Centroid Based 3D Localization Technique Using RSSI With a Mobile Robot

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***Abstract*—Knowledge of sensor node 3D location in a sensor network is more important, because many practical applications needs to know the location of sensor data source. This paper presents a new technique for finding indoor 3D location of a sensor node by using Received Signal Strength Indication (RSSI). Proposed localization algorithm is derived from centroid algorithm with composition of empirical path loss model. It gives less error in estimating 3D location of sensor node in a sensor network when compared to its actual location. Algorithm has been implemented and analysed by using IITH motes and a Mobile Robot.**

***Index Terms*—RSSI, Centroid algorithm, 3D localization.**

I. Introduction

Development in wireless communications and electronics has enhanced micro sensors technology, smartness in controlling and monitoring sensors in a sensor network [1]. Wireless sensor networks are used for sensing physical factors like temperature, humidity and also for monitoring and detecting environmental factors, chemicals, smoke etc. There are many theoretical and practical works for designing and deployment of wireless sensor network. Authors of [2] proposed a deployment tool for wireless sensor network. After deployment phase, knowledge of sensor node location is crucial in many practical applications like forest fires location detection, marine monitoring, animal monitoring and so on. For outdoor localization GPS is used, but in indoor environment GPS does not work. Most of the localization works are based on 2D localization. In [3] and [4] they discussed RSSI based localization algorithms for 2D. In real-time applications, sensor nodes will be placed in three-dimensional space. Our work is concerned with mobile Robot based 3D localization of a sensor node in a sensor network. We use Roomba machine, termed as mobile Robot as shown in Fig.1.

Paper [5] provides survey on 3D localization of sensor nodes. Existing algorithms on localization can be divided into two types as described in [9]. One is co-ordinate based localization and other is co-ordinate free localization (Fig.2). Co-ordinate based localization algorithms depends on RSSI and path loss modelling of environment as discussed in [6]. We focused on co-ordinate based localization algorithm. In most of the 2D and 3D localization techniques anchor nodes are used to collect RSSI values as discussed in [7]. Estimated

Fig. 1: Roomba machine-Mobile Robot

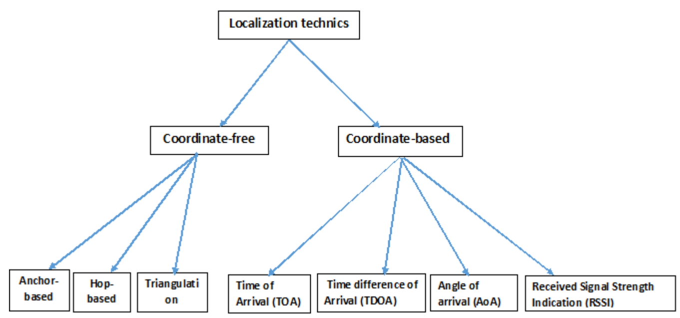

Fig. 2: Classification of localization algorithms

location accuracy depends on number of anchor nodes used. System cost will increase with increasing of anchor nodes. To eliminate this problem we have used moving Robot (Roomba) as the anchor node. Roomba provides user interface to program it easily. We used Roomba instead of using more number of anchor nodes. Here we place one sensor node on Roomba, called as beacon node. Roomba moves in defined area to estimate location of a target node. Roomba will have its location details. The Roomba location will be the location of beacon node as it is placed on Roomba and also beacon node will have RSSI values with respect to target node. Our algorithm is composition of basic centroid finding method and RSSI based location finding method. For finding distance

Fig. 3: IITH Mote

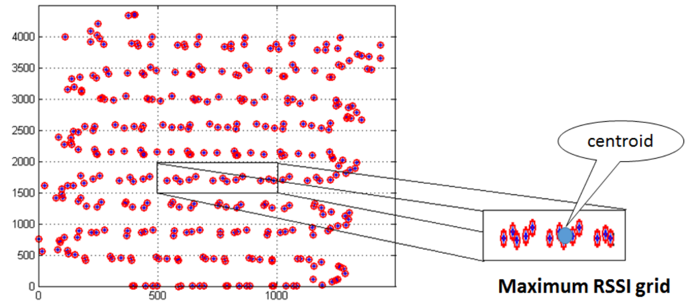

Fig. 4: Max. RSSI value grid and centroid finding

between two nodes, we use path loss model. In [8] and [9] authors discussed about basic centroid method considering RSSI values. Authors of [10] proposed a practical path loss model for indoor localization.

In this paper we propose a 3D localization algorithm, which is less cost and will give less error in predicting a target node location. Proposed 3D localization algorithm has been tested using an in house developed IITH Mote shown in Fig.3, which makes use of IEEE 802.15.4 standard for PHY and MAC layers [14].

The rest of the paper is organized as follows. Section II describes proposed 3D localization algorithm. Section III describes the experimental setup. Section IV describes experimental results and analysis. Finally, section V concludes the paper, with future scope of work.

II. Proposed 3D localization algorithm

Centroid Location (CL) algorithm is well known for finding target node positions [12]. In CL algorithm, beacon nodes initially knows their location information, then broadcasts their position details to all the remaining nodes which are in network range. After the target node gets all beacon nodes information, it calculates position $T_e(x,y)$ from n beacon nodes as shown in equation (1). The localization error E(x,y) is defined as distance between estimated target position ($T_e(x,y)$) to actual target position ($T(x,y)$) as shown in equation (2).

$$T_e(x,y) = \frac{\sum_{j=1}^{n} B_j(x_j,y_j)}{n} \tag{1}$$

$B_j(x_j,y_j) \rightarrow j^{th}$ beacon position.

$$E(x,y) = |T(x,y) - T_e(x,y)| \tag{2}$$

In this paper, it is assumed that target node is placed above the ground level within considered experimental area. Mobile Robot moves on the ground within the experimental area and passes below the target node. In our proposed 3D localization algorithm, the defined area is divided into grids and average RSSI value is computed over each grid. The grid with maximum average RSSI value is considered, then the centroid (X_e, Y_e) of the grid is calculated using equation (1) as shown in Fig.4. After finding centroid in 2D plane, to estimate height of the target node we need distance between target node and beacon positions which are in maximum averaged RSSI value grid. In order to estimate distances between beacon positions and target node path loss model is used. Here we estimate distances between each beacon node position to target node by using RSSI value of known beacon positions. In our algorithm, Revised Hata Okumara model [11] is used to calculate distance from RSSI values of beacon positions for indoor localization as shown in equation (3).

$$logD_{ei} = \frac{1}{10\eta}[P_{TX} - P_{RXi} + G_{TX} + G_{RX} - X_\alpha + 20log\lambda - 20log(4\pi)] \tag{3}$$

Where $D_{ei} \rightarrow$ estimated distance between the target node (X_e, Y_e, Z_e) and i^{th} Beacon node (X_i, Y_i).

$G_{TX}(dBi) \rightarrow$ Transmit antenna gain

$G_{RX}(dBi) \rightarrow$ Receiver antenna gain

$P_{TX}(dBm) \rightarrow$Target node transmit power

$P_{RXi}(dBm) \rightarrow$ Measured received power at i^{th} beacon position

$\eta \rightarrow$ Measure of influence of obstacle like partitions and obstacles in indoor environment ranges from 4 to 5 and for free space it is equal to 2.

$X_\alpha \rightarrow$ Normal random variable with standard deviation of α and varies from 3dB to 20dB.

$P_{RXi}(dBm)$, measure received power at beacon positions from respective RSSI values is given by equation (4). This is specified in IITH Mote radio IC [13].

$$P_{RXi} = -91 + 3(R_i - 1) \tag{4}$$

Where $R_i \rightarrow$RSSI value of i^{th} beacon position.

Parameter	Value
P_{TX}	-17.2 (dBm)
G_{TX}	0 (dBi)
G_{RX}	0 (dBi)
X_α	3 (dB)
λ	0.1250 (meters)
η	2

TABLE I: Path loss model parameter values used

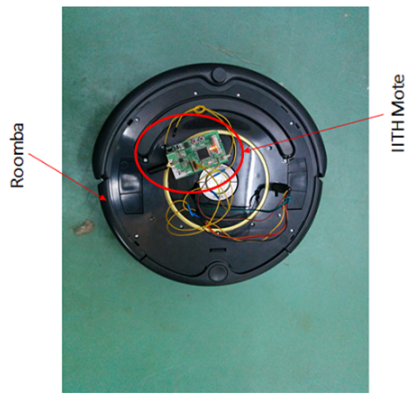

Fig. 5: IITH Mote interfacing with Roomba

TABLE.I shows path loss model parameters considered for experimentation. To estimate height of target node i.e Z axis value, we used Euclidian distance formula (5).

$$D_{ei} = \sqrt{(X_i - X_e)^2 + (Y_i - Y_e)^2 + (Z_{ei})^2} \tag{5}$$

Where D_{ei} can be computed from path loss model (3), (X_e, Y_e) values from Centroid location algorithm (1). Maximum range expected between beacon positions and target node is 5.95m, calculated from experimental area and height of the room.

(X_i, Y_i) values are beacon positions of maximum average RSSI value grid. Substituting these values in (5) gives unknown values Z_{ei}, which is estimated Z-axis value of target node with respect to i^{th} beacon position. From all n beacon positions we get n size vector of Z_{ei}. To estimate Z_e, we find mean of it as given in (6).

$$Z_e = \frac{\sum_{i=1}^{n} Z_{ei}}{n} \tag{6}$$

The pseudo code for proposed 3D localization algorithm is described in Algorithm 1.

Algorithm 1 Estimate (X_e, Y_e, Z_e)

Require: Beacon positions (X_i, Y_i) with respective RSSI values R_i

Take starting point, stopping point from (X_i, Y_i)

Divide area in to m no. of grids (1 $\leq$ m $\leq$ M)

Let in each grid have n points (1 $\leq$ n $\leq$ N)

Calculate average RSSI value of each grid

while $m > 0$ **do**

  while $n > 0$ **do**

    $avg - rssi_m = \frac{\sum_{i=1}^{n} R_i}{n}$ (1$\leq$ i $\leq$ n)

  end while

end while

Consider grid which has maximum averaged RSSI value($avg - rssi_m$)

From maximum averaged RSSI value grid calculate estimated 2D location

$$(X_e, Y_e) = \frac{\sum_{i=1}^{n} B_i(x_i, y_i)}{n}$$

$B_i(x_i, y_i) \rightarrow i^{th}$beacon position of maximum averaged RSSI value grid.

$(X_e, Y_e) \rightarrow$estimated (X,Y) location of target node

Calculate received power from respective RSSI at i^{th} beacon position (R_i)
$P_{RXi} = -91 + 3.(R_i - 1)$

Calculate estimated distance from each i^{th} node to target node
$logD_{ei} = \frac{1}{10\eta}[P_{TX} - P_{RXi} + G_{TX} + G_{RX} - X_\alpha + 20log\lambda - 20log(4\pi)]$

Calculate Z_{ei} from
$D_{ei} = \sqrt{(X_i - X_e)^2 + (Y_i - Y_e)^2 + (Z_{ei})^2}$

Z_e=mean(Z_{ei})

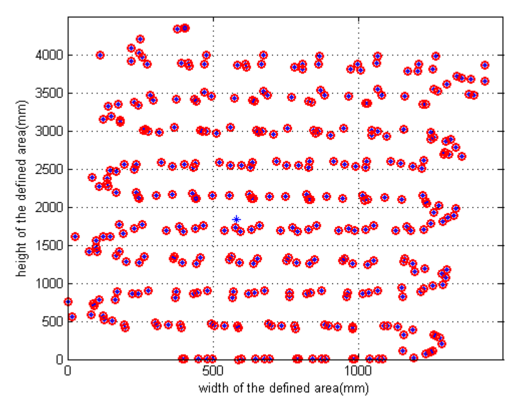

Fig. 6: Roomba moved path in defined area from top view

III. Experimental Setup for 3D Localization Using Roomba

The experiment is performed in a room by considering area 1700mm*4500mm. Height of the room is 3500mm and the area is divided into grids size of 0.5m*0.5m. Considered experimental area is empty and remaining area of the room is having furniture. We took a moving Robot Roomba [15] and fixed one sensor node (Beacon node IITH Mote) as shown in Fig.5. The beacon node is programmed to give instruction of movement to Roomba through serial port communication. Beacon node sends command to Roomba to move in zigzag way in a defined area as shown in Fig.6. Target node is placed in defined 3D location and it is also programmed to send

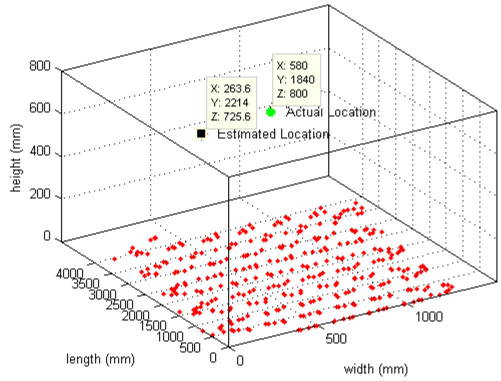

Fig. 7: Estimated position and actual position at height = 800mm

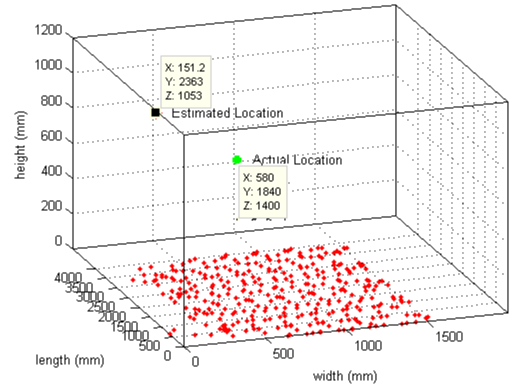

Fig. 8: Estimated position and actual position at height = 1400mm

periodical dummy packets through wireless communication to beacon node with a period of 250 milliseconds. While Roomba moving in zigzag way in the defined area, beacon node get packets periodically from target node. Beacon node calculates RSSI values and has its position details received from Roomba (by sending commands through serial communication to Roomba) with respect to Roomba movement. Zigbee 802.15.4 with frequency of 2.4GHz is used for wireless communication and to get RSSI values. After getting RSSI values and respective position details from Roomba it will send a Location packet (a packet consists RSSI values and respective position details) through wireless communication to base node which is connected to Server (Server is a PC which takes data from base node through serial port). Base node is a sensor node which is programmed to receive data from beacon node and send it to Server. At Server our algorithm runs to estimate 3D location of target node. For the communication between base node and Server through serial port we used java program. After getting results of RSSI values with respective position details we used matlab to analyse data and to apply our algorithm. For programming beacon node, target node, base node we used Tinyos-2.1.1 nesC Script. In brief all software's used for experimental setup are tabulated in TABLE.II.

nesC	Program to IITH Motes
Matlab	proposed algorithm implemented at the Server
Java	Data collection at Server

TABLE II: Programming languages used

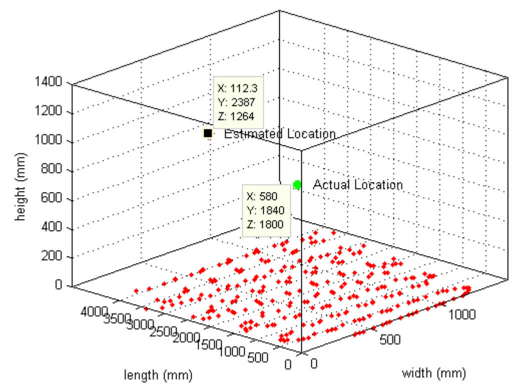

Fig. 9: Estimated position and actual position at height = 1800mm

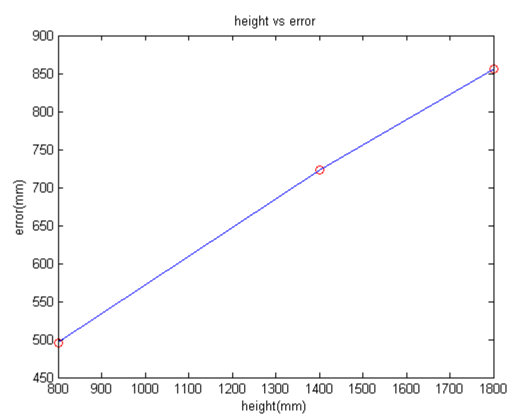

Fig. 10: Predicted Location error

IV. Experimental Results analysis

Experiment is performed by placing target node at three different heights. Actual and estimated positions for this three different heights are shown in Fig.7, Fig.8 and Fig.9. Let us consider the scenario of 3D localization as shown in Fig.7 for further analysis. From Fig.7 11^{th} grid has maximum average RSSI value of -66.0750 dBm. This grid consists 13 beacon locations (X_i, Y_i), and calculated centroid (X_e, Y_e) is (263.6, 2214)mm by using equation (1). From 13 beacon positions (X_i, Y_i) and respective RSSI values R_i, distance vector D_{ei} of size 1x13 is calculated by using equation (3). Z_{ei}(1x13) is obtained by substituting (X_i, Y_i), (X_e, Y_e) and D_{ei} values in equation (5). Finally Z_e calculated from equation (6) using Z_{ei} vector of size 1x13 and Z_e value is 725.6mm. Locations of estimated and actual target node positions and error is tabulated in TABLE.III. Error versus height of the target node is plotted in Fig.10. Experimentation results show that proposed algorithm can estimate target node location with less than 1 meter estimation error.

Actual location(X,Y,Z)	Estimated location(X_e, Y_e, Z_e)	Error
(580, 1840, 800)mm	(263.6, 2214, 725.6)mm	495.7mm
(580, 1840, 1400)mm	(151.2363, 2363.5, 1053.1)mm	722.4mm
(580, 1840, 1800)mm	(112.2869, 2386.5, 1263.7)mm	855.8mm

TABLE III: Error comparison

V. CONCLUSION

In this paper we proposed a 3D localization algorithm for knowing the location of sensor node in a sensor network. We used IITH Mote and mobile Robot to perform experiment in real field deployment area (Indoor). The experimental results shows that the proposed algorithm gives very less error of 3D location of target node (< 1 meter). Our future plan is to develop a dynamic algorithm to get still more accurate 3D location of a desired sensor node.

VI. ACKNOWLEDGMENT

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