioning. Some typical localization algorithms including triangulation, trilateral and multilateral positioning on the basis of fundamental constraints in WSN and IoT are compared. At last, some prospective work as a future work direction is also proposed.

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