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Comparison of Various Indoor Positioning Systems Techniques

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Abstract: ***Localization is one of most important topic. GPS is perfectly using outside environment. However it is not possible to use indoor environment. In this paper, Triangulation, Maximum Likelihood and Fuzzy Logic algorithms were developed. Algorithms work with same environment and same conditions. Algorithms were compared each other in order to find better accuracy.***

Index Terms**:** ***Indoor positioning, triangulation, maximum likelihood, fuzzy logic, received signal strength, wireless network.***

I. INTRODUCTION

Nowadays, Location based services (LBSs) are very important for people's life. People need to know things (people, buildings, objects etc.) physically location. Indoor location awareness is important for such fields as ambient intelligence, assisted daily life, behavior analysis, social interaction studies, and myriads of other context-aware applications.

In order to estimate people location, many techniques have been investigated. GPS is most widely-used tracking technology in the world. GPS technology is using received signal strengths from multiple satellites and uses triangulation algorithm to find location of object [Figure 1]. Object locations can be determined within 1-5 meters with GPS technique. However High Sensitive GPS technique has been implemented to estimate location in indoor environments. GPS is working with line-of-sight (LOS). In indoor environments, there is no direct line from the satellites. Also buildings reflections, diffractions and scatterings are decreasing accuracy of estimations. [1] Thus, GPS technique is not suitable for indoor environment.

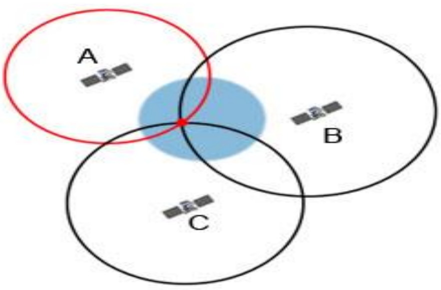

Fig.1 GPS working principle with satellites

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Besides GPS technology, there are lots of wireless network systems and sensors are implemented for indoor environment. Widely known Indoor Positioning Systems with named using technology are, Infrared Positioning Systems, Ultrasonic Positioning Systems, and RSSI Positioning Systems. [1] RSSI Positioning system is using Wireless Local Area Network (WLAN). There are many indoor positioning systems that using WLAN estimate positioning such as Time of Arrival (TOA), Time Difference of Arrival (TDOA), and Angle of Arrival (AOA). Those methods are needed extra configuration and measurement. RSS (Received Signal Strength) is getting signals directly from access points (APs) which they are exits on any WLAN adapter. [2] In this paper; Triangulation, Maximum Likelihood and Fuzzy Logic algorithms were implemented and compared with each other by using RSSI values.

II. TRIANGULATION ALGORITHM INDOOR POSITIONING DESIGN

Basic principle is using geometric properties of triangles to complete object location. Lateration is using distance measurement, angulations is using primarily angle or bearing measurements. [3] Lateration or Trilateraion is most well known estimation location in indoor positioning. Lateration is required three known positioned APs. We are collecting RSSI values from receivers. Measured RSSI values are converting into distance measurement by using path loss model. The path loss model shows the expected path loss in signal strength at a given distance (At one meter, dBm). Then known three distances from known APs are using Euclidean distance in order to estimate unknown object location Figure 1.15 [4].

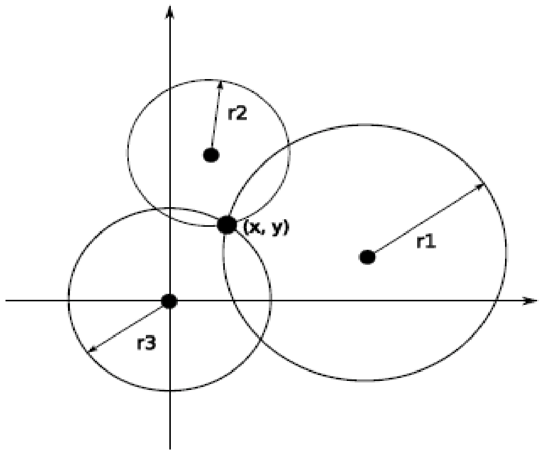

Fig.2 Triangulation Method

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The distance d_i is estimated from RSSI values are used to compute centered in the three reverences anchor nodes. Ideally, the target should be intersection of the circles like in Figure 2

From General Euclidean distance, radius can be find as

$$r_1 = \sqrt{(x_1 - x)^2 + (y_1 - y)^2}$$

$$r_2 = \sqrt{(x_2 - x)^2 + (y_2 - y)^2}$$

$$r_3 = \sqrt{(x_3 - x)^2 + (y_3 - y)^2} \quad (2.1)$$

After we re-arrange basic equation, we have matrix form;

$$\begin{bmatrix} (r_1)^2 - (r_2)^2 + (x_2{}^2 + y_2{}^2 - x_1{}^2 - y_2{}^2) \\ (r_1)^2 - (r_3)^2 + (x_3{}^2 + y_3{}^2 - x_1{}^2 - y_2{}^2) \end{bmatrix} =$$

$$\begin{bmatrix} 2(x_2 - x_1) & 2(y_2 - y_1) \\ 2(x_3 - x_1) & 2(y_3 - y_1) \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix}$$

$$\bar{A} = \bar{B} * x \quad (2.2)$$

Target location can be estimated after matrix equation is solved in (2.2)

$$\begin{bmatrix} x \\ y \end{bmatrix} = (\bar{A}^T A)^{-1} * (\bar{A}^T B) \quad (2.3)$$

III. MAXIMUM LIKELIHOOD ALGORITHM INDOOR POSITIONING DESIGN

Maximum Likelihood (MLE) is lateration-based position estimation algorithm. It is required coordinate known APs. The main idea is calculate least mean square error (MSE) to estimate location of target device. Firstly, we are finding distance between target point and anchor nodes. Then the estimated target node defines an error which is error that actual and estimated distance for target node. We consider $(x_1, y_1), (x_2, y_2), (x_3, y_3)$, and$(x_4, y_4)$ are our AP locations. (X, Y) is the target node. Euclidean distance formula is using to find distance between anchor nodes and target node. (3.1) d is shows Euclidean distance, s_i represent coordinate calculated from RSSI measurement, s_i' is shows real coordinate for target node. [5, 6]

$$(x_1 - X)^2 + (y_1 - Y)^2 = d_1^2 \dots (x_n - X)^2 + (y_n - Y)^2 = d_n^2 \quad (3.1)$$

To solve equation and estimate location for(X, Y), we are subtracting (x_4, y_4) from other APs distance:

$$2(x_{4-} x_1)x + 2(y_{4-} y_1)y = (d_1^2 - d_4^2) - (x_1^2 - x_4^2) - (y_1^2 - y_4^2) \quad (3.1.a)$$

$$2(x_{4-} x_2)x + 2(y_{4-} y_2)y = (d_2^2 - d_4^2) - (x_2^2 - x_4^2) - (y_2^2 - y_4^2) \quad (3.1.b)$$

$$2(x_{4-} x_3)x + 2(y_{4-} y_3)y = (d_3^2 - d_4^2) - (x_3^2 - x_4^2) - (y_3^2 - y_4^2) \quad (3.3.c)$$

Re-write equation with matrix form;

$$2 * \begin{bmatrix} x_4 - x_1 & y_4 - x_1 \\ x_4 - x_2 & y_4 - x_2 \\ x_4 - x_3 & y_4 - x_3 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} =$$

$$\begin{bmatrix} (d_1^2 - d_4^2) & (x_1^2 - x_4^2) & (y_1^2 - y_4^2) \\ (d_2^2 - d_4^2) & (x_2^2 - x_4^2) & (y_2^2 - y_4^2) \\ (d_3^2 - d_4^2) & (x_3^2 - x_4^2) & (y_3^2 - y_4^2) \end{bmatrix} \quad (3.4)$$

Since we have matrix form as follows;

$$A = \vec{x} * \vec{b} \quad (3.5)$$

We can solve equation by using basic formula from (3.5), where

$$A = \begin{bmatrix} 2(x_4 - x_1) & 2(y_4 - x_1) \\ 2(x_4 - x_2) & 2(y_4 - x_2) \\ 2(x_4 - x_3) & 2(y_4 - x_3) \end{bmatrix}, \; x = \begin{bmatrix} x \\ y \end{bmatrix},$$

$$b = \begin{bmatrix} (d_1^2 - d_4^2) & (x_1^2 - x_4^2) & (y_1^2 - y_4^2) \\ (d_2^2 - d_4^2) & (x_2^2 - x_4^2) & (y_2^2 - y_4^2) \\ (d_3^2 - d_4^2) & (x_3^2 - x_4^2) & (y_3^2 - y_4^2) \end{bmatrix} \quad (3.6)$$

Equation (5.5) can be solved by using (5.7)

$$\vec{x} = A^{-1} * \vec{b} \quad (3.7)$$

$$x = (A^T A)^{-1} * A^T * b \quad (3.8)$$

IV. FUZZY LOGIC INDOOR ALGORITHM INDOOR POSITIONING DESIGN

Fuzzy set theory has been introduced by Zadeh in 1965. According to [7], a fuzzy set is characterized by membership function which assigns to each object a grade of membership ranging between one and zero. In real world, there are not exactly defined classes. For example, we can characterize weather with terms like hot, warm or cold. This condition like hot or warm is called membership function. A set of membership function is connected linguistic term, in our example temperature. [8] Fuzzy logic works on the level of possibilities of input to achieve the defined output.

To sum up, fuzzy logic helps to deal with uncertainty. By using fuzzy logic system we can obtain more accurate results. Fuzzy logic indoor positioning system (FLIPS) is widely using method. By designing fuzzy logic system, target location can be found in indoor environment.

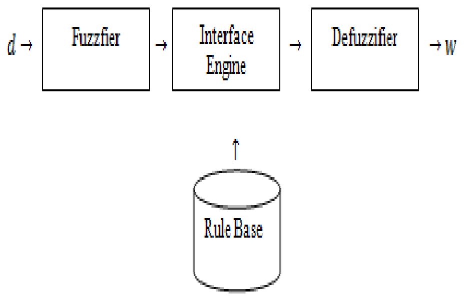

Fig3. Fuzzy Logic System

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In the FLIPS, w is representing weight of coordinate of each anchor nodes. Fuzzier represents triangular membership function. Interface engine represents madmani max-min method. Defuzzifier represents center of gravity method. And d represent distance between target node and anchor nodes, APs.

We used [9]' fuzzy logic membership and algorithm to estimate target nodes for our measurement areas 6 square meter and 12 square meter. According to these rules, we are getting coordinates for each anchor nodes. In order to estimate target location;

$$x_0 = \frac{x_1 * w_1 + \cdots + x_N * w_N}{\sum_{i=1}^{N} w_i} \quad (4.1)$$

$$y_0 = \frac{y_1 * w_1 + \cdots + y_N * w_N}{\sum_{i=1}^{N} w_i} \quad (4.2)$$

In equations (4.1),(4.2) x, y are real coordinates of anchor nodes and w is a variable that we are getting from fuzzy logic member rules by using anchor node distance to target node. By using these equations, target node location can be estimated.

V. MEASUREMENT AREA

In order to compare algorithms with each other, real RSSI data were used. Kadir Has University's canteen was chosen as a measurement area. Indoor environment are effected with person movement thus we choose holiday in order to avoid students' effect on our environment. 6 square meter and 12 square meter areas were created.

In 6 square meter area, 255 features and for 12 square meter are 444 features were used. Cell phone gathered RSSI values from each features inside of measurement area. During experiment, another cell phone (agent) is placed at the middle of measurement area and measured RSSI values from same node. In 6 square meter area agent coordinate is (3, 3) and for 12 square meter area agent coordinate is (6, 6). Agent provides to find A value (1 meter value for path loss) from 4 different access point. N values are calculating with Brute Force technique.

Path Loss Formula is;

$$\text{RSSI (dBm)} = -(10n \log10(d) + A) \quad (5.1)$$

$$d = 10^{\left(\frac{(\text{RSSI}-(A))}{10*n}\right)} \quad (5.2)$$

RSSI: is the value received by the smart phone (dBm)
d: distance in meters
A: received signal strength in dBm at 1 meter
n: propagation constant or path-loss exponent [5]

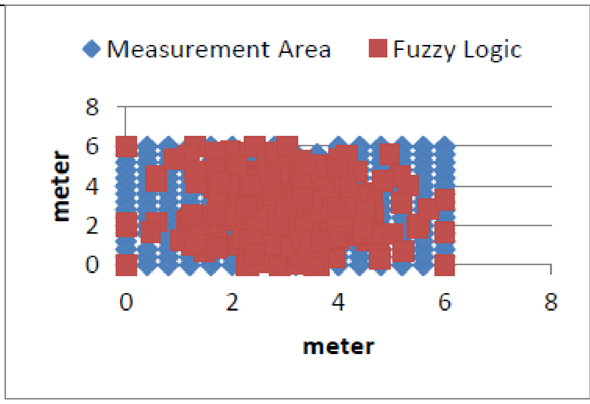
Brute Force algorithm is used to find optimum N values. Basically algorithm finds path loss exponent value for each access point. Algorithm find exponent until estimated distance and real distance is equal to each other for each RSSI values. N values for access point is;

N represents each calculated point in measurement area.

$$n_{avg} = \sum_{i=0}^{N} n_i$$

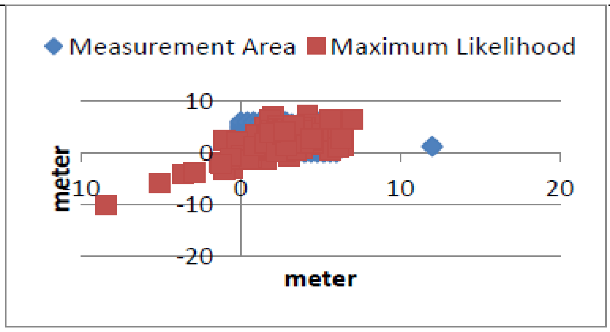
5.1 Experiment Result

Fuzzy Logic, Triangulation and Maximum Likelihood algorithms run with same environment. Algorithms result and target nodes real coordinates and estimated coordinates graphs on 6 square meter areas are shown in below figures.



Average	Maximum	Minimum	Standard Deviation
1.71	10.74	0.05	1.05

Fig4.Fuzzy Logic Algorithm 6mx6m



Average	Maximum	Minimum	Std Deviation
2.15	16.16	0.16	1.63

Fig5.Maximum Likelihood Algorithm 6mx6m

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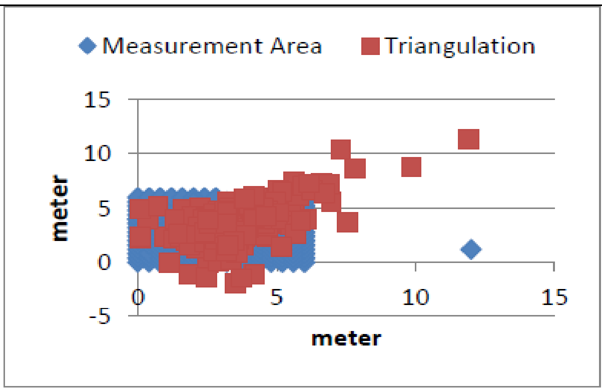
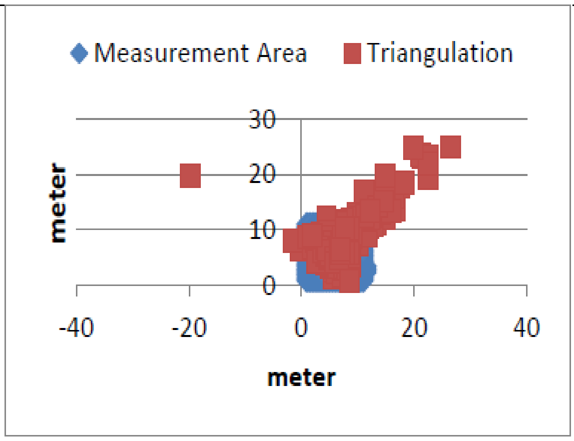


Average	Maximum	Minimum	Std Deviation
2.32	10.13	0.2	1.35

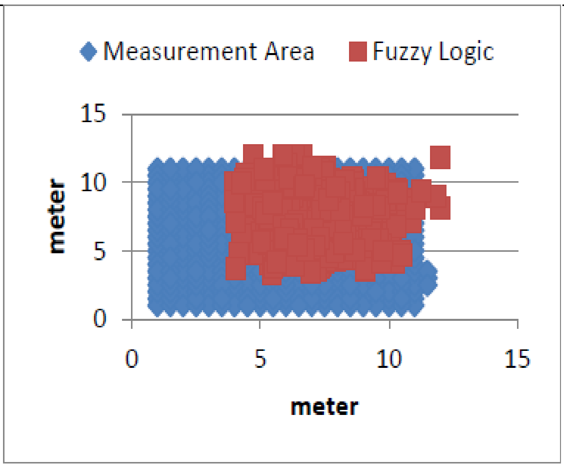
Fig6.Triangulation Algorithm 6mx6m



Average	Maximum	Minimum	Std Deviation
4.23	25.39	0.41	3.21

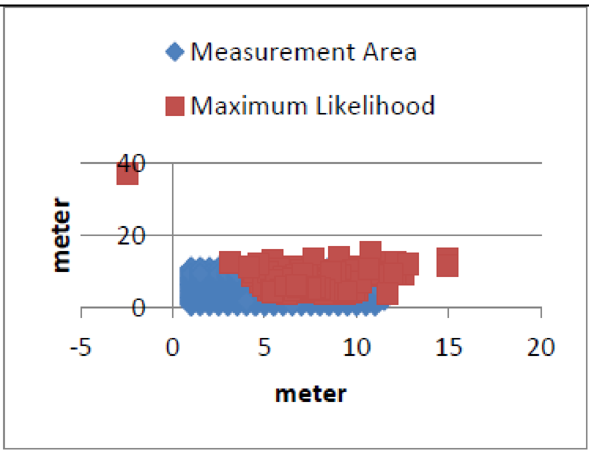
Fig9. Triangulation Algorithm 6mx6m

Algorithms result and target nodes real coordinates and estimated coordinates graphs on 12 square meter areas are shown in below figures



Average	Maximum	Minimum	Std Deviation
3.13	11.36	0.26	1.6

Fig7.Fuzzy Logic Algorithm 12mx12m



Average	Maximum	Minimum	Std Deviation
3.3	29.97	0.29	2.08

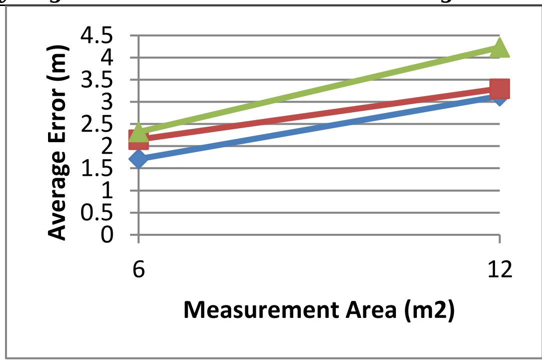
Fig8.Maximum Likelihood Algorithm 12mx12m

VI. COMPARISON OF ALGORITHM

In figure, we can observe relationship between average error and environment. In the beginning with small environment (6mx6m), algorithms' success on estimating location is close each other. However with getting large environment, average error is increasing.

Experiment show that in both 6 square meter area and 12 square meter area Fuzzy Logic algorithm gave best result. However, Maximum Likelihood algorithm tolerance in large environment is better than Triangulation algorithm. Generally success on estimation is;

Fuzzy Logic > Maximum Likelihood > Triangulation



		Avg	Max	Min	Std
6x6	Fuzzy	1.71	10.74	0.05	1.05
	MLE	2.15	16.16	0.16	1.63
	TRI	2.32	10.13	0.2	1.35
12x12	Fuzzy	3.13	11.36	0.26	1.6
	MLE	3.3	29.97	0.29	2.08
	TRI	4.23	25.39	0.41	0.41

Fig10.Algorithm Comparison with Environment

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Moreover, Maximum Likelihood and Triangulation algorithm is similar with each other. MLE requires 4 access points, Triangulation requires 3 access points. We observed that with two different environments and same conditions Maximum Likelihood algorithm is better than Triangulation Algorithm.

In figures we can see Triangulation algorithm and Maximum Likelihood algorithms' distribution of estimated location. In Triangulation graphs (Fig6. and Fig.9); estimated locations agglomerate with left side where access point signals are coming. On the other hand, Maximum Likelihood graphs (Fig7 and Fig8); estimated locations are distributed with measurement area. We can say that access point number increase success on estimation location.

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