A Bluetooth Signal Strength Based Indoor Localization Method

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Abstract **– Indoor location awareness is intended for many applications like patient monitoring and store navigation. Short range wireless protocols are usually preferred when other ways of location sensing methods such as Global Positioning Systems or Inertial Measurement Units may not be feasible to use indoors. Devices using Bluetooth protocol have the advantage of being low cost and also being widely available. In this paper an affordable indoor localization system is proposed where location evaluation is performed by measuring unknown positioned Bluetooth transmitters' signal levels at some known base stations. A localization method is proposed which uses calculated values of a defined error function to estimate the positions of unknown transmitters. The error function is based on a modified Root-Mean-Square-Error (RMSE) metric. The error function is calculated using Received Signal Strength Indicator (RSSI) measurements at each point under consideration. The error function is calculated at discrete points in the area of interest and the points with low calculated error values indicates locations where transmitters may be located with a high probability. The validity of the decision method is verified with a real-world experiment.**

Keywords – **Indoor Localization; Bluetooth; Error Function; RMSE; RSSI**

I. INTRODUCTION

Location based applications are one of the most popular fields of mobile devices. Especially indoor localization is of particular interest where satellite based positioning systems can not be used, since receivers usualy fail if line of sight visibility to the satellites are lost [1]. The limits of satellite based positioning systems to provide location information in indoors have fostered the use of other wireless technologies [2]. Due to the increasing popularity of location based applications, a considerable amount of research effort has been made to develop indoor localization systems [3].

Bluetooth is a wireless technology standard for exchanging data over short distances. It uses the frequency band between 2400 MHz and 2480 MHz [4]. Bluetooth is a widely used standard for wireless personnel area networks and is a pervasive technology among mobile devices [5]. It is primarily used for low power and short range connections which is desirable for mobile and embedded devices. In recent years with the growth of mobile phone and tablet market, it became the preferred method for short range connections. Many PC accessories such as mice, keyboards, and headsets also include the Bluetooth standard for wireless connection [6].

Bluetooth has been used among other Radio Frequency (RF) technologies for indoor localization since it is a cost effective and easy-to-deploy solution [7]. Wi-Fi [8] and ZigBee [9] are also suitable for indoor localization but Bluetooth is easier to use in general and has the advantage of being widely available. A recently introduced system called iBeacon uses Bluetooth technology for indoor positioning purposes [10], [11].

There are different methods for localization such as Cell Identity (CI), Angle of Arrival (AOA), Time of Arrival (TOA), Time Difference of Arrival (TDOA), and received power level based localization. All of these methods have their own advantages and disadvantages but in general received power based method may be considered as an easy way to do localization considering both hardware and software requirements [3].

Received power levels are typically measured in wireless networks for transmit power control and roaming, however the results of measurements can also be used for localization as well. Bluetooth devices measure the received power level indirectly by RSSI, which is implemented in the Bluetooth module and can be read easily [4]. Consequently the received power level based localization seems to be the most applicable one for Bluetooth [12].

The accuracy of the wireless localization systems relies heavily on distance metrics. Using RMSE is a good choice due to its simplicity and relatively stable performance [13].

II. LOCALIZATION METHOD

The localization method will be studied for a two dimensional placement where all of the unknown transmitters and known base stations are on the same plane so that there are no height differences.

For a two dimensional placement at least three base stations are needed to localize the transmitters without ambiguities. The formulation may also be extended if there are more base stations than the required minimum number.

In Fig. 1 the distances from the transmitter T_k to base stations B_1, B_2, and B_3 are indicated as d_1, d_2, and d_3 respectively.

The received signal levels at base stations B_1, B_2, and B_3 are S_1, S_2, and S_3 respectively.

The Error Function (EF) is defined as:

$$EF = \sqrt{\left(\frac{(d_1/d_2)^2}{S_2/S_1} - 1\right)^2 + \left(\frac{(d_1/d_3)^2}{S_3/S_1} - 1\right)^2} \quad (1)$$

In this equation, the received signal level S_1 at the base station B_1 is taken as the reference and signals levels at stations B_2 and B_3 are compared with respect to this signal level. It is also possible to choose B_2 or B_3 as reference base stations and comparing signal levels with respect to S_2 or S_3. Another possiblity is to calculate Error Function by taking all base stations as reference for once and calculating each Error Function accordingly and obtaining the mean value of these Error Functions to get an averaged Error Function.

For a particular point, the ratio of the square of distances to the base stations are compared to the ratio of signal levels in Equation (1). It is assumed that the received signal levels decreases with respect to the the squared distance from the transmitters as in free space propogation.

The inside of the square root may also be divided by the number of beacons minus one if it is desired to compare the effect of variable number of beacons on the performance of the localization. For the sake of simplicity it is omitted here.

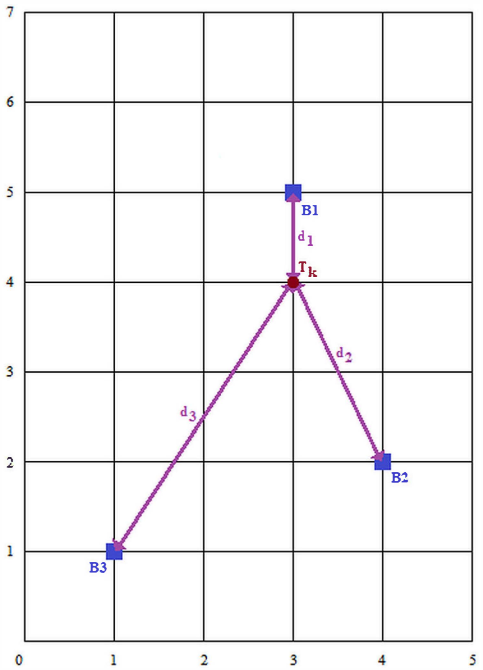

Figure 1. The Bluetooth transmitter T_k and the distances d_1, d_2, and d_3 to the base stations.

It is seen that if the received signal levels S_1, S_2, and S_3 are inversely proportional with the square of the distances d_1, d_2, and d_3 respectively, the divisions in the formula turns out to be unity and the Error Function is equal to zero, which means that the transmitter T_k in Fig. 1 should be located at the point under consideration ideally. If the Error Function gets a value greater than zero for a particular point, this means that there is not any transmitter at this point or if there is really a transmitter at this point then it can be said that there are some disturbances such as obstacles, reflections, and measurement errors that alter the calculations.

III. EXPERIMENT

The experiment is done in a 5m x 7m room with furniture inside. Three Bluetooth receivers are placed in the room and they function as base stations (B_1, B_2, and B_3). There are a total number of six separate Bluetooth transmitters as indicated in Fig. 2. All of the base stations and transmitters are placed at the ground level, which is thought to be the worst case. It should be noted that all base stations and transmitters have both transmit and receive capability, but their names are given accordingly to indicate their functionality.

The base stations and transmitters are placed randomly at discrete points. The locations of the base stations are not optimum. There maybe a better placement or placements for base stations in this particular transmitter placement or for all possible placements.

Easily obtainable commercial equipments are used throughout the experiment. The base stations are GSM phones which have Bluetooth RSSI measurement software embedded. Bluetooth transmitters are composed of a GSM phone, a media player, and four Bluetooth wireless headsets.

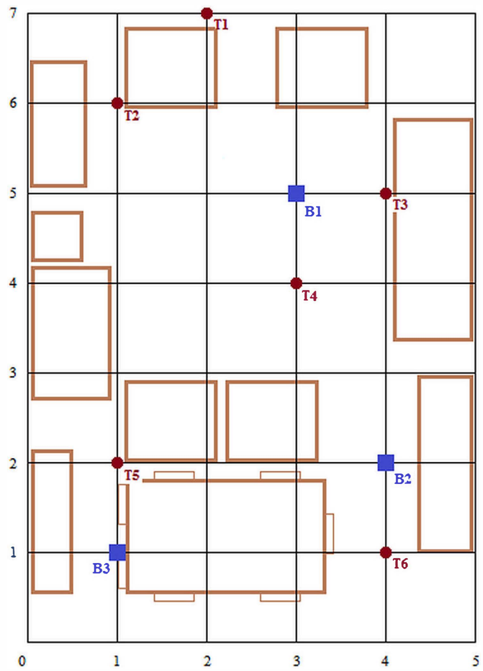

Figure 2. Locations of Bluetooth base stations and transmitters in a 5m x 7m room with furniture.

All of the transmitters are activated during the test and the measurement software's RSSI readings on the base stations are monitored. Since Bluetooth protocol may change transmitted Radio Frequency (RF) power, the maximum power readings are obtained from a number of sequential measurements. If all signal levels are porocessed at the same time, a few seconds seems to be enough for obtaining the required RSSI readings. The measured maximum readings are listed in Table I.

TABLE I. MAXIMUM RECEIVED SIGNAL STRENGTH INDICATION VALUES OF THE TRANSMITTERS AT BASE STATIONS

Transmitter	Maximum RSSI Levels (dBm)		
	Base 1 (B1)	*Base 2 (B2)*	*Base 3 (B3)*
T1	-58	-67	-71
T2	-52	-57	-60
T3	-61	-70	-76
T4	-59	-67	-72
T5	-67	-60	-56
T6	-78	-66	-75

All base stations are of the same type so they have the same hardware and they have similar RSSI readings under the same conditions. Among the transmitters only T_2 and T_5 have the same hardware, so except for T_2 and T_5 power levels should be considered separately for other transmitters. For the localization method this is not a shortcoming since the localization of every transmitter is independent from each other and calculated separately. It should be noted that it is also possible to use power levels of the transmitters with similar hardware in localization estimations, but in the context of this paper this knowledge is not taken into account.

B3 is located in a region where it is blocked with furniture and as seen in Table I this results in lower measured signal levels for T_1, T_2, T_3, and T_4 compared to B_1 and B_2. Similarly the position of T_5 results in lower signal levels received at base stations and may be compared with T_2 directly, since they have the same hardware and T_2 is not heavily blocked with furniture.

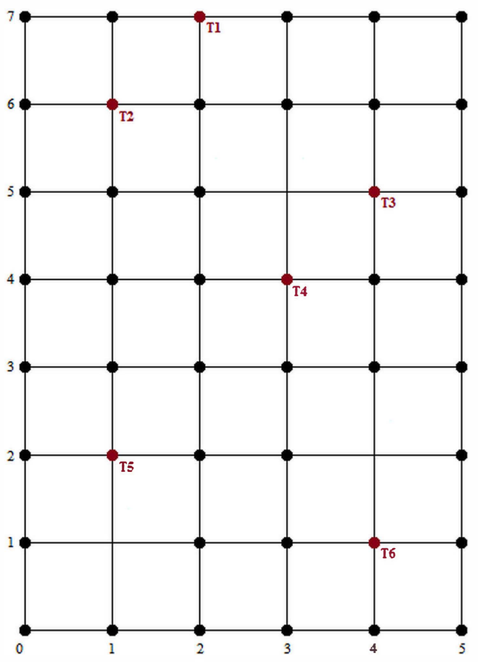

Figure 3. Locations where the Error Function is calculated are shown as dots (base stations are excluded).

After RSSI measurements are taken, the Error Function in Equation (1) is calculated for each discrete point in Fig. 3 using both the positions in Fig. 2 and the measured RSSI values in Table I.

TABLE II. THE CALCULATED ERROR FUNCTIONS VALUES ARE LISTED IN TABLE II.MINIMUMS OF THE CALCULATED ERROR FUNTIONS FOR ALL OF THE TRANSMITTERS

Transmitter	Maximum Received Levels (dBm)			
	First Minimum Error Value (Coordinates)	*Second Minimum Error Value (Coordinates)*	*Third Minimum Error Value (Coordinates)*	*Actual Point Error Value (Coordinates)*
T1	0.123 (4,6)	0.165 (4,5)	0.301 (2,5)	1.228 (2,7)
T2	0.028 (5,7)	0.170 (5,6)	0.237 (2,4)	0.319 (1,6)
T3	0.205 (4,5)[a]	0.382 (3,6)	0.608 (4,6)	0.205 (4,5)
T4	0.193 (4,6)	0.255 (4,5)	0.384 (2,5)	0.421 (3,4)
T5	0.250 (2,0)	0.336 (2,1)	0.426 (3,0)	0.504 (1,2)
T6	0.064 (4,1)[a]	0.313 (3,2)	0.371 (5,1)	0.064 (4,1)

In Table II it is seen that at the actual positions of T_3 and T_6, the Error Function gets minimum and may be considered as perfect matches for the localization of these transmitters. The position of B_3 results in decreased RSSI readings at B_3 and these results in higher Error Functions and so erroneous location estimations especially for T_1, T_2 and T_4.

When the lowest minimum (first minimum) error valued points in Table II are selected as the estimated locations of transmitters, the degradation from the actual locations due to these estimations are found to be as shown in Fig. 4.

If the lowest minimum error valued points are selected as estimated locations, Root-Mean-Square-Error (RMSE) of the localization is found to be 2.309 meters in this particular experiment.

When estimating a particular transmitter's location, it is also possible to take into account points other than lowest minimum error valued point. A weighted sum of other points may also be used to estimate a transmitter's location. In this case the estimated location may be found at a non-discrete point which should be most probably the case in a real life application.

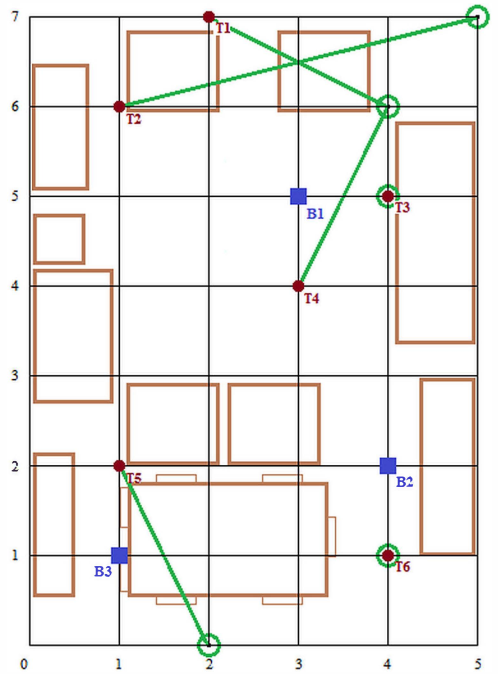

Figure 4. The true and estimated (circled) locations of the transmitters.

IV. CONCLUSION

A Bluetooth signal strength based localization method is presented in this paper. An Error Function is defined to estimate the positions of unknown transmitters. The Error Function is based on a modified RMSE metric. For each discrete point in a region the Error Function is calculated by using the distances to the base stations and the RSSI levels at the base stations. The points with lowest Error Function values are estimated as the transmitter locations.

Accuracy of the method was evaluated with an experiment. It turned out to be that the accuracy needs to be improved for practical implementations. One of the error sources is thought to be non optimum placement of the base stations. The position of B_3 is the main reason for large estimation errors in general, since it is blocked with furniture. The furniture and the walls deteriorates signal propogation and results in reflections. Although using three base stations is theoretically enough for location estimation in a two dimensional environment as in the experiment, it is thought that the addition and proper placement of a fourth base station would decrease localization errors considerably.

As part of the future work, it is planned to carry out the same experiment with four base stations. Furthermore, the optimization of base station placements is also planned.

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