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***Research paper***

# RSS Based Wi-Fi Positioning Method Using Recursive Least Square (RLS) Algorithm

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**Abstract**

Due to rapid increase in demand for services which depends upon exact location of devices leads to the development of numerous Wi-Fi positioning systems. It is very difficult to find the accurate position of a device in indoor environment due to substantial development of structures. There are many algorithms to determine the indoor location but they require expensive software and hardware. Hence receiving signals strength (RSS) based algorithms are implemented to find the self-positioning. In this paper Newton-Raphson, Gauss-Newton and Steepest descent algorithms are implemented to find the accurate location of Wi-Fi receiver in Koneru Lakshmaiah (K L) University, Guntur, Andhra Pradesh, India. From the results it is evident that Newton -Raphson method is better in providing accurate position estimations.

***Keywords:*** *Wi-Fi positioning; Receiving Signal Strength; Recursive Least Square Algorithm; Receiving Station.*

## 1. Introduction

The demand for indoor positioning techniques has been increasing rapidly as Global Positioning System (GPS) is not suitable for indoor environment, where the signals are easily attenuated by large constructions for locating device. In order to get accurate indoor positioning, many algorithms are in existence such as Bluetooth, Finger printing, Zig bee and Wi-Fi. The fundamental technique to estimate the accurate position in indoor environment is Time of arrival (TOA) and Angle of arrival (AOA) estimation [1]. However, this kind of estimation is complex and small timing error leads to large error in position [1]. Indoor positioning using Bluetooth signals require complex algorithms but they can't achieve high accuracy due to variation in signal propagation [2]. Finger printing has two major problems. One is survey of location takes too much time and human power while doing offline process and other one is accuracy which is low [3]. Nidhi Verma [4] has given a new methodology for accurate localization in sensor networks in indoor environment like polygon. This approach gives accurate distance and location. Maxim Shchekotov [5] proposed an approach on the basis of trilateration to determine the location of a device in indoor environment but it deals with TOA and AOA calculation which is complex to determine the user position estimate the location without mathematical complexity and to find accurate position, receiving signal strength based algorithms are taken into consideration. To estimate the accurate position, path loss and error estimation in signal are much needed. This technique is implemented not only for Line Of Sight (LOS) but also for Non Line Of Sight (NLOS). RSS based algorithms are implemented in order to estimate the approximate position of the receiver [6]. These three algorithms are implemented under the basis of recursive least square algorithm (RLS) for Wi-Fi positioning. The recursive least square is an adaptive filter which recursively determines the coefficients and minimizes the mean square error. By reducing the error in the signal strength, the location of receiver device can be estimated. Generally receiver estimation can be done in two ways either it may be linear or non linear approach. In linear approach, methods like linear least squares (LLS), weighted least squares (WLS), subspace estimators [7] are used. In non-linear approach, methods like Non linear least square (NLS), Maximum likelihood (ML) are used. In this approach, location of the receiver can be estimated without using any linear equations. In this paper, NLS estimator is used for the implementation of Newton-Raphson, Gauss-Newton and steepest descent algorithms. These algorithms are used to estimate the approximate location of receiver with less complexity.

## 2. Methodology

The layout shown in fig1 is $7^{th}$ floor, library block at K L University, Guntur, India. In this paper the position of a device is determined with respect to four base stations BS1, BS2, BS3 and BS4 and RS is the fixed receiving station. By using NETSPOT software, the RSS (DBm) from the four different base stations has been recorded in single receiver device on $28^{th}$ December 2017. The longitude and latitude of the base stations has been taken using GPS satellite app from windows store. The Cartesian coordinates of the base station are calculated using obtained longitudes and latitudes.

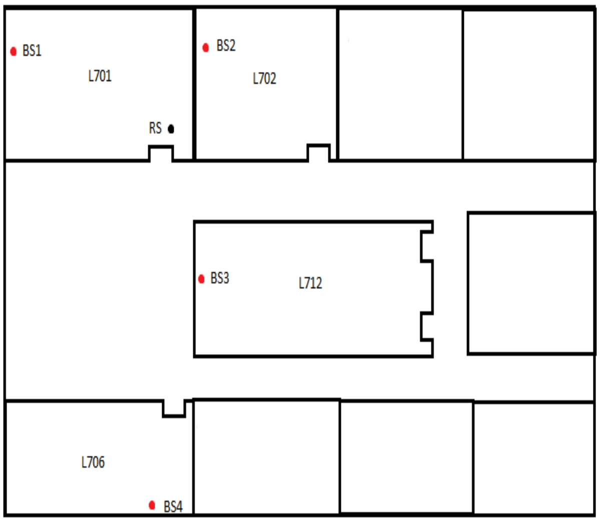


**Fig. 1:** layout of 7th floor, library block of K L University

These coordinates of the base stations are given as input to three different algorithms mentioned above to find accurate position of receiver. Convergence is not guaranteed as optimization is different for three algorithms. In NLS method noise is less compared to ML estimation. But NLS estimator is simpler than ML method as it is the weighted version of NLS method. In ML estimation additional term noise covariance is added. In Newton-Raphson method position estimation is done using Hessian matrix and gradient vector. Similarly in Gauss-Newton method position estimation is done using Jacobian matrix. But in Steepest descent method there is a constant μ which is directly proportional to convergence rate. In order to obtain stability μ value should be as small as possible. Steepest descent method has slower convergence when compared with other two algorithms. As μ is included descent algorithm is stable but not highly convergent.

## 3. Mathematical Approach

This paper deals with three algorithms which are Newton-Raphson, Steepest decent and Gauss Newton. In order to determine the accurate position of receiver, mathematical analysis of three algorithms is explained below.

### 3.1 Newton – Raphson Method:

This is a Non-Linear Least Squares method. It can also be estimated using Maximum likelihood estimation. Newton Raphson method uses iterative method to find position estimate. The initial position estimate is taken in the form of (x, y) in Cartesian co-ordinate system. The Hessian matrix and gradient vector should be computed in order to find position estimate using Newton- Raphson method [2]. They are denoted by H and $\nabla$.

$$H(J_{NLS,RSS}(x)) = \frac{\partial^2 J_{NLS,RSS}(x)}{\partial x \partial x^T}$$

$$H(J_{NLS,RSS}(x)) = \begin{bmatrix} \frac{\partial^2 J_{NLS,RSS}(x)}{\partial x^2} & \frac{\partial^2 J_{NLS,RSS}(x)}{\partial x \partial y} \\ \frac{\partial^2 J_{NLS,RSS}(x)}{\partial y \partial x} & \frac{\partial^2 J_{NLS,RSS}(x)}{\partial y^2} \end{bmatrix} \quad (1)$$

$$\nabla(J_{NLS,RSS}(x)) = -2\begin{bmatrix} \sum_{i=1}^{L} \frac{r_{RSS,l} - \sqrt{(x-x_1)^2+(y-y_1)^2}\,(x-x_1)}{[(x-x_1)^2+(y-y_1)^2]^{1/2}} \\ \sum_{i=1}^{L} \frac{r_{RSS,l} - \sqrt{(x-x_1)^2+(y-y_1)^2}\,(y-y_1)}{[(x-x_1)^2+(y-y_1)^2]^{1/2}} \end{bmatrix} \quad (2)$$

Where NLS function is given by

$$J_{NLS,RSS}(x) = ((r_{RSS} - f_{RSS}(x))^T * ((r_{RSS} - f_{RSS}(x))) \quad (3)$$

(x, y) is guess location of Receiver. $(x_1, y_1), (x_2, y_2), (x_3, y_3), (x_4, y_4)$ are locations of four base stations. $r_{RSS}$ is mean value of received signal strength. L indicates number of base stations. After obtaining the gradient vector and hessian matrix, position is updated using equation

$$\hat{x}^{k+1} = \hat{x}^{k} - H^{-1}(J_{NLS,RSS}(\hat{x}^{k})) * \nabla(J_{NLS,RSS}(\hat{x}^{k})) \quad (4)$$

### 3.2 Gauss Newton Method:

This method is modified method of Newton or Newton – Raphson method. This method is used to minimise the sum of the squared values. This algorithm is derived from Newton method. Position estimate is done using G($f_{TOA}$(x)) where it is jacobian matrix [2]. It is computed using the following expression

$$G(f_{RSS}(x)) = \begin{bmatrix} \frac{\partial\sqrt{(x-x_1)^2+(y-y_1)^2}}{\partial x} & \frac{\partial\sqrt{(x-x_1)^2+(y-y_1)^2}}{\partial y} \\ \frac{\partial\sqrt{(x-x_2)^2+(y-y_2)^2}}{\partial x} & \frac{\partial\sqrt{(x-x_2)^2+(y-y_2)^2}}{\partial y} \\ \frac{\partial\sqrt{(x-x_n)^2+(y-y_n)^2}}{\partial x} & \frac{\partial\sqrt{(x-x_n)^2+(y-y_n)^2}}{\partial y} \end{bmatrix}$$

$$G(f_{RSS}(x)) = \begin{bmatrix} \frac{x-x_1}{[(x-x_1)^2+(y-y_1)^2]^{1/2}} & \frac{y-y_1}{[(x-x_1)^2+(y-y_1)^2]^{1/2}} \\ \frac{x-x_2}{[(x-x_2)^2+(y-y_2)^2]^{1/2}} & \frac{y-y_2}{[(x-x_2)^2+(y-y_2)^2]^{1/2}} \\ \frac{x-x_n}{[(x-x_n)^2+(y-y_n)^2]^{1/2}} & \frac{y-y_n}{[(x-x_n)^2+(y-y_n)^2]^{1/2}} \end{bmatrix} \quad (5)$$

Updating equation is given by

$$\hat{x}^{k+1} = \hat{x}^{k} + (G^T(f_{RSS}(\hat{x}^{k})) * G(f_{RSS}(\hat{x}^{k})))^{-1} * G^T(f_{RSS}(\hat{x}^{k})) * (r_{RSS} - f_{RSS}(\hat{x}^{k})) \quad (6)$$

### 3.3 Steepest Descent Algorithm:

This algorithm has low convergence rate but more stability. Stability depends on μ which is taken as step size parameter. The iterative method for steepest descent algorithm is given by [2]

$$\hat{x}^{k+1} = \hat{x}^{k} - \mu(J_{NLS,RSS}(\hat{x}^{k})) \quad (7)$$

μ is considered as 0.1 during implementation.

## 4. Results and discussion

RSS measurements of base stations are taken in a fixed single receiver. Table.1 presents the specifications of Base stations used during implementation.
Base Station specifications:
Hp router product id- j9846a ,
Model- IEEE 802.11n/ac 2.4GHz

**Table 1:** Base station specifications

| Data Rate | MCS23-450 Mbps | MCS16-45 Mbps |
|---|---|---|
| Receiver sensitivity | -82dBm | -97dBm |
| Transmit power | 20dBm | 20dBm |

Receiver specifications:
Dell wireless 1705 802.11b/g/n/ac (2.4GHz)
Driver version- 10.0.0.298
Co-ordinates of the 4 Base stations are BS1- (1.0518, 6.3684), BS2- (1.0523, 6.3695), BS3- (1.0534, 6.3706), BS4- (1.0542, 6.3715).Experiments are performed and RSS values from different BS are recorded. Their mean and standard deviation are calculated which will be further used for position estimation. Fig.2 and Fig.3 shows the recorded RSS values from 4 base stations.

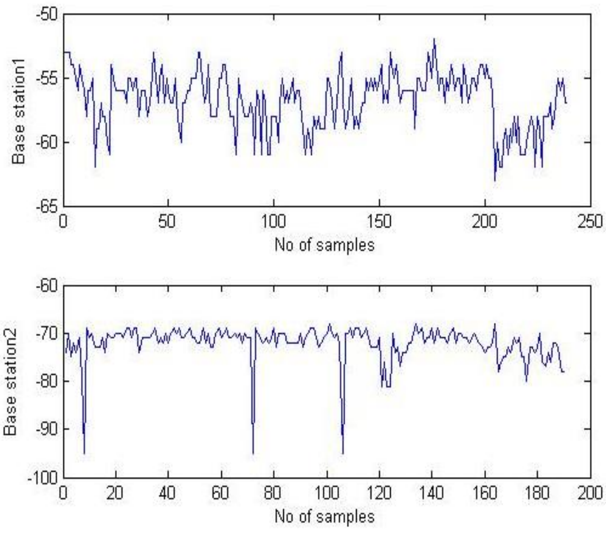


**Fig. 2:** RSS values for BS1 and BS2

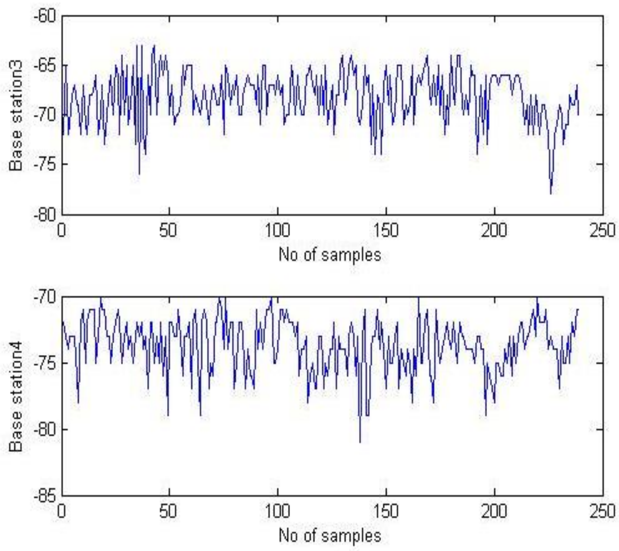


**Fig. 3:** RSS values for BS3 and BS4

Latitudes and Longitudes of 4 BS are converted to Cartesian co-ordinates using MATLAB. In Newton-Raphson method using equation (4) position of RS is estimated. Similarly using equations (6) & (7) position is estimated in Gauss-Newton and steepest descent algorithm. From table 2 and 3, it is observed that in Newton-Raphson method accurate location is obtained after 10 iterations, but in other two methods after 15 iterations accurate location is obtained. Fig4 depicts the co-ordinate of x and Fig5 depicts the co-ordinate of y for receiver station. From our results it can be noticed that Newton- Raphson method position provided the accurate position for less number of iterations when compared to Gauss-Newton method and steepest descent methods.

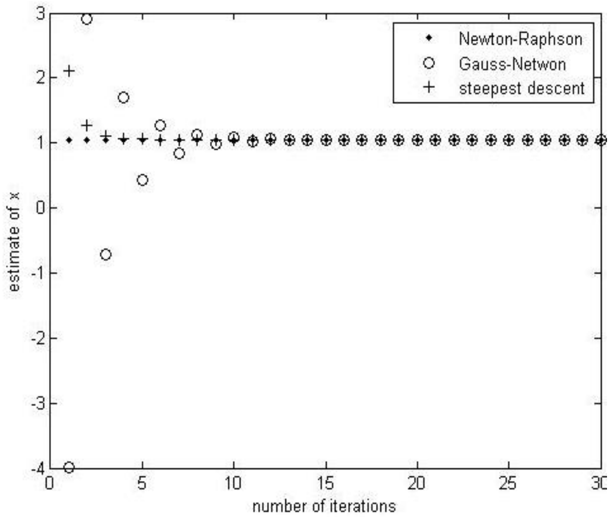


**Fig. 4:** Estimation of x co-ordinate

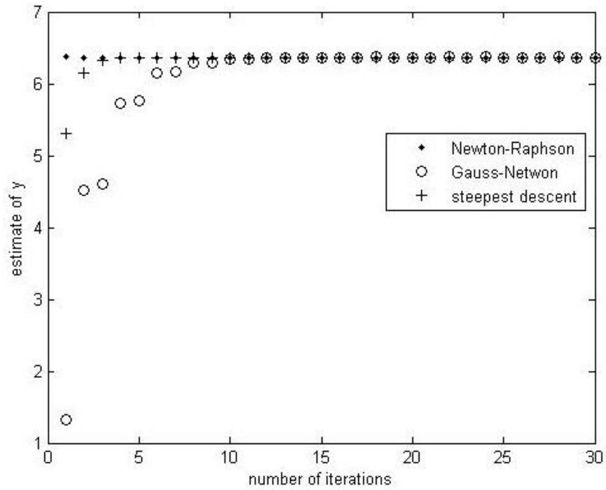


**Fig. 5:** Estimation of y co-ordinate

**Table 2:** Estimates of x co-ordinate for all algorithms

| Number of iterations | Newton-Raphson method | Gauss-Newton method | Steepest descent algorithm |
|---|---|---|---|
| 5 | 1.056 | 0.4409 | 1.055 |
| 10 | 1.053 | 1.078 | 1.055 |
| 15 | 1.052 | 1.052 | 1.052 |
| 20 | 1.052 | 1.052 | 1.052 |
| 30 | 1.052 | 1.052 | 1.052 |

**Table 3:** Estimation of y co-ordinates for all algorithms

| Number of iterations | Newton-Raphson method | Gauss-Newton method | Steepest descent algorithm |
|---|---|---|---|
| 5 | 6.367 | 5.758 | 6.366 |
| 10 | 6.368 | 6.364 | 6.366 |
| 15 | 6.368 | 6.368 | 6.368 |
| 20 | 6.368 | 6.368 | 6.368 |
| 30 | 6.368 | 6.368 | 6.368 |

## 5. Conclusion

Wi-Fi positioning depends on wireless communication technology to estimate device location in indoor environment, which has great importance in present indoor positioning applications. This paper mainly focuses on the improvement of present Wi-Fi positioning algorithms based on RSS. From our results it is evident that Newton-Raphson has faster convergence when compared with other two algorithms. When number of iterations is increased, these three algorithms indicate same location. The outcome of this work would be useful for developing efficient RSS based algorithms for Wi-Fi positioning systems

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