Design and Development of Prototype System for Estimating Localization Error in Wireless Sensor Network

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Abstract : Localization is very important in wireless sensor networks for determining the position of the sensor node. In real time application the multilateration range based scheme gives better accuracy information about the location of the sensor node. A prototype system with three anchor nodes and one unknown target node was implemented using trilateration technique and experiments were conducted to find out the location of unknown target node by using three known location of anchor nodes. The localization algorithm calculates the distance and angle of the unknown target node with reference to three anchor nodes. The goal of this paper is to present a comprehensive real-world evaluation method for calculating the location of the unknown target node based on Time Difference of Arrival (TDOA) and range measurements. The experimental result concluded that localization algorithm gives sufficiently accurate localization results with mean error of 3.7 cm in a 3*3 meter area.

***keywords* - Wireless sensor network, localization, multilateration, trilateration, TDOA.**

I. INTRODUCTION

Wireless sensor network (WSN) is consisted of number of miniature devices recognized as sensor nodes empowered with sensing, processing and computing abilities. The main role of WSN is sensing, gathering, and transmission of data to the destination. In real time applications like acquiring the position of the underwater vehicle or underwater object, the location data is very important. Such type of information is acquired by localization technique. Hence, localization turns out to be a crucial research topic in WSNs. Global positioning system (GPS) is an easiest system for locality estimation. In case of indoor applications and underwater applications where GPS system does not work there localization techniques are implemented in the system to get the location information. The localization techniques can be classified on account of specific factors such as: GPS, computation model, range estimates, and scalability [2]. Based on range measurements, localization algorithms divided into range based and range free methods. Range based methods need absolute distance or orientation information among nearby nodes. However, the range free schemes need only connectivity or proximity information in place of distance or orientation information among nodes. Range based system gives better accuracy as compared to range free techniques.

Multilateration is a method used to determine the position of an object based on simultaneous range measurements from three or more anchors located at known positions. If the number of anchors used is three, it becomes a case of trilateration. Trilateration has been implemented in ultrasonic-based localization systems like Active Bat, Cricket, and Dolphin [1]. Alternate localization methods like Received Signal Strength (RSS), triangulation, and Time Difference of Arrival (TDOA) were popular research topic in the recent past. RSS has insufficient precision and lower resolution [1] for an indoor environment. Triangulation requires expensive hardware like directional antennas and the equations employed are more complex than trilateration equations. Ultrasonic sensors are relatively inexpensive and robust against environmental noise. This makes them preferable to other location techniques that employ visual, tactile, and magnetic systems [1].

In this paper, main focus is on the 2D ultrasonic positioning system using trilateration range-based technique for real time dynamic platform applications like underwater positioning system. A prototype system was developed using four sensor nodes where three nodes were anchor nodes (whose location is known) and one unknown target node (whose location is not known). The prototype system is tested with different experimental tests for positioning accuracy where different static scenarios were evaluated with experimental tests and results were analyzed.

II. RELATED WORK

Various studies have proposed different localization algorithm for different localization techniques such as Time of Arrival (TOA), TDOA, AOA (Angle of Arrival), RSS. All these techniques have its own advantages and disadvantages. [1] Paper demonstrated the feasibility of an indoor 3D positioning system based on multilateration using ultrasonic beacons. The mentioned approach is particularly suitable for navigation of autonomous vehicles in indoor and urban environments. The inherent nature of the slow propagating speed of ultrasonic waves allows for higher signal resolution and thus leads to increased accuracy in position estimations. The system was tested for robustness in the presence of noise, obstructions in line of sight of sensors, sensors being out of range, and failures. [2] Paper discussed that due to the non-line-of-sight (NLOS) and multipath fading channel (MPF) of the wireless networks, the non-existence of the intersection point often occurs in the range-based localization methods. To overcome this author suggested a new intersection determination criterion for all the possibilities of intersection is provided to solve the consistency and ambiguity problem. [3][5] This paper is usable to understand the operation of varies localization methods and some evaluation factors were introduced to validate new proposed methods or to compare different existence techniques in order to find the best one.

III. TRILATERATION PRINCIPLE

In 2D localization, trilateration requires at least three measured distances between anchors and an unknown target node, the location of which is to be determined. The anchors should not be collinear and their position should be fixed and known for higher accuracy [1]. After the measurements are acquired, the location of the node can be determined as the intersection of three circumferences whose geometric center coincides with the anchor positions. The measured distance is represented by the radii from the anchors. Fig.1 depicts the trilateration principle in 2D involving three anchors nodes. The confidence area, depicted in blue, is the intersection of all three circles.

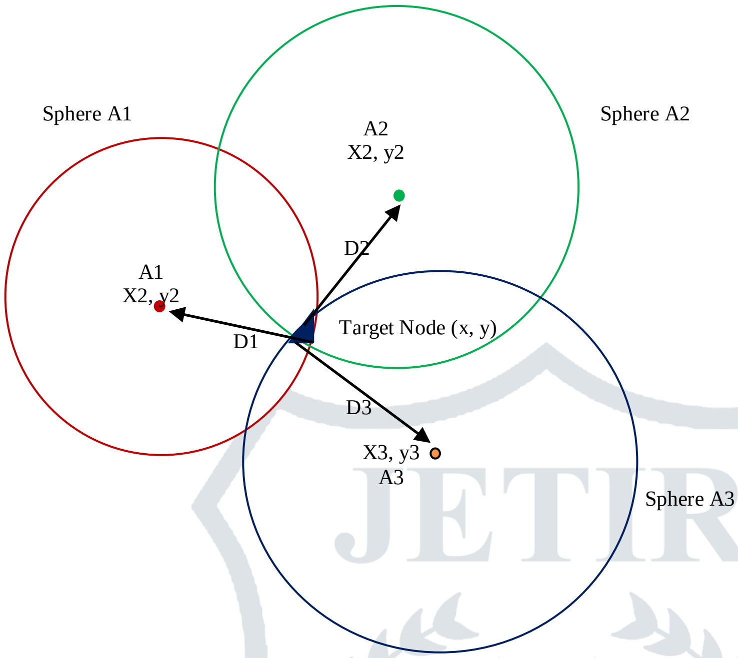

Fig. 1: Trilateration Localization

Considering the basic formula for the general equation of a sphere as shown in equation (1.0);

$$d^2 = D1^2 + D2^2 + D3^2 \quad (1.0).$$

Assumption is all the nodes are on the same plane. The three anchor nodes (A1, A2 and A3) with distance (D1, D2, D3) to the unknown target node as illustrated in Fig. 1. Equation (1.0) gives the distance d and location (x, y) of target node with reference to anchor nodes.

IV. PROPOSED WORK

The localization algorithm proposed in this research work is TDOA-based trilateration localization technique. The trilateration and Centroid method are used to find the unknown target node locations. The anchors should not be collinear and their position should be fixed and known for higher accuracy [1]. The algorithm for calculating the intersection point of three spheres is implemented and evaluated with experimental tests. The result was improved by implementing the confidence level logic to identify the real target node. Due to the noise, interferences or other practical issues three circles may not intersect at a common point in such case by increasing the number of anchor nodes gives better results [4].

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LOCALIZATION ALGORITHM:

The localization algorithm is described below.

Step 1 : Initialize the parameters

Step 2 : Search for anchor node starting from a particular scan angle for HC SR04 ultrasonic sensor.

Step 3a : If anchor node is identified. Then assign a confidence level as one. Then re-scan for the same anchor node in the same scan angle. If the same anchor node is identified then increase the confidence level by 1. Once confidence level reaches two declare it as anchor node. The confidence level is to remove the false detection of anchor nodes as well as increasing the confidence of the real anchor nodes. Then calculate the distance and angle of the anchor node form unknown node.

Step 3b : Search for next anchor node by increasing scan angle with jump angle. Add the jump angle to the current scan angle and look for anchor node in that angle. Repeat steps 3a and 3b until three anchor nodes and their respective distances from unknown nodes are found.

Step 4 : If three anchor nodes found then calculate the intersection point of three Anchor nodes
Else repeat step 3b.

Step 5 : If intersection point found without any ambiguity then declare the result. Else calculate the Centroid of the triangle of overlapping circles.

Step 6 : Declare the result: unknown node position, angle and localization error.

Performance Metric:

The localization error was found by using the following formula

$$\text{Localization error} = \frac{1}{n}\sum_{i=1}^{n}\sqrt{(xa - xe)2 + (ya - ye)2} \qquad (2.0).$$

Where, n= number of nodes, (xa, ya) are the actual and (xe, ye) are the estimated coordinates of unknown target node.

V. EXPERIMENTAL SETUP

The experiments consist of two phases. In the first phase of experiment, anchor nodes are placed in a 3 meter * 3 meter area. The anchor nodes were assumed as objects. With reference to these three objects, the distance and angle of each object was calculated using ultrasonic sensor HC-SR04.Then unknown node position was calculated. The unknown node position was varied from minimum of 0.5 meter to maximum of 3 meter distance from anchor nodes and set at 15 different locations one by one within that area. With different scenarios unknown node locations were calculated and results were evaluated.

In the second phase of the experiment the motion parameters i:e gyro angle, roll and pitch of the unknown target node were sensed using MPU6050 motion sensor then the motion parameters were processed using Arduino Uno Microcontroller. The gyro drifts over the time and the accelerometer does not have any drift, but it is too unstable for shorter time span. To improve the precision of sensor data kalman filter is used. Then the Kalman filter outputs i:e gyro angle, accelerometer roll, pitch values were transmitted to the three anchor nodes by using RF transceiver.

The instruments used during experimental setup are

- Arduino Uno microcontroller board for programming the nodes.
- Ultrasonic sensor HC-SR04 used for unknown target node distance and angle measurement from anchor nodes.
- Motion sensor MPU 6050 used for unknown target node motion measurement.
- Laptop where unknown target node is slotted for data collection and programming of nodes.
- RF transceiver NRF24L01.
- Measuring scale.

VI. RESULTS AND DISCUSSION

The Experimental results were shown below. The Fig.2 shows the unknown node different position vs. localization error. Fig.3, Fig.4, Fig.5 shows the anchors actual distance vs. error in cm.

Fig. 2: Unknown node position vs. Localization error

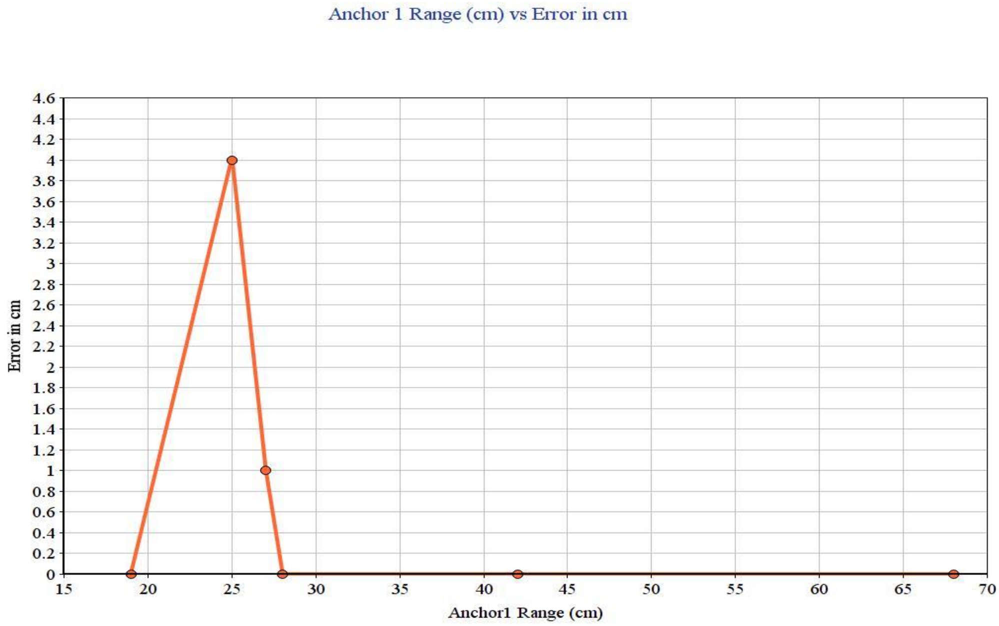

Fig.3: Anchor1 actual range (cm) vs. Error in cm

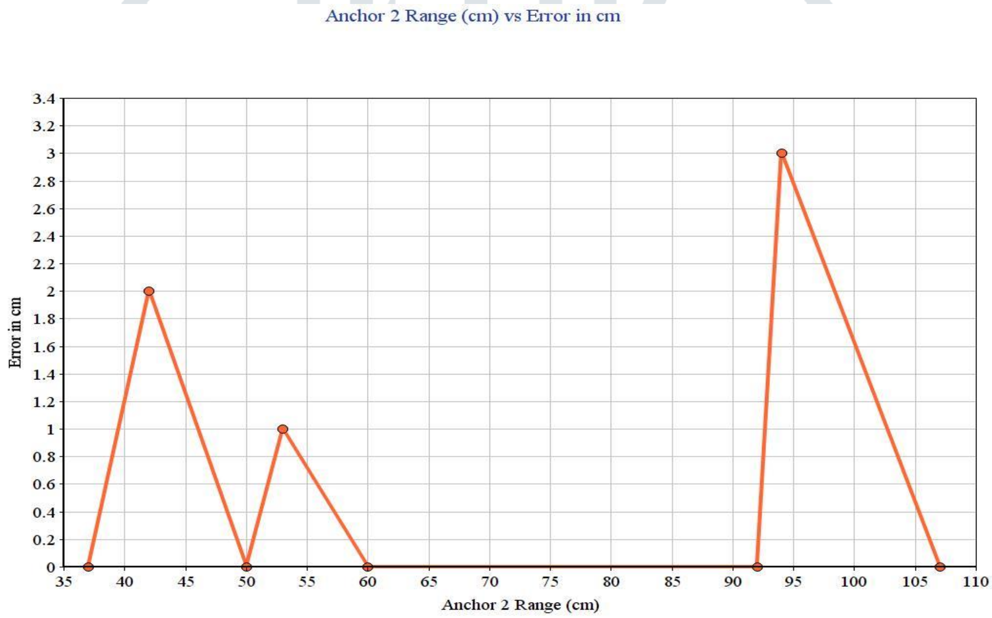

Fig.4: Anchor2 actual range (cm) vs. Error in cm

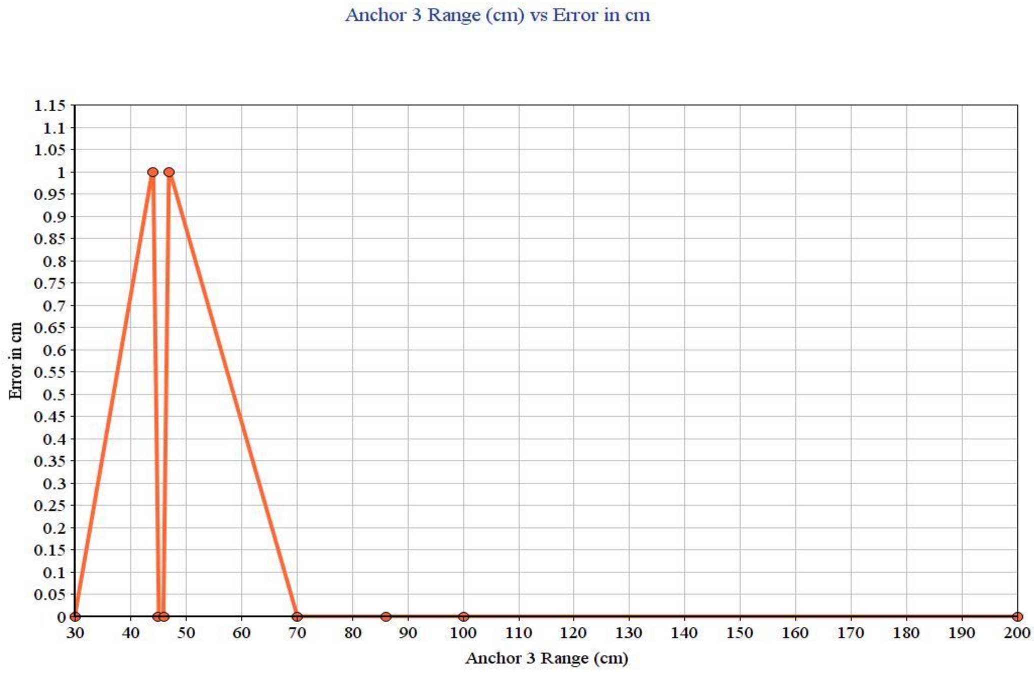

Fig.5: Anchor3 actual range (cm) vs. Error in cm

As shown in fig.2 the unknown target node was placed in four different coordinates and results were evaluated. The experimental results of different scenarios shows that the localization error found is in the range from 0 cm to 5 cm. The mean localization error 3.7 cm is less and it is in an acceptable range for an area of 3meter * 3meter.

VII. CONCLUSION AND FUTURE SCOPE

The localization in WSN is used for military application, target tracking, location based application and data logging etc. The trilateration algorithm used in the prototype system determines the location of unknown node. The experimental results have indicated that the algorithm is effective. Localization algorithm used is based on linear algebraic method so has low computational complexity and can be applicable to real-time applications and in wireless sensor nodes. The slow propagating speed of ultrasonic waves allows for higher signal resolution and thus leads to increased accuracy in position estimations [1].

Future developments of the ultrasonic positioning system will include the implementation of mobility speed of unknown node. These developments will support further applications of positioning system for variety indoor and underwater applications.

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