Adopting Centroid and Amended Trilateration for better accuracy of range-based non-GPS localization

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Abstract— **There has been massive amount of research have been conducted in the area of indoor positioning systems specifically it's upwards research trending in Localization Based Services (LBS) within a non-open space environment or in the vicinity of high rise buildings due to the incapability of Global Positioning System (GPS) to do so. Most of the indoor localization techniques proposed by researchers to discover an optimized solution for indoor location tracking that has high precision and accuracy. This paper proposes a model for better accuracy on range-based localization algorithm in non-GPS positioning systems. The proposed model adopts the enhanced Kalman Filter (KF) and Centroid Localization Algorithm that can manipulate noise signal from raw Received Signal Strength Indicator (RSSI). There are 12 tests conducted in two different environments; at the area with less-obstacles and at the area with more obstacles. Three different algorithms are deployed with and without KF where a series of observations and comparisons are made to measure the effectiveness and reliability of KF implementation. Our analysis and finding show that the proposed model improves the accuracy percentage by more than 80%.**

Keywords—Centroid Localization Algorithm, Indoor Localization Tracking, Kalman Filter, Trilateration, RSSI, Wi-Fi technology

I. Introduction

In general perspective, the location tracking is ideally a mechanism to track an object in a real-time situation. Usually, location tracking is based on the advance system used for tracking purposes which refer to a Global Positioning System (GPS) run over the network and with the help of global satellites. Combination of GPS and multiple existing global satellites orbiting the Earth, a certain position of a target searched can be easily detected. Unfortunately, when it comes to the indoor area, GPS technology is not reliable due to the incapability of GPS to detect an object within a non-open space environment such as inside a building [1] hence need another alternative for positioning [2]. There are already various positioning technologies that have been reported in literature, created, amended or deployed commercially to provide indoor positioning coverage using wireless communication and mobile computing where the development of location-based services (LBSs) is very much demanded [3]. The reason is to discover the greatest solution for indoor location tracking that gives a great precision and accuracy which can create the same result as the GPS mechanism for the outdoor environment. It is not only limited to tracking an object within an indoor environment, proximity, monitoring and navigation are what the system also provide which engages with multiple applications. Indoor localization and tracking is best used to secure and monitor company assets and also to the event that deals with lots of audience in one closed environment where people spend most of their time like working, shopping, meeting friends and eating in different locations such as malls, offices, campus, etc and where the traditional GPS system cannot be used.

Conventionally, location estimation or positioning frameworks for indoor environments are designed based on different available infrastructures such as WiFi, Bluetooth and RFID without the needs of implementing extra network gadgets [4]. However, the implementation of indoor location tracking is more complex and challenging than outdoor due to lots of interference and obstruction exist in a building which the signal usually will be fluctuated due to many obstacles such as walls, furniture, the presence of human beings and the wireless signal level [5]. The interferences yield in errors in positioning as the accuracy is not the same as the actual location of an object itself.

The rest of the paper is organized as follows: Section 2 gives a brief description of several indoor location tracking techniques that have been discussed by other researchers. Section 3 describes the proposed research. The experiment and results are discussed in Section 4. Finally, we conclude the paper with some observation and suggestion based on the findings from the experiment in Section 5.

II. Classification of Indoor Location Tracking Techniques

Currently, wireless technology has become one of the most preferred choices and widely used due to its reliability, scalability, low cost of implementation, and easy to manage [6]. It is a common and accessible technology used by many people which has the basic components for indoor positioning and at the same time, WiFi does not require additional hardware to provide support with this [7]. As far as it may concerned, the localization process for wireless approach differs from one technique to another in term of the process and implementation. However, the implementation of indoor location tracking is more complex than outdoor due to lots of interference happen in detecting an object inside a building. By using the wireless technology for indoor localization, it comes with great challenges in which the signal usually will be fluctuated due to many obstacles or obstructions such as walls, furniture, the presence of humans [20] and the wireless signal level [8]. The interferences

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resulting on an error in positioning as the accuracy is not the same as the actual location of an object itself.

According to [9], localization schemes can be divided into two categories namely range based and range free approaches. The range-based approach is based on angle or distance/range measurement techniques for location estimation of the mobile node. On the other hand, the range-free approach ignores the using of range measurement techniques and they also do not require extra hardware, hence, they are cost-effective. Thus, in order to estimate the location of unknown nodes, it works on attributes that proximate the distances; for instance the hop count [9-10], the flooding of topology information and connectivity [10]. It explores the availability of radio signals for location estimation. Some foremost range-free algorithms that have been introduced by previous researchers are Centroid Localization Algorithm (CLA) [11-13], Approximate Point In triangulation (APIT) [14-15], DV-Hop Algorithm (DV-HA) [16-17] and Amorphous Positioning Algorithm (APA) [18]. Gu et al. in [19] describes that there are basically four types of positioning estimation techniques available with regards to a range-based approach which include Triangulation, Finger Printing, Proximity Based Location and Vision Analysis. In range-based techniques, distance estimation is achieved by using one of the following techniques: Received Signal Strength Indicator (RSSI), Angle of Arrival (AOA), Time of Arrival (TOA) or Time Difference of Arrival (TDOA) [8-10].

AOA is a measurement technique that takes full consideration of the angle between the propagation directions of the transmitted signal wave to certain reference direction, known as the orientation [22]. In this context, orientation is well defined as a static direction against which the AOA being measured. The AOA measurements usually represented in a form of degrees that whenever the degrees equivalent to 0^o or facing to North direction, the AOA is equal to an absolute value else it is a relative value. The mechanism of this measurement technique estimates a certain location from the intersection point produced which usually due to signals arrived from the location of the source to the receiving sensor. In order for it to work in determining the exact angle of direction, additional highly directional antennas or antenna arrays [23] are used to get information and this incurs a high cost of its implementation. Additionally, complex AOA estimation algorithms require multiple receivers/sensors as well as phase calibration between those receivers. Using multiple receivers usually consume more power and expensive to implement. From hardware perspective, AOA implementation with a single receiving sensor is hence cheaper and more practical.

TOA measurement technique is best defined as a one-way propagation time of the radio frequency signal travelling time from a source (transmitter) or a device such as mobile phone to its signal receiver [24]. The source and the receiver are accurately synchronized in order to get the absolute time of arrival at the certain point of receiver station. It means that the synchronization is to generate useful information and a two-way communication between sources to the receivers. During the process, TOA information (such as speed and time) is generated to which the measured information of TOA will represent a circle with its centre that indicates where the receiver located. Upon having several same processes from the source to another receiver location, an intersection point of the circle to another circle will automatically produce to which the intersection point representing the coordinate of the source of radio frequency signal or devices location. In order for it to work, at least three number of receivers are required to produce three circles to which if the number is less than that, an intersection point of the circle produced will not give meaningful information for localization process. This implementation somehow involves expensive equipment that is GPA-assisted equipment which is not used in the indoor environment [25].

In conventional TDOA-based localization technique, it is used to determine the location of the source by evaluating the difference in arrival time of the signal at spatially separated base stations. TDOA measurements are obtained by calculating the difference between two TOA measurements and eliminating the unknown time of emission [26]. It does not need time synchronization between transmitters and receivers but it requires the synchronization between the transmitter which this becomes too expensive if it to be deployed in the large area.

Of all the above four range-based measurement techniques, RSSI has the advantages of easy hardware installation and low-cost implementation with easy distance measurement calculation that can be adopted in Wi-Fi ready environment. However, the accurate positioning of RSSI can be compromised by some other obstacles and this must be improved. The improved technique on localization on RSSI range-based is further discussed in section 4 of this paper. Fig. 1 summarizes the description of the two categories of Non-GPS localization.Maintaining the Integrity of the Specifications

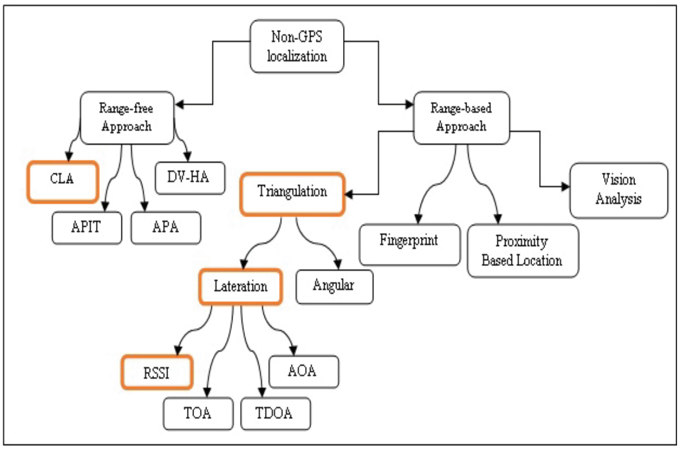

Fig. 1. Non-GPS localization category

At a time of this research is conducted, the focus is given to the triangulation technique as this technique was chosen as an initial experiment for the research done by the author in [27]. A combination of RSSI of Trilateration and Centroid Localization Algorithm (CLA) is selected for further testing and observation on an improved localization with the implementation of Kalman Filter (KF).

III. PROPOSED RESEARCH

The proposed model is amended on trilateration technique from the existing system model of previous work in [27] where it is integrated with an algorithm to find whether the accuracy of observed result can be improved and the error rate can be minimized. This proposed model is related to the implementation of KF algorithm which is used to filter and manipulate the noise from the RSSI value to ensure that the localization process can be improved and have a higher accuracy result. KF is basically an algorithm contains a series of measurement where it enables a prediction of uncertain information for a dynamic system [28]. It filters the signal data using two-step process as illustrated in Fig. 2. The algorithm is recursive where it starts with the prediction of the state. In the prediction stage, the noise value are defined and processed on the off-line RSSI values which stored from previous work. During the estimation and correction stage, the results from previous stage are captured and corrected or updated based on defined noise value using on-line RSSI values captured from APs. The measurement and noise that exist within the RSSIs state value are clearly defined which technically helps to filter the RSSIs and produce an updated new RSSIs state value. This process iterates over time until it meets the end of the process to gain an optimum result of signal data.

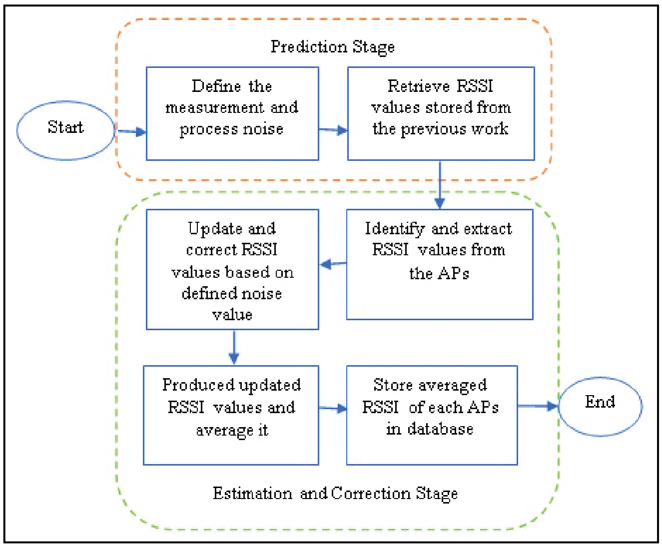

Fig. 2. KF process

Detailed of the KF process and equations used have been discussed in [29]. Based on this initial work conducted by the author, amended trilateration with KF feature is then being implemented on Centroid Localization Algorithm (CLA).

CLA is a range-free localization algorithms that is based on the coordinate of APs deployed which also related to the uses of trilateration process. The core idea of the CLA is to use the connectivity relationships among nodes to calculate the unknown node's position information. In this scenario, by using the coordinates of deployed APs, a sequence of the line will connect the APs and produce a triangle-shaped model. From the produced triangle-shaped model, a center point of the coordinate is computed and pinpointed. This center point is used as a reference model to determine the devices coordinate and measure the rate of accuracy during the localization process. From the observed result produced in trilateration technique, the coordinate of this result is taken and used together with the center point coordinate. A final coordinate is then computed and observed to check for any improvement in the localization. Fig. 3 summarizes the processes of the proposed model.

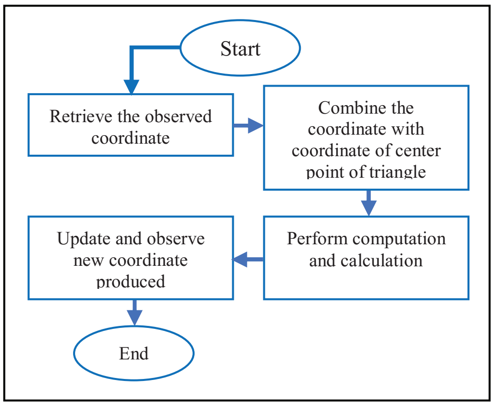

Fig. 3. Flow of the Proposed Model

CLA is used whenever the coordinate of three related APs has been determined. In order to initiate the algorithm, information of the AP coordinates that placed within the environment is the only things that matter to which it will identify unknown coordinates of subject or device [31]. This algorithm principle indicates that the range of localization process will always occur inside the formation range created [32]. To determine the center of the triangle, assumed that AP1, AP2 and AP3 coordinates are set to (x1,y1), (x2,y2) and (x3,y3). The center point of coordinate (xN,yN) then is computed according to the following equation:-

$$x_N = \frac{x_1 + x_2 + x_3}{3}$$
$$y_N = \frac{y_1 + y_2 + y_3}{3} \quad (1)$$

where, x1,y1 is the coordinate for AP1, x2,y2 is the coordinate for AP2, x3,y3 is the coordinate of AP3 and xN,yN is the center coordinate of triangle-shape formation.no matter how many APs are exist within the setup environment, the center point of the formation-shape will always be pointed and link connection between the APs are created as presented in Fig. 4.

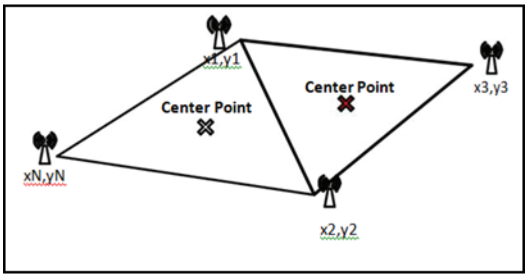

Fig. 4. Triangle-shape Formation Created in Relation to Aps

A final coordinate is then computed and observation is made to check whether improvement has been achieved or not. This allows new results of coordinate generated which the performance and accuracy can be analyzed whether it gives a better solution for localization processes or not. Fig. 5 below shows the new improved localization model. It is divided into two phases; offline and on-line that is following the Trilateration technique method.

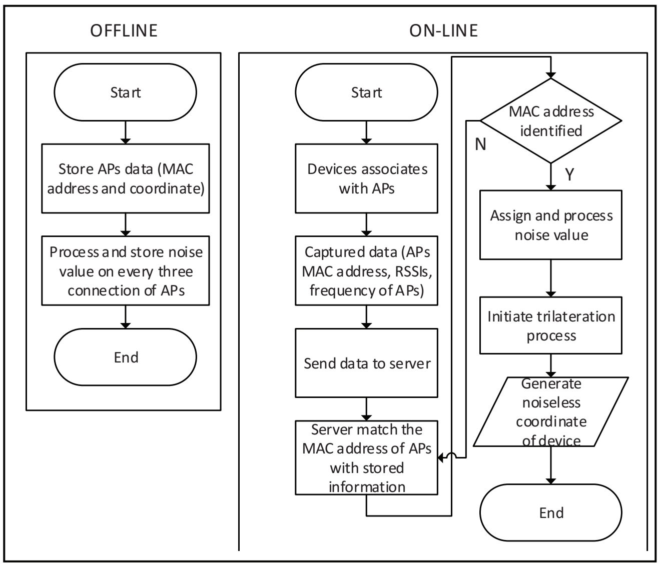

Fig. 5. System Model [33]

A. *Off-line Stage*

During this stage, two main processes are needed:

i. Store APs data in the system database that include the coordinates of three APs and its MAC address. This is for the request and retrieval localization services.

ii. Define the measurement and noise element/value where the assumption is made based on environment factor depending on the environment scale and correlation of APs that covers the range.

B. *Online Stage*

To improve the devices positioning during the online localization process, the RSSI value is filtered using KF algorithm. The purpose of this new implemented technique is to manipulate, minimize and find the most optimum predicted noise value from the raw RSSI. KF algorithm implementation will ensure that the true state of RSSI is captured and it visualizes an improved positioning of devices on the map.

The newly improved result outcome then shows the final observed coordinate of the device which considered true. It gives the best estimation of the location of the device although it may change over time due to obstacles and presence of noise. The steps in estimating the location of the device with an assistance of KF are described as follows:

i. Mobile devices need to associate with three APs for the trilateration process.

ii. Third-party software running in the background captures MAC address of all APs, signal strength and the frequency of APs and send it to the server.

iii. Server process services by identifying MAC address of APs and retrieve its coordinate.

iv. The server allocates the noise value and processes it.

v. The system starts trilaterate these data to get the distance of devices from the associated APs.

vi. Server again allocates the center-point coordinate of the triangle-shape relation of associated APs to the system process. The observed result from the trilateration process is combined with the center-point coordinate and observation is made after the result is averaged.

vii. The improved coordinate is generated once the averaging process between the produced coordinate from trilateration and midpoint coordinate from the APs triangle-shape is done. Device coordinate then is shown in the location map.

IV. EXPREIMENT RESULTS

12 experiments are conducted and the results are observed to see the accuracy level of the improved KF and CLA. The testing works are conducted in a condominium unit of 1020sqft by changing the position of the APs and mobile device, and manipulating the noise value. The effectiveness and efficiency of the newly proposed technique are based on the testing run on different indoor environment area. As the environment area will be affected by outside sources such as noise, human presence and obstacle interference, the number of these variables are manipulated in order to gather different result for a conclusion and justification of the research work. Based on the previous work in [27], the experiment and localization process in Fig. 3 and Fig. 5 are conducted in two different environments/scenarios; an area with less-obstacles and area with more obstacles. For every situation above, the test is conducted twice with different positions (coordinates) of the actual device. Three positioning algorithms are implemented and tested:

i. Trilateration
ii. Improved Trilateration with KF
iii. KF with CLA

Fig. 6 below shows the experimental set-up for both scenarios.

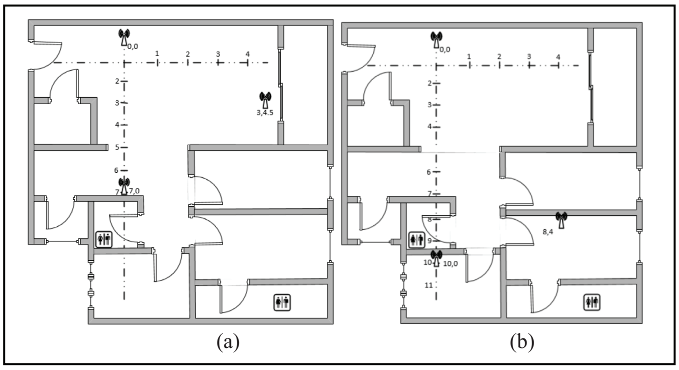

Fig. 6. Experiment Set-up

For the first test run on the less-obstacle scenario, APs are placed relatively closed to each other in the same room. This can be seen in figure 6(a). Figure 6(b) illustrates the position of the three APs that are placed a bit further (in separate rooms) for the test that is conducted in the area with more obstacles. This is to verify whether the presence of noise that exists from obstacles such as walls and doors really affect the accuracy of device's position. The coordinates of all three APs and the actual

TABLE I. COORDINATE OF DEVICES

Devices	Less Obstacle Scenario	More Obstacle Scenario
AP1	(0, 0)	(0, 0)
AP2	(7, 0)	(10, 0)
AP3	(3, 4.5)	(8, 4)
Actual Device	1st test (4, 2) 2nd test (6, 3)	1st test (4, 1) 2nd test (6.5, 3)

A set of 12 tests are conducted and the results of each test are presented in table II, III and IV. In any test cases conducted, results obtained for more obstacle scenario is taken into account to check the accuracy of indoor positioning as it is known that RSSI values are less noise in an open space environment. Based on the observed results and accuracy percentage generated in all scenarios, a normal trilateration algorithm produces an accuracy result 28.7% and below from the actual coordinate as shown in Table II.

TABLE II. TRILATERATION

	Less Obstacle Scenario		More Obstacle Scenario	
Test Number	1st test	2nd test	1st test	2nd test
Actual Coordinate	(4, 2)	(6, 3)	(4, 1)	(6.5, 3)
Observed Result	(2.2, -4.9)	(3.4, -9.7)	(-19.5, 10.4)	(1.1, 16.9)
Error Rate	(1.8, 6.9)	(2.6, 12.7)	(23.5, 9.4)	(5.4, 13.8)
Distance Difference (m)	7.13	12.96	25.31	14.82
Accuracy (%)	28.7	-29.6	-153	**-48.2**

TABLE III. IMPROVED TRILATERATION + KF

	Less Obstacle Scenario		More Obstacle Scenario	
Process Noise (Q)	0.0001		0.0001	
Measurement Noise (R)	0.1		0.1	
Test Number	1sttest	2nd test	1st test	2nd test
Actual Coordinate	(4, 2)	(6, 3)	(4, 1)	(6.5, 3)
Observed Result	(3.3, 0.1)	(3.5, 0)	(-10.4, 0.2)	(3.6, 5.1)
Error Rate	(0.7, 1.9)	(2.5, 3)	(14.4, 0.8)	(2.9, 2.1)
Distance Difference (m)	2.02	3.91	14.42	3.58
Accuracy (%)	79.9	61	-44.2	**64.2**

Second positioning algorithm that refers to KF is amended to the same environment setup as to observe whether it creates a more accurate result or not. Prior to getting this testing done, noise value carefully assigned where the process noise (Q) equals to 0.0001 and measurement noise (R) is equals to 0.1. As shown in table 3, KF algorithm improves the positioning accuracy more than 50%, which is better than the normal trilateration algorithm. By using KF algorithm, noise presence that exists inside the RSSIs data is processed and minimized based on the assumption of value given for Q and R.

The third position algorithm technique uses the center of the coordinate of the triangle that formed based on the relationship between three deployed APs. The center of coordinate from the triangle produced by AP1, AP2 and AP3 is equals to (3.33, 1.5) in less obstacle scenario and coordinate (6, 1.3) is implemented in more obstacle scenario. By using the produced center of coordinate, the result generated from KF algorithm is integrated with this coordinate value and is averaged to observe the result.

TABLE IV. KF + CLA

	Less Obstacle Scenario		More Obstacle Scenario	
Test Number	1st test	2nd test	1st test	2nd test
Actual Coordinate	(4, 2)	(6, 3)	(4, 1)	(6.5, 3)
KF Coordinate	(3.3, 0.1)	(3.5, 0)	(-10. 0.2)	(3.6, 5.1)
CLA Coordinate	(3.3, 1.5)	(3.3, 1.5)	(6, 1.3)	(6, 1.3)
Observed Result	(3.2, 0.8)	(3.4, 0.7)	(-2.2, 0.8)	(4.8, 3.2)
Error Rate	(0.8, 1.2)	(2.6, 2.3)	(6.2, 0.2)	(1.7, 0.2)
Distance Difference (m)	1.44	3.47	6.20	1.71
Accuracy (%)	85.6	65.3	38	**82.9**

As shown in Table IV, the accuracy percentage increases and the coordinate is close to the actual position of devices. The distance difference is 1.71m compared to the first and second technique which reveal the distance difference of 14.82m and 3.58m respectively. This proof that the integration between the KF and CLA is able to increase a better result for indoor positioning system with the accuracy percentage of more than 80%.

V. CONCLUSION

From the finding and results output, it can be concluded that using a different type of algorithms are really affecting the localization performance within the indoor environment. In fact, the placement of the APs also determined the localization process performance where if devices range is closed to every AP, it gives better results. Instead, if there are any blockages or high noise presence in between of devices and APs, the positioning result will be lowered. A proposed model that is a combination of CLA and together with the result produced from KF increases the performance of an existing system where it gives better results on the indoor location tracking system. This is subjected to the best estimation made of the noise values, which plays a major role to increase the accuracy of device's positioning. The research will be further conducted in a larger area with more mobile devices communicating thus generating more RSSI. This will be more reliable to signify the actual situation of indoor positioning or tracking system.

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