HYBRID ALGORITHM FOR INDOOR BASED LOCALIZATION

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Abstract

Localization algorithm plays the major rule for different applications such as tracking, positioning, and monitoring. The general framework presented by localization approaches may not work well in practical environments, due to many reasons related with dealing with 2 Dimensional space only or having high computational costs. As a result, Hybrid Localization Algorithm (HLA) was proposed and presented in this paper based on the use of both Received Signal Strength (RSS) and Angle-of-Arrival (AoA). The algorithm has been tested in a 3 Dimensional indoor scenario, with considering the effects of different building materials. Obtained result indicate an effectiveness in localizing the received points by using 2 transmitters for more accuracy in positioning coordination with average ranging error of less than 0.23m for both Line of Sight (LoS) and Non Line of Sight (NLoS) cases.

Keywords: AoA, RSS, Localization algorithm, indoor, hybrid

I. Introduction

The development of smart phones and wireless devices has resulted in a wide range of services. The most interesting service was indoor localization. Such process can be defined as the process of obtaining the location of the device or the user in an internal environment [IV]. The services based indoor localization has increased its significant recently [XVII]. Due to its uses in many applications for tracking and monitoring. Despite Global Positioning System (GPS) has been used for outdoor localization, it shows ineffectiveness in indoor environment [XIV]. Localization based Indoor scenario has suffered from many challenges as compared to outdoor. These challenges were due to its complexity and the presence of different objects in
the indoor environment [I]. As a result, the need for low and accurate indoor positioning system has been increased in the last few years [XI, XXII].

Recently, the efforts of researcher academy and industry have resulted in contributing many approaches for both accurate and low cost localization methods for indoor environment [VI, XVI, III, XII]. One of the most interesting methods was based on the use of Angle of Arrival (AoA) measurement, where the orientation of radio frequency (RF) waves have been determined [X]. AoA has been utilized to obtain the direction by measuring the difference in time of arrival for elements individually of an array of points and be obtaining these delays the AoA can be estimated easily. Many researchers have focused on improving localization using AoA technique as in [XX] and by using directional antenna. However, their method has required extra time and cost. In addition, other researchers estimated AoA by finding the Mean Received Power (MRP) and determine the Time of Arrival (ToA) value to obtain the orientation and θ to achieve better estimation in indoor localization [VII]. Furthermore, in [X] localization based AoA has been presented by using two Access Point (AP) devices to estimate the location of 10 random unknown locations. However, their method shows inaccurate results where the estimation error for each location was about 2.5 meter. On the other hand, researcher in [XXI] uses channel state information for localization and by using four AP devices, the researchers could achieve and accuracy of 6.5 meter. While, by increasing the number of utilized AP devices such accuracy has been increased up to 5 meter. However, their method has been reported to be required many devices and the results didn’t reach the required. In addition to that, an infrastructure for the estimation of AoA has been proposed in an indoor environment [II]. However, this method achieves accuracy of less than 2 meter. Meanwhile, great efforts have been made by researchers in [XXIV] to propose system for localization and based on using both Received Signal Strength (RSS) and AoA. Their presented algorithm could achieve about 10 cm average in localization error for a small area. However, the presented algorithm has not been tested for a large indoor environment.

In this work, a localization method based on the use of AoA and RSS has been presented and investigated. The presented algorithm used to locate several received points within the entire targeted building and with considering the multi-floor localization. Building materials effects have been considered with this work, and based on the use of Wireless In Site (WI) simulation software [XVIII]. The paper was divided into sections, section II described the localization based hybrid approach. Section III and IV presents the Hybrid localization algorithm and the case study respectively. The obtained results would be discussed in section V and finally the conclusion is listed in section VI.

II. Localization based hybrid method

Recently, the method of hybrid localization has gain higher emphasize by researchers due to reason of its higher accuracy and being used in a wide range of applications. Range based hybrid approach is one type of such localization, which can be any combination of ToA, TDoA, AoA and RSS [VIII, V]. The most interesting...
combination was the RSS-AoA based hybrid localization, which has a significant in improving the estimation accuracy at lower cost \([V]\). For that reason, the measurement of AoA has been used to achieve self-localization. While, RSS could be obtained easily with low accuracy in the harsh environment. Furthermore, such hybrid method doesn’t require a time synchronization procedure as it required in ToA and TDoA \([XIII]\).

**Angle of Arrival (AoA)**

It can be defined as the angle between a reference direction known as orientation and the direction of path propagation of an incident wave. AoA is measured and presented in degree and it has an absolute value when the orientation is zero or pointing to the north. Otherwise, it would have relative value \([XV]\). AoA can be represented by two main values, which are \((\theta \text{ and } \phi)\). The representation of these two angles in the axis coordination can be seen in Figure 1.

![Figure 1: The representation of theta and phi angle for AoA based method.](image)

The calculation for the Direction of Arrival (DoA) depends on these two values and can be calculated based on equation 1\([XVIII]\)

\[
g_{\theta}(\theta, \Phi) = \sqrt{|G_{\theta}(\theta, \Phi)|e^{j\Psi_{\theta}}}
\]

Where \(G_{\theta}\) the theta component of the receiving antenna is gain and \(\Psi_{\theta}\) is the relative phase of the \(\theta\) component of the far zone electric field. For our scenario these two angles would be calculated via WI software.

**Received Signal Strength (RSS)**

It represents the indication for signal strength which measured the power value transmitted from an AP and received by the receiver or reference point (Rx) \([XIV]\). In recent localization approaches Received Signal Strength was one of the most significant aspects. This significant has been increased since most of the wireless AP devices provide direct access to the RSS measurement \([XIII]\). It is worth noting that RSS represent the summation of the received power, total noise and interferences and as expressed in equation 2\([XVIII]\).
Where $P_R$ represent the received power value obtained from the received point, $I_{Total}$ represent the value of the total interferences and $N_{Total}$ represent the total noise in the system. For our scenario, WI software will consider the value of $P_R$ and calculate based on below equation [XVIII].

$$P_R = \sum_{i=1}^{NP} \frac{\lambda^2 \beta}{8\pi \eta_0} |E_{\theta},i g_{\theta}(\theta i,\Phi i) + E_{\Phi},i g_{\Phi}(\theta i,\Phi i)|^2$$

(3)

Where $\lambda$ represents the wavelength, $\beta$ is the spectrum overlapping, $\eta_0$ is the impedance of the free space, $E_{\theta},i$ and $E_{\Phi},i$ are the components of theta and phi of the electric field of the $i^{th}$ path at the receiver point, NP is the total number of paths and finally $\theta i,\Phi i$ gives the direction of arrival.

### III. Hybrid Localization Algorithm (HLA)

It has been designed a hybrid algorithm for the purpose of localization estimation for indoor environments. This algorithm has been designed by using Matlab program shown in figure 2. The flowchart of the algorithm has been drawn as seen in figure 3. The first step of the HLA is to prepare the database and collect the data from WI software based on both RSS and AoA parameters. The next step is to enter the AP coordination of XTx and YTx, which is supposed to be known for our localization algorithm. Then the algorithm would obtain the optimum path based on the values of RSS of each received point and from each AP device. Based on the previous step the several parameters of optimum path would be selected such as distance, theta ($\theta$) and phi ($\Phi$). The algorithm would calculate the angle between the AP and the received point $\beta_{(AP, Rx)}$ and based on equation 4. The final step includes calculating the values of x and y coordination for the received point or target within the indoor environment based on equation 5 and 6 respectively. Please follow this logic in writing the paper: first, briefly highlight the idea, then describe the methods for achieving the goal and the planned results, and only after that proceed to the detailed presentation. When reviewing the literature, you should not simply list the sources, but analyze them. You should explain with specific examples what has already been done by other scholars, what tasks are ahead, and in which direction you plan to move, that is, you have to introduce the reader to the research background and explain the place of your study in it.

$$\beta_{AP,Rx} = \alpha + \pi.$$  

(4)

Where $\alpha$ is direction of arrival in phi ($\Phi$) which has been obtained from WI software and for each received point.

$$X_{Rx} = X_{Tx} + d \times cos (\beta)$$  

$$Y_{Rx} = Y_{Tx} + d \times sin (\beta)$$  

(5) (6)

Where $(X_{Rx}, Y_{Rx})$ represent the coordination of the targeted received point which represent the output of our presented algorithm.

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IV. Case Study

The site intended for investigation in this work is the building of electrical department in university of technology which consists of ground and 4 floors. The case study has been designed, modelled and simulated using wireless In Site software and shown in figure 4. The floors selected for investigation were the 2nd and 3th

Fig. 2: GUI window for the Hybrid Localization Algorithm

Fig. 3: Flowchart of our proposed localization algorithm.
floors, where it has been deployed two predefined transmitters per each floor. For the received point which will be considered as the target points for testing our presenting localization algorithm, it has been distributed 11 and 10 points for the two investigated floor respectively. Such distribution was based on the structure requirement of our targeted building. The distribution location of each AP and received point per each floor can be seen in figure 5. In addition, the properties of these devices were pictured in Table 1. In context, the serious effects of different building materials on propagation characteristics were taken into consideration by obtaining the value of Relative Permittivity ($\varepsilon$) and Conductivity ($\sigma$) as listed in table 2 and as recommended by International Telecommunication Union (ITU) [IX]. It is worth to mention, that the selected bandwidth is 20 MHz working with 2.4 GHz frequency.

![Fig. 4: The simulated model of the targeted building](image)

**Table 1: The antenna proprieties of AP and receivers.**

| properties       | AP Antenna | Rx Antenna |
|------------------|------------|------------|
| Antenna type     | Omni-Directional | Omni-Directional |
| Power (in dBm)   | 30         | -          |
| Antenna Gain (dBi)| 9          | 2          |
| E-Plane HPBW     | 90'        | 90'        |
| Polarization     | V          | V          |

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Table 2: Material values for each utilized material in our case study

| Materials | Thickness (cm) | ε   | σ   |
|-----------|----------------|-----|-----|
| Concrete  | 30             | 5.31| 0.066 |
| Wood      | 4.5            | 1.99| 0.012 |
| Glass     | 0.3            | 6.27| 0.012 |
| Brick     | 28             | 3.75| 0.038 |
| Drywall   | 0.9            | 2.94| 0.021 |

**Fig. 5:** The distribution of AP’s and received points per (a) 2nd floor and (b) 3rd floor.

V. Result and Discussion

The previous displayed case study has been investigated using WI software. The result obtained from this software will form the database for our HLA. Result obtained from our proposed algorithm for localization estimation in both 2nd and 3rd floor can be seen in figure 6 and 7 respectively, where it can be notice that the estimated locations are very close to the actual locations, which verify the accuracy of the proposed algorithm. The values of all requested parameters such as Optimum Path (OP) RSS, distance, theta angle value and the estimated locations coordination from both Tx’s have been listed in Table 3 and 4 and for both 2nd and 3rd floor respectively. It’s worth to mention, that the obtained parameters and coordination represent the values for the optimum path based on RSS signal in each received point. They should be referred to in numerical order. Number the tables sequentially, according to their appearance in the text.
Fig. 6: The actual and estimated coordinates of RXs in the 2nd floor.

Fig. 7: The actual and estimated coordinates of RXs in the 3rd floor.

Furthermore, the average estimated coordination's have been compared with actual coordination's for each floor and as seen in figure 8 and 9. Where it can be seen that more accurate results have been achieved by taking the average values of the estimated coordination's from the two transmitters in each floor. As a result, the ranging error has been calculated for both scenarios and listed in Table 5 and 6 for the same two floors respectively. It can be seen that the coordination minimum error was (0.003, 0.018) m and the coordination maximum error was (0.618, 0.453) m for the second floor. While, for the third these values were (0.039105, 0.0143) m and (0.315, 0.584) m for minimum and maximum coordination errors respectively. Meanwhile, the average ranging error for positioning was (0.234, 0.193) and (0.103, 0.225) for 2nd and 3rd floor respectively.

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Table 3: The Tx locations and estimated Rx locations for 2nd floor

| Rx's | OP(RSS) d α x y | OP(RSS) d α x y |
|------|----------------|----------------|
| Rx1  | -37.167 4.86988 214.07 25.4498 19.3389 | -55.83 31.1692 344.49 26.0587 19.8158 |
| Rx2  | -21.049 2.9309 272.75 21.2752 19.6383 | -55.83 23.5547 199.58 21.1682 19.3746 |
| Rx3  | -38.89 16.3588 212.83 15.1618 20.5979 | -53.46 18.509 208.22 15.2645 20.233 |
| Rx4  | -52.82 16.4705 327.14 7.5806 20.6475 | -40.235 12.0707 225.32 7.46296 20.0637 |
| Rx5  | -49.56 19.4376 25.49 3.87029 8.34758 | -29.64 9.56916 121.41 3.96255 8.31401 |
| Rx6  | -29.43 9.68986 66.14 17.4998 7.85719 | -37.157 20.6999 155.34 17.7876 7.8422 |
| Rx7  | -40.008 14.7112 142.04 33.0147 7.66179 | -62.88 30.0468 125.19 16.2912 8.07471 |
| Rx8  | -54.633 16.1979 116.99 28.767 3.27711 | -58.232 33.6516 155.92 29.6986 3.59056 |
| Rx9  | -32.67 22.3372 97.32 34.2618 2.44434 | -81.557 37.854 158.5 34.1955 2.60736 |
| Rx10 | -68.02 24.3875 172.13 45.5736 13.3715 | -67.506 45.7071 177.74 44.647 14.6785 |
| Rx11 | -42.235 35.5721 350.1 -13.627 17.8267 | -26.972 13.9326 333.9 -13.536 17.6104 |

Table 4: The Tx locations and estimated Rx locations for 3rd floor

| Rx's | OP(RSS) d α x y | OP(RSS) d α x y |
|------|----------------|----------------|
| Rx1  | -31.967 14.4377 327.98 24.8807 19.3389 | -55.28 27.1811 193.5 25.5415 18.9496 |
| Rx2  | -27.186 8.63125 240.64 21.3538 19.2213 | -53.989 27.055 346.02 21.2322 19.1401 |
| Rx3  | -27.582 9.0765 306.53 11.7192 18.9921 | -40.789 14.45 209.18 11.6376 18.6495 |
| Rx4  | -47.591 20.2016 331.97 -0.7101 21.1921 | -22.678 4.1561 267.45 0.7937 20.7563 |
| Rx5  | -42.056 15.954 35.86 4.19197 7.35274 | -30.131 10.226 120.46 4.2033 7.7896 |
| Rx6  | -30.923 11.1911 122.89 23.1599 7.36181 | -41.068 28.1767 147.93 22.8983 7.64374 |
| Rx7  | -47.346 18.8029 133.93 30.1646 3.15484 | -54.119 36.284 147.14 29.4999 3.08297 |
| Rx8  | -34.722 26.612 98.03 34.8394 2.65227 | -76.911 37.928 157.45 34.0946 2.09931 |
| Rx9  | -56.255 25.205 338.46 -6.3228 20.9527 | -38.544 10.2189 300.68 -6.1927 20.3929 |
| Rx10 | -39.809 30.887 399.5 -13.764 16.9062 | -32.735 12.84 358.61 -13.815 16.9158 |

Fig. 8: The actual locations Vs. Av. estimated locations of floor2.
Fig. 9: The actual locations Vs. Av. estimated locations of floor 3.

Table 5: Comparison between actual locations vs. Average estimated locations and ranging error for second floor localization.

| Rx's | Actual Location | Av. Estimated Location | Ranging Error |
|------|-----------------|------------------------|---------------|
| Rx1  | 25.258 19.2997  | 25.75425 19.62735     | 0.49625 0.32765 |
| Rx2  | 21.2941 19.2258 | 21.2217 19.50645      | 0.0724 0.28065  |
| Rx3  | 15.3298 20.3874 | 15.22315 20.40635     | 0.10665 0.01895 |
| Rx4  | 7.4859 20.2784  | 7.52178 20.3556       | 0.03588 0.0772  |
| Rx5  | 3.9132 8.3904   | 3.91642 8.329895      | 0.00322 0.0605  |
| Rx6  | 17.5344 7.9697  | 17.6437 7.850705      | 0.1093 0.119    |
| Rx7  | 25.2715 7.4151  | 24.65295 7.86825      | 0.61855 0.45315 |
| Rx8  | 29.6729 3.1792  | 29.2328 3.41388       | 0.4401 0.23468  |
| Rx9  | 34.0779 2.7377  | 34.22865 2.52585      | 0.15075 0.21185 |
| Rx10 | 44.6007 14.2229 | 45.1103 14.025        | 0.5096 0.1979   |
| Rx11 | -13.6221 17.5757| -13.5815 17.71855     | 0.0406 0.14285  |

Table 6: Comparison between actual locations vs. Average estimated locations and ranging error for third floor localization.
VI. Conclusion

In this work, it has been designed a Hybrid Localization Algorithm for both low cost and computational process. Algorithm works based on the use of RSS and AoA, where RSS is used to select the optimum path, which will select the desired parameters based on these paths for each tested received point. The localization estimation has been based on the use of direction angles of theta and phi for each optimum path in each received point. Obtained results indicate high accurate indoor localization estimation with average ranging error of less than 0.23 m for both LoS and NLoS cases and by only using two transmitters or Access points. For the future, the presented algorithm could be developed and tested for localizing multi-floor scenarios.

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