ENVIRONMENTALLY CORRECTED RSSI BASED REAL TIME LOCATION DETECTION SYSTEM

Hakan Koyuncu and Baki Koyuncu

Final International University, Cyprus

ABSTRACT

RSSI based localization techniques are effected by environmental factors which cause the RF signalsemitted from transmitter nodes fluctuate in time domain. These variations generate fluctuations on distance calculations and result false object position detection during localization.Smoothing procedures must be applied on distance values either collectively or individually to minimize these fluctuations. In this study,proposed detection system has two main phases. Firstly, calibration of RSSI values with respect to distances and calculation of environmental coefficient for each transmitter.Secondly, position estimation of objects by applyingiterative trilateration on smoothed distance values. A smoothing algorithm is employed to minimize the dynamic fluctuations of RF signals received from each reference transmitter node. Distances between the reference nodes and the objects are calculated by deploying environmental coefficients. Experimental measurements are carried out to measure the sensitivity of the system. Results show that the proposed system can be deployed as a viable position detection system in indoors and outdoors.

KEYWORDS

RSSI (received signal strength indication), environmental factor, dynamic fluctuation, iterative trilateration, smoothing algorithm, localization technique.

I. INTRODUCTION

There are many localization techniques which focus on indoors or outdoors by using different sensor devices such as RF-code andJennic [1, 2]. Some examples in the literature to determine the object positions are Cricket [3], Radar [4] and GPS [5]. However, due to different environmental characteristics, sensor devices are affected differently and the localization results will reflect these effects. Hence the accurate calculation of object locations becomes a difficult task.

Sensor devices are called wireless sensor nodes and thesenodes can be transmitters or receivers. Receiver nodes receive the transmitted RSSI values from transmitter nodes and transfer them to a server. Localization procedures use existing WLAN infrastructures to communicate with the server [6,7]. During the RF signal propagation from transmitters, signal amplitudes greatly vary due to environmental conditions when they arrive to receivers. Some signals are weak and their contributions with the distance calculations are minimal. Other signals have good signal strength levels and contribute well in calculations
Hence RSSI values must be carefully considered and the effects of their fluctuations on distance calculations in time domain must be minimized in order to integrate them in position calculations. Many localization systems deal with the smoothing of RSSI values. Some other systems deal with

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the smoothing of localization distances before determining the object location. Filtering techniques such as Kalman filtering [8], Bandpass filtering [9] and etc, are utilized to reduce the random variations of calculated distance values. Sudden changes in RSSI signal levels are also eliminated by using outlier techniques [10].

In literature,many smoothing algorithms are employed in localization procedures.[11],[12] An environmental factor is usually integrated collectively during smoothing as the average of environmental effects for all the transmitters. In this case, localization errors are reduced but not completely minimized due to the fact that environmental effects arequantized locally for each transmitter. Hence, an environmental factor for each transmittermust be introduced during calculations.

In the proposed approach, RSSI values arriving sequentially from each transmitter are considered and an environmental factor for each transmitter is introduced as an environmental coefficient. Each transmitter and receiver pair is calibrated with respect to distances between them and the environmental coefficientis calculated for thattransmitter acrossthe test area. To estimate the object location, there must be minimum 3 transmitters sending RSSI values to object receiver. An initial estimated object location is deployed and the distances between this location and transmitters are used together with environmentally corrected distances between transmitters and objects. Iterative technique is carried out with Taylor expansion series of the above distance differences by reducing the differencewhich is termed as error distanceat every iteration. Error distance reduction eventually approaches to actual object coordinates.

Hence, a new localization technique is proposed in this study where an environmental coefficient is calculated for each transmitter node and object position is determined by using iterative error distance calculations. After a brief introduction in section 1, determination of environmental coefficients and the theory of iterative error distance calculations are given in section 2. In section 3, implementation of the study is presented. Results and general discussions are given in section 4 together with conclusions in section 5.

II. SYSTEM THEORY

The system consists of a set of static reference transmitter WSNs at known coordinates and a mobile object receiver WSN.Transmitter nodesat certain distances to object node broadcast RSSI values to onboard object receiver. Received $RSSI_i$ data and is sent from the object receiver to a base station through a wireless connection. Similarly, reference transmitter node position information (x_i, y_i) is also sent to base station via a wireless LAN. Flow chart of the proposed system is shown in Fig. 1.

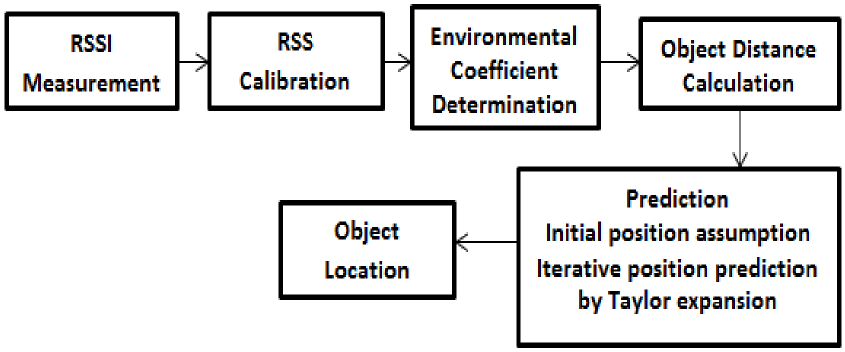

Figure 1: Flow chart of the system.

a) RSSI CALIBRATION

This phase is identified as the calibration phase of the localization. RSSI values are received from individual reference transmitters and gathered in a data base with respect to transmitter coordinates in base station PC. RF signals travel through the environment and they exhibit path loss in different transmission media and directions. In order to quantize these irregular path losses, many RSSI measurements are carried out across the test area at various object distances from transmitters. These RSSI values are plotted against distances and calibration curves are obtained which are expressed empirically by the following equation (1).

$$RSSI = 10\log_{10} Cx^{-n} \tag{1}$$

where 'n' is taken as the environmental coefficient,($10\log_{10} C$) is the RSSI constant value at 1 m across the test area and 'x' is termed as the distance between transmitter and receiver during the calibration phase only. RF signal propagation across the test area is affected by different medium surrounding the reference nodes. If identical environmental coefficients are considered for all the reference nodes this situation introduces errors in distance calculations. Hence, different environmental coefficients are determined for different reference node transmissions and 'n_i'environmental coefficient canbe definedin equation (2) as

$$n_i = -\frac{RSSI_i - 10\log_{10} C}{10\log_{10} x_i} \tag{2}$$

where (i =1,2,3...N) and N is the number of RSSI measurements from one transmitter.

During the calibration of $RSSI_i$ values against a range of 'x_i' distances, 'n' is calculated for each RSSI and a known 'x' value. A set of n_i values are generated and averaged out to give the environmental coefficient $n_{avg}$for one transmitter as shown in equation (3).

$$n_{avg} = \frac{1}{N}\sum_{i=1}^{N} n_i \tag{3}$$

Hence environmentally corrected or smoothed x_j distances between a transmitter and the objectlocation can be expressed in equation (4) as:

$$x_j = 10^{\frac{A-RSSI_j}{10n_{avg}}} \quad (4)$$

j = (1,2,3,4….M) where M is the total number of RSSI measurements at object distance 'x_j' with average environmental coefficient $n_{avg}$and A constant of $10\log_{10}C$.

Secondly, a well-known real time smoothing algorithm called KalmanFiltering is applied on previous $x_j$values to further smooth them for higher position accuracies. In conclusion, 2 levels of smoothing are applied on x distance calculations, one with average environmental coefficient and another with Kalman filtering.Hence, a sufficient reduction of distance variations due to RSSI fluctuations is realized during localization.

b) General System

The above smoothing mechanisms aredeployed on the object distances with transmitters to reduce the effects of RSSIfluctuationsin time. In this section, smoothed x distances are termed as d distances between transmitters and object receiver. N number of 'T' transmitters and the object receiver are employed during measurements.There are 'j' numbers of 'd' distances calculated from j number of RSSI measurements for each transmitter. This can be displayed for N transmitter with the following set.

$$\begin{bmatrix} T_1 \\ T_2 \\ \vdots \\ T_N \end{bmatrix} \supset \begin{bmatrix} d_1^1, d_1^{11}, d_1^{111}, \ldots\ldots, d_1^j \\ d_2^1, d_2^{11}, d_2^{111}, \ldots\ldots, d_2^j \\ \vdots \\ d_N^1, d_N^{11}, d_N^{111}, \ldots\ldots d_N^j \end{bmatrix}$$

Hence there are j number object location calculations with N transmitters and each calculation stage is defined as iteration. Each iteration contains N number of d values shown as { d_1^j d_2^j , d_3^j ,…, d_N^j } corresponding to N transmitters.

c) Location Determination

In order to estimate the object location, (x,y), there is a need for transmitter nodes with coordinates (x_i,y_i) and their respective distances d_i, to object receiver.An iterative technique is employed to calculate (x,y) location with respect to 'd_i' distances. Algorithm requires the coordinates of minimum three transmitters and their 'd_i' distances with the object. Initially, a finite estimated position, (x_f,y_f), is required to start the operation. Difference between the distance 'd_i' and the estimated distance between (x_i,y_i) and (x_f,y_f) is calculated. Initially, (x_f,y_f) is substituted for (x,y) and the difference is given by;

$$f_i = \left\{ d_i - \sqrt{(x_i - x_f)^2 + (y_i - y_f)^2} \right\} \quad (5)$$

Correction parameters, (Δx, Δy), are introduced to (x_f, y_f) in each iteration. These parameters are added to (x_f,y_f) to approach object coordinates after a number of iterations.

d) CORRECTION PARAMETERS (ΔX, ΔY)

In calculus, a Taylor series represents a function as an infinite sum of terms which are calculated by a function's derivatives at a single point. For example,Taylor's expansion of a function f(x) at point c(x,y) can be expressed as:

$$f(x) = f(c) + \frac{f^{'}(c)}{1!}(x-c) + \frac{f^{''}(c)}{2!}(x-c)^2 + ... \tag{6}$$

1st degree Taylor series is defined by the first 2 terms of f(x) and it can be written for (x_f,y_f) as

$$f(x) = f(x_f) + f'(x_f)(x - x_f) \tag{7}$$

$$f(y) = f(y_f) + f'(y_f)(y - y_f) \tag{8}$$

Correction parameters (Δx, Δy) can be calculated by using the 1st order Taylor expansion of f_i in equation (5). $f^{'}(x_f, y_f)$ derivativeis given as $D = (\frac{\partial f_i}{\partial x_f}, \frac{\partial f_i}{\partial y_f})$ and it is expressed as shown here.

$$D = \left\{ \frac{x_i - x_f}{\sqrt{(x_i - x_f)^2 + (y_i - y_f)^2}}, \frac{y_i - y_f}{\sqrt{(x_i - x_f)^2 + (y_i - y_f)^2}} \right\} \tag{9}$$

Equations(7), (8) and (9) can be displayed in symbolic form as

$$f = f(x, y) = D * \Delta \tag{10}$$

where $\Delta = (\Delta_x, \Delta_y)$ and it is given in matrix form as $\Delta = \begin{bmatrix} \Delta x \\ \Delta y \end{bmatrix}$

By using 2D matrix calculations Δ can be calculated as follows.

Multiplying both sides by D^{-1}, equation (10) becomes;

$$D^{-1} * f = \Delta \tag{11}$$

Both sides of the equation (11) is multiplied with ($D^{-T} * D^T$) where $D^T$is thetranspose matrix as shownby

$$(D^{-T} * D^T) * D^{-1} * f = (D^{-T} * D^T) * \Delta$$

Left side of the above equation can be expressed as

$$(D^T * D)^{-1} * D^T * f = \Delta = \begin{bmatrix} \Delta x \\ \Delta y \end{bmatrix}$$

Δx and Δy values are added to x_f and y_f initial values to generate the new estimated values of x_{f+1} and y_{f+1} for next iteration.

e) CASE STUDY

A numerical example is presented here to display the matrix operations to calculate (Δx, Δy) values for the case of 3 transmitters.

Suppose $D = \begin{bmatrix} 1 & 0 \\ 2 & -6 \\ 3 & 7 \end{bmatrix}$, $f = \begin{bmatrix} 3 \\ 4 \\ 2 \end{bmatrix}$ and $D^T = \begin{bmatrix} 1 & 2 & 3 \\ 0 & -6 & 7 \end{bmatrix}$

Hence, $(D^T * D)^{-1} * D^T = \begin{bmatrix} 0.076 & -0.0081 \\ -0.0081 & 0.0126 \end{bmatrix} \begin{bmatrix} 1 & 2 & 3 \\ 0 & -6 & 7 \end{bmatrix} = \frac{1}{1109} \begin{bmatrix} 85 & 224 & 192 \\ -9 & -102 & 71 \end{bmatrix}$

Therefore $\Delta = (D^T * D)^{-1} * D^T * f = \begin{bmatrix} -1.3841 \\ 0.2642 \end{bmatrix}$

III. IMPLEMENTATION

The approach presented here considers the environmental effects which cause the random fluctuations on recorded RSSI values. These random fluctuations in return generates fluctuations in distance calculations. In this study, environmental effects are included as environmental factorsin the calculations and they are deployed to reduce the distance fluctuations between the transmitters and receivers due to RSSI variations. A Classical Kalman filtering stage is also included on pre-smoothed distance values to smooth them further in order to increase the positioning accuracies. A living room with physical dimensions of 5m x 4m is considered as the test area See block diagram in Fig.2.

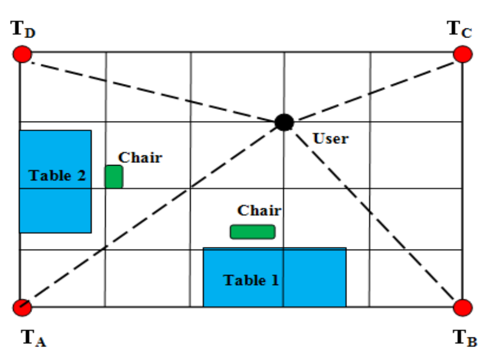

Figure 2: Experimental Test area

There are simple obstacles as tables, chairs and walls in the room. 4 transmitters are placed at the corners of the ceiling. A mobile user with a receiver stands in the middle of the room. Transmitters transmit RSSI data to receiver on the user. Base station is connected to receiver via WLAN. Experiments are conducted at a time when the room is empty.

a) CALIBRATION

RSSI values transmitted from transmitters are received by the object receiver at sequential distances and they are plotted as graphs of RSSI values versus distances across the test area. See Fig.3 for an example transmitter.

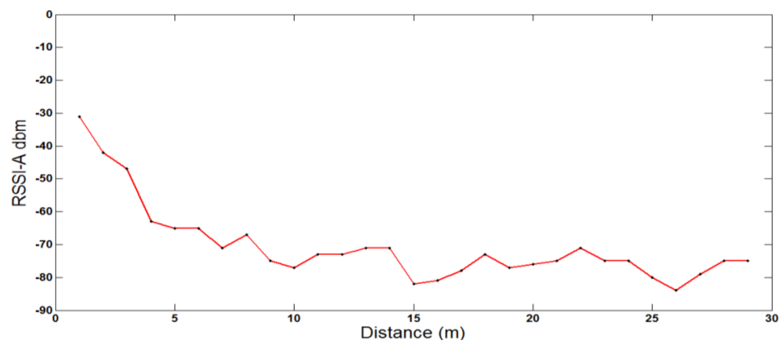

Figure 3: RSSI values versus distances for transmitter A

Empirical formula in equation (1) is generated from these graphs in time domain and environmental coefficient 'n' is calculated by using equation (2). Environmental coefficients for each transmitter at 1 meter intervals are displayed for an example distance range together with their average values in Fig.4. n_{avg} value is derived for each transmitter from 'n' values and used as smoothing factor in x distance calculations using equation (4) for each transmitter. Secondly, smoothed distance values between transmitters and receivers are Kalman filtered after outliers are checked and removed.

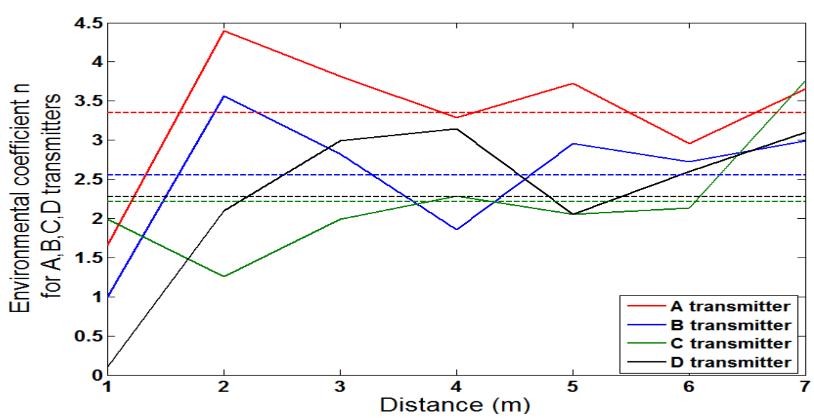

Figure 4: Plot of Environmentalcoefficients for A, B, C, D transmitters

where n_{avgA}= 3.35 n_{avgB}= 2.55 , n_{avgC}=2.21 , n_{avgD}= 2.28

b) Corrective Positioning

Correction parameters ($\Delta x,\Delta y$) are calculated as in section II.d.bydeploying (x_i,y_i) values and (x_f,y_f) coordinates. Object coordinates, (x,y), are estimated by adding ($\Delta x,\Delta y$) values to (x_f,y_f) for each iteration. For example, small random values of (x_f,y_f) = (0.5,0.75) are chosen and (x,y) coordinates are calculated for 10 iterations. These estimated coordinates are plotted against the number of iterations given in Fig.5, Fig.6 and Fig.7.

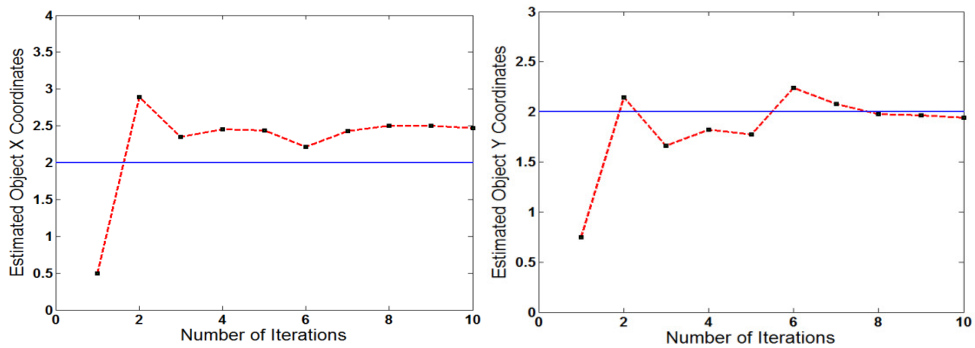

Figure 5: Estimated object (x,y) coordinates for object point (2,2) after 10 iterations

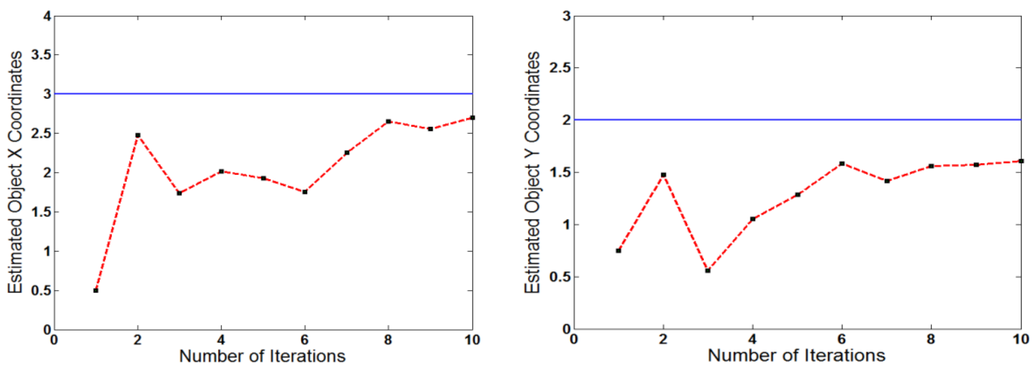

Figure 6: stimated object (x, y) coordinates for object point (3,2) after 10 iterations

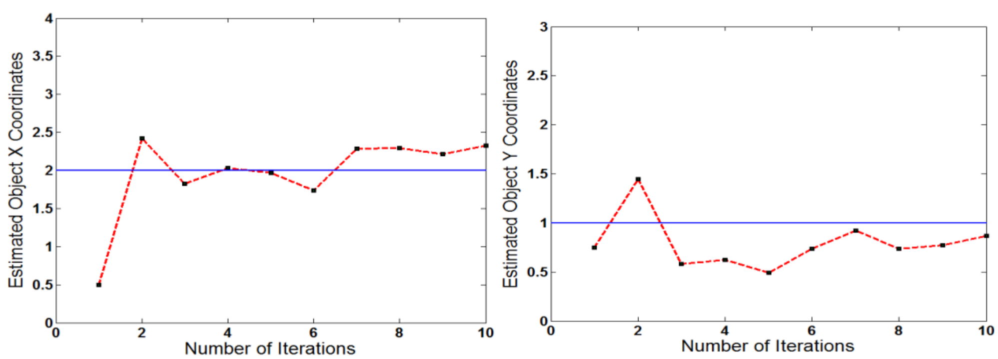

Figure 7: Estimated object (x, y) coordinates for object point (2, 1) after 10 iterations

IV. DISCUSSIONS

A localization approach is presented by using'd' distances between the transmitters and receivers. Calculated'd' distances with measured RSSI values and the estimated distances between the transmitters and initial (x_f, y_f) valuesare utilized. Their difference is defined as a difference function and it is expressed as a first order Taylor series. Correction parameters Δx and Δy are added to user defined initialcoordinates, (x_f,y_f), inx and y direction. These parameters are changed with the change of calculated'd' values at every iteration.After a number of iterations, the object location coordinates are approached with the best possible error margin.

Recordings of the raw RSSI data by the receiver on the object are placed in a database in the base station. These recordings contain variations due to RF signal variations. In the proposed study, calculated object distances from transmitters are subjected to 2 level smoothing procedures one with environmental coefficients and the other with Kalman filtering.

Examples in Figures (5), (6) and (7) show that an initial starting (x_f,y_f) = (0.5,0.75) values are iterated to (2.4 ,1.8) , (2.7, 1.6) and (2.3, 0.8) at the end of 10 iterations. These estimated object coordinates correspond to physical object points of (2,2), (3,2) and (2,1) with error marginsof 0.45m, 0.50m and 0.36m respectively. Hence the proposedtechnique has a localization error of average 0.44m in a grid space of 1m. This level of accuracy is reasonably good comparing to many localization systems in literature where the localization accuracies are around 1 grid space. In majority of localization procedures, RSSI measurements are carried out and different algorithms are applied to find the object locations in real time. In some cases, prediction techniques are applied and final object location is determined by using previous object location calculations. Kalman filtering technique is one of them. Object location coordinates are calculated in real time and Kalman filtering is applied to smooth these coordinates. Consequently, fluctuations amongthem are reduced and a final object location is obtained.

On the other hand, Taylor series method is employed in this study.. Initial values for object coordinates are assumed approximately close to object location. Distance betweenthis locationand the calculated location from RSSI measurements is taken as the error function. Taylor expansion series of the error function approaches to the actual object location by reducing the amplitude of the error function. This is an alternativesmoothing technique. In second stage Kalman filtering is also applied to reduce the fluctuations further.

V. CONCLUSIONS

A new approach with an average positioning accuracy of half a grid space is introduced in indoors. Measurements are carried out in an area with minor obstacles. Hence the effects of environmental conditions are taken into account for every transmitted RF signal from the transmitters. Each transmitter radiation is calibrated with respect to environmental effects and an environmental factor'n' is introduced during the calculation of d distances between the transmitters and receivers.

Distance difference between calculated and estimated object distances is considered as a function. This function is used to introduce correction parameterson the initial estimated object coordinatesduring every iteration.

Positioning accuracies in literature is around the grid space of the test areas. In most of the systems, a number of reference nodes are utilized across the test area. Fingerprint maps are generated andk-NN algorithms are employed. The positioning accuracies are still around or slightly less than the grid space. These techniques in return increase the cost and efforts.

In this approach cost and effort factors are reduced to minimum. An object receiver just collects RSSI data from transmitters. The user only needs to introduce small initial coordinates as the startup condition. An applied algorithm calculates the object location iteratively. In conclusion, the system introduced here is a very simple and fairly accurate localization system.

VI. REFERENCES

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